SUMMARIES OF SYTYKE-PROJECTS

SEppo Ruonala (ed.)

NATIONAL BOARD OF WATERS AND THE ENVIRONMENT
SYTYKE-Programme
Helsinki 1993
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The purpose of the Environmental Research and Development Programme for the Finnish Forest Industry, SYTYKE, was, through research and studies, to create scientific and technical bases for the long-term environmental protection objectives and measures of the forest industry, to combine studies serving the forest industry's air and water protection and waste management and to promote cooperation between major research sponsors and researchers.

SYTYKE's fields of research were production and production technology, treatment of emissions, use of raw materials and energy, emissions and loads, costs, the environmental effects of waste waters and the advantages and disadvantages of environmental protection measures. The programme was divided into 19 projects; 32 research reports and 28 summaries which were made into 19 publications and which are also published in this summary publication.

The research and studies show that despite increases in production, in regard to almost all parameters, emissions from the Finnish forest industry will decrease during the period covered by the research until the year 2010.

The sulphate process will continue to dominate chemical pulp production. There will be improvement in the efficiency of removing ligning during pulp cooking. Enzymes and oxygen chemicals will be increasingly used in bleaching whilst the use of chlorine will decrease. The circulation of chemicals and water will be more carefully confined than before. In addition to reducing emissions, this will also result in difficulties in the availability of chemicals and balancing the mills' input. A reduction in nutrients (P and N) and organic chlorine compounds (AOX) can be achieved in treating the waste water of the Finnish forest industry by activated sludge treatment plants. Such plants have already become widespread. According to research, the current amounts of AOX do not explain the effects seen in the ecosystem. Combustion of the black liquor which has a high solid content, treatment of gases and vapour recovery, incineration and washing reduce the amount of sulphur dioxide emissions and maladorous sulphur compounds (TRS). The amount of waste may increase if waste paper will be imported into Finland and unless the incineration of organic waste becomes more widespread.

Keywords
Pulp and paper industry, environmental protection, research, production, production technology, costs, emissions, environmental effects

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Suomen metsätalouden ympäristötäyttyvyyden ja jätevesien käsittelytapojen kehittelyssä on ollut tärkeää, että Suomen metsätalouden terveyden ja kaltaisena ympäristön kehityksen kannalta välttämätöntä. Työntekijöiden osallistumisen lisäksi järjestelyjen kehittelyssä on ollut tärkeää, että kaikki osallistuvat eri aloilta ja maasta eri puolilta.

**Asiasanat (avainsanat)**
- Metsätaloudellinen tutkimus
- Ympäristönsuojelu
- Tutkimus
- Tuotanto
- Tuotantotekniikka
- Kustannukset
- Päästöt
- Ympäristövaikutukset

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**Tutkimuksessa ja selvityksissä on todettu, että Suomen metsätalouden päästöt alenevat tutkimusjaksolla vuoteen 2010 asti lähes kaikkien parametrien suhteen, vaikka tuotannost kasvavat.**


**Asiasanat (avainsanat)**
- Metsätaloustutkimus
- Jättiteollisuus
- Ympäristönsuojelu
- Tuotanto
- Tuotantotekniikka
- Kustannukset
- Päästöt
- Ympäristövaikutukset
Forsknings- och utvecklingsprogrammet för den finländska skogsindustrins miljövård, SYTYKE, hade till syfte att med hjälp av undersökningar och utredningar skapa vetenskapliga och tekniska grunder för långsiktig målsättning och åtgärder för skogsindustrins miljövård, att koordinera den forskning som betjänar skogsindustrins luftvård, vattenskydd och avfallshantering samt att stärka samarbetet mellan de viktigaste finansiärerna av forskningsarbetet och de institutioner som utför detta arbete.

SYTYKE—programmets forskningsområden omfattade produktion och produktionsteknologi, hantering av utsläpp, användning av råvaror och energi, utsläpp och belastningar, kostnader, avloppsvattnets miljöeffekter samt miljövårdsåtgärdernas för- och nackdelar. Programmet bestod av 19 projekt, som behandlades i 19 publikationer i form av 32 forskningsrapporter och 28 sammandrag, vilka även publiceras i denna sammandragsrapport.

Undersökningarna och utredningarna visar att utsläppen från den finländska skogsindustrin kommer att minska under undersökningsperioden fram till år 2010 i fråga om nästan samtliga parametrar trots att produktionen ökar.

Med hjälp av aktivslamanläggningar vilka blivit allt vanligare vid hanteringen av avloppsvattnet från den finländska skogsindustrin åstadkommer man en reduktion av näringsämnen (P och N) samt organiska klorföringarna (AOX). Enligt undersökningar förklarar de nuvarande mängderna AOX inte de verkningar man kunnat påvisa i ekosystemet. Förbättringen av svartluten vid hög torrsubstanshalt, behandlingen av gaser samt uppsamlingen, förbättringen och reningen av utluftningar reducerar utsläppen av svaveldioxid och luktande svavelföreningar (TRS). Om man börjar importera returfiber till Finland och om förbättringen av organiskt avfall inte blir allmännare, kan det leda till att avfallsmängden ökar.
Zusammenfassung

Ziel des SYTYKE-Programms, eines Programms der Finnischen Holzindustrie zu Umweltschutzforschung und -entwicklung, war es, durch Forschung und Studien die wissenschaftlichen und technischen Grundlagen für die langfristigen Umweltschutzziele und -massnahmen der Holzindustrie zu schaffen, den Forschungen der Holzindustrie zu Luftreinhaltung, Gewässerschutz und Abfallentsorgung zu koordinieren und die Zusammenarbeit der wichtigsten Kosten- und Leistungsträger der Forschung zu verstärken.


In den Forschungen und Studien wurde festgestellt, dass die Emissionen der finnischen Holzindustrie im Forschungszeitraum bis zum Jahre 2010 bei steigendem Produktionsvolumen in fast allen erfassten Parametern sinken werden.


Sichwörter
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Sonstige Angaben
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SYTYKE, The Environmental Research and Development Programme for the Finnish forest industry, was set up on March 29th 1989 by joint cooperation agreement between the Ministry of the Environment, the Central Association of Finnish Forest Industries and the Maj and Tor Nessling Foundation. The purpose of the programme and the scope of the research, the organisation to carry out the programme, the organisations with whom cooperation was to be made, and the amount of financial assistance and its duration were all determined in the agreement. It was agreed that the programme was to be a fixed term project of a particular nature, which was to be carried out between 1989–1992. Seppo Ruonala MSc Eng was the director of research for the programme.

The purpose of SYTYKE was to create scientific and technical bases for the long-term environmental protection objectives and measures of the forest industry. These objectives focus on production methods and processes and treatment of emissions as far as water protection, air protection and waste management are concerned. For this reason the research concentrates on the flow of substances, materials and energy which exceed the balance limits of the mill site. Similarly, this study does not cover environmental emissions and effects resulting from the production of purchased energy and raw materials.

The research and studies focus on the years 1995–2005, but also extend to the year 2010. This is because the targets concerning water and air protection and waste management which the authorities have established for the forest industry are scheduled mostly for the mid-90s.

SYTYKE made a total of 22 financing decisions. These resulted in the realisation of 19 projects the findings of which have been published by the National Board of Waters and the Environment in a total of 19 different series A publications. These include the summaries of 28 research reports published in the same series in Finnish, Swedish and English. A final report on the SYTYKE programme has also been published separately.
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MICROBIAL TRANSFORMATIONS OF PHOSPHORUS AND NITROGEN IN THE ACTIVATED SLUDGE TREATMENT OF FOREST INDUSTRY WASTEWATER

Summary

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The discharge of nutrients from pulp and paper industry has received attention during the last few years due to increased eutrophication of inland and coastal waters. There are at the moment 25 activated sludge treatment plants at pulp and paper mills in Finland. The operation of the plants is improving, and nutrient discharges have diminished. The wastewater amounts are, however, very big, and for that reason, nutrient concentrations in the effluents should be minimized.

Pulp and paper wastewaters are in general characterized by a high carbon to nitrogen ratio. To ensure proper growth of bacteria in activated sludge nitrogen is often added to the activated sludge system. In some cases also phosphorus is added, especially to treatment plants treating paper wastewater.

The goal of the present study was to investigate whether nutrient concentrations in the effluents from the treatment plants of the forest industry could be further reduced by biological means (other than needed for growth of the biomass).

The biological removal of nutrients in activated sludge treatment is based on specialized functions of certain groups of bacteria. In biological nitrogen removal bacteria convert soluble nitrogen to gaseous nitrogen, which escapes to the atmosphere. Biological phosphorus removal is based on the ability of a certain group of bacteria to take up excess phosphate from the liquid phase. Phosphorus is removed with the biomass.

These processes have been applied with success in municipal wastewater treatment, where nitrogen and phosphorus always are present in excess amounts. By excess amounts we mean that there are more nitrogen and phosphorus than needed for growth of the biomass as such.

In pulp and paper wastewaters there are less nutrients or only slightly more than needed for biomass growth. Can the methods for biological removal of nutrients be applied to pulp and paper wastewaters that have been well amended with nutrients? Can excess amounts of nutrients be removed? What happens if nutrient additions are very low or if they are not added at all?

**Nitrogen**

The microbial nitrogen cycle is fairly complicated. To obtain the gaseous product $N_2$ from organic $N$ in the wastewater, nitrogen must first be converted to ammonium, $\text{NH}_4^+$. This can then be oxidized to nitrate, $\text{NO}_3^-$, in the so called nitrification process. Now $\text{NO}_3^-$ can be reduced to $N_2$ in the so called denitrification process if there is no oxygen present in the environment.
In this study we measured the rates of the nitrification and the denitrification processes using specific assays for these processes. The goal was to measure the potential or the capacity for these processes to occur in the treatment plants as they are run now. Measuring potential rates means that during the assay substrates are added in non-limiting concentrations. The potential can be interpreted to be a measure of the size of the population in the sample. The in situ rate of the process in the activated sludge means the activity of the population at ambient substrate concentrations.

The measurements have been obtained in activated sludge samples originating from nine pulp and paper mills in Finland. Fresh samples were transported to the laboratory within a few hours, and short-term experiments were performed.

Our results have shown that the first step in the nitrogen removal process, the nitrification, is always the limiting step. Nitrification potential was detected at several treatment plants, which means that nitrifying bacteria were present in those activated sludges. For the nitrification to proceed in situ, ammonium must be present.

In the treatment plants treating paper wastewater we found rates of nitrification from 0 to 4.8 mg N g\(^{-1}\) dry sludge d\(^{-1}\). The experiments showed that a nitrifying population can be present even if the ambient ammonium concentration is very low. In one case the mineralization of NH\(_4\)\(^+\) from the biomass seemed to be fast enough to maintain a fairly high nitrification rate. In other treatment plants with the same free ammonium concentration, the nitrifying population disappeared.

Nitrification potential was also studied in a treatment plant treating wastewater from a NSSC pulp mill. This mill uses ammonium as the cooking base in the pulping process, and therefore the wastewater has a very high ammonium concentration. Fairly high rates of nitrification, up to 12 g N g\(^{-1}\) dry sludge d\(^{-1}\), were measured. The highest nitrification rate was, however, not high enough to oxidize all incoming NH\(_4\)\(^+\) to NO\(_3\)\(^-\) with the present configuration of the treatment plant. The concentration of NH\(_4\)\(^+\) was about five times as high as in municipal wastewater. In the studied treatment plants treating sulfate pulp wastewater (two investigated), we were never able to detect any nitrification activity.

It was also studied whether pulp wastewater would be toxic to nitrifiers. A well nitrifying sludge from a municipal treatment plant was exposed to pulp wastewater, and the nitrification assay was carried out. No reduction in nitrification activity was observed suggesting no acute toxicity.

The following step in a biological nitrogen removal, the denitrification process, was determined in short-term experiments with fresh sludge from the same nine mills that were investigated for nitrification activity. The method used for measurement is very sensitive, and even very small rates of gas production could be detected.

The highest potential denitrification rate was measured in the treatment plant of the NSSC mill that also showed the highest nitrification activity. The potential rates were up to 63 mg N g\(^{-1}\) dry sludge d\(^{-1}\). This rate was higher than what was detected in a sludge treating municipal wastewater. This activity in situ was limited by the carbon source required by denitrification. The inclusion of an anaerobic zone and supply of a carbon source would be needed to make the process to occur at this rate.
In all sludges studied a significant potential for denitrification was observed, i.e. denitrifying bacteria were present. Again the rates were lowest in the plants treating pulp wastewater (other than the NSSC pulp mill). The rates were ranging from 0.3 to 26 mg N g\(^{-1}\) dry sludge d\(^{-1}\). In all cases the denitrification rates measured were higher than the nitrification rates. This means that all NO\(_3^-\) produced by nitrification could right away be denitrified.

The other extreme of the nitrogen cycle, the nitrogen fixation, can occur when a treatment plant with high carbon to nitrogen ratio is operated without any nitrogen addition at all. In this process N\(_2\) is fixed by microorganisms, reduced to NH\(_4^+\) and incorporated into the biomass. Both blue-green bacteria and heterotrophic bacteria can carry out this process. In activated sludge conditions for photosynthetic organisms are unfavorable. There is very little light penetration. High carbon concentrations in the wastewater promote growth of heterotrophs. We investigated nitrogen fixation potential in two treatment plants treating pulp wastewaters and in two plants treating paper wastewaters.

Nitrogen fixation is known to be optimal under oxygen saturation of about 2 %. In the sludges from the two pulp mills there was a high nitrogen fixation activity if the assay was carried out under 2 % O\(_2\). At full aeration with 21 % O\(_2\) no or very little activity was detected. Addition of urea to the assay in the laboratory inhibited the nitrogen fixation activity after a short lag. Oxygen seemed to be the main factor regulating the nitrogen fixation activity. One pulp mill had operated the treatment plant with no nitrogen addition for more than two years. The mass balance of the treatment plant showed an input of nitrogen to the system. Addition of urea to the activated sludge plant in full scale for four weeks lowered the nitrogen fixation potential with only 25 to 50%. It seems that the nitrogen fixing population was fairly stable in the sludge.

The pulp plant mentioned in the previous chapter was operating with very low oxygen concentrations at the beginning of the aeration basin, down to 0.3 mg O\(_2\) l\(^{-1}\). This oxygen concentration is low enough to promote nitrogen fixation at a rate of 1.3 mg N g\(^{-1}\) dry sludge d\(^{-1}\). This maximum rate was found a few hours after mixing of the incoming wastewater with the recycled biomass. If the biomass in the whole aeration basin would fix nitrogen at this rate it could almost account for the calculated input of nitrogen. However, the oxygen concentration at the end of the aeration basin was too high to allow this high nitrogen fixation activity. The significance of the time the wastewater stays in the equalization basin with a low oxygen concentration with respect to nitrogen fixation is unknown.

The other pulp mill, where some activity was detected, also has a fairly low oxygen concentration at the beginning of the aeration basin. This treatment plant was operated with very low nitrogen addition, and the measured potential was about one fifth of that in the plant operated without nitrogen addition. In both paper mill treatment plants, nitrogen was added to the activated sludge. A low nitrogen fixation potential was detected at one of these two mills after lowering of the nitrogen addition. No potential was detected in the other paper mill treatment plant.

In conclusion it can be stated that removal of excess nitrogen by nitrification and denitrification would be possible in pulp and paper industry wastewaters if there is enough nitrogen in the system. In the activated sludge treating wastewater from the NSSC pulp mill (ammonium as the cooking base) there was a high nitrification potential, which, however, was not high enough to oxidize all ammonium in the
wastewater to nitrate. The lowest nitrification activities were found in treatment plants treating pulp wastewater under minimum addition of nitrogen or no addition at all. It should, however, be kept in mind that free ammonium concentration in the wastewater is not the only parameter determining the nitrification activity. A rapid in situ mineralization of nitrogen can happen. In some cases where nitrogen addition was very small or there was no addition we observed the opposite reaction to nitrogen removal: biological nitrogen fixation.

Addition of nutrients may improve the removal of other compounds (SYTYKE 3), and the settleability of the sludge. More than half of the nitrogen pool in the effluent may be in particulate form, and more than three quarters of the remaining soluble nitrogen is organic. By a better settling of the biomass it would be possible to diminish the particulate fraction of nitrogen. By better mineralization of the soluble organic nitrogen pool it would be possible to further reduce the nitrogen load to the recipients.

**Phosphorus**

Biological phosphorus removal has been studied in activated sludges treating municipal waste waters in many countries for more than 20 years. In spite of the active research microbial ecology of the activated sludge and the factors influencing the activities of the microbes are not very well known. On the microbes in the activated sludge process treatment of pulp and paper waste waters there is hardly any data.

According to the present knowledge biological phosphorus removal is based on the enrichment of bacteria capable of taking up more phosphorus than is needed for their growth. These bacteria are called "polyphosphate bacteria", because excess orthophosphate is stored as polyphosphates. *Acinetobacter* sp. is considered to be the most important of polyphosphate bacteria. In sludges treating municipal waste waters acinetobacters can represent even 60 % of the cultivable bacterial population. Phosphorus is removed from the treatment plant with the bacterial biomass.

Polyphosphate formation is a very important function for the competetiveness of these bacteria. Polyphosphates apparently act as energy reserves. In anaerobic conditions polyphosphates are degraded to orthophosphates and energy is released. This can be observed as an increase of the orthophosphate concentration of the growth medium. The energy is used to create a carbon reserve in the cell. When the polyphosphate bacteria again come to aerobic conditions, they have a carbon and energy reserve that can be immediately used for phosphate uptake and growth processes. In this way they can start multiplying faster than other bacteria, and harvest most of the nutrients of their growth medium (waste water).

In this project it was studied phosphate uptake and release kinetics of acinetobacters (model organisms for polyphosphate bacteria), and how growth and activities of polyphosphate bacteria could be enhanced and optimized. It was also investigated whether acinetobacters are significant in the aerobic activated sludge processes of pulp and paper mills in the way the treatment plants are operated now.

Bacteria in influents and activated sludges were studied in the treatment plants of two pulp and three paper mills. The bacteria were cultivated from homogenized sludges. Acinetobacters were also enriched from some samples. The ability of the sludge to
become enriched with polyphosphate bacteria was considered a measure of its "acinetobacter potential".

The number of acinetobacters was determined on acetate plates. Of all the bacteria growing on an acetate plate from 0 to 100% were acinetobacters depending on the sample. This percentage was used to estimate acinetobacter numbers from counts on acetate plates. The identified bacteria were picked from the most diluted samples, i.e. they represented the most common bacteria of the sample that could grow on that media. Acinetobacter estimates were compared to the total amount of aerobic heterotrophic bacteria (colony count on a general medium).

Acinetobacters constituted some two percent at the most of the total bacterial population in the treatment plants of both pulp and paper mills. In the influents to the treatment plants of paper mills there may be quite high densities of acinetobacters, but acinetobacters cannot compete with the other bacteria in the sludge. In the influents to the pulp mills studied there were usually not acinetobacters (i.e. in the most diluted samples). As an exception was the period when nitrogen (urea) was added to the influent. During this period a big part of the total aerobic bacterial flora in the influent was acinetobacters. The addition was made before the equalization basin where acinetobacters could possibly be enriched. There are also other implications that the nutrient content would affect acinetobacter numbers. Acinetobacters were found more frequently when the waste water was spiked with nutrients. With decreasing nutrient additions fewer acinetobacters were found — if found at all.

Numbers of acinetobacters can hardly be increased with any kinds of inocula — whether the inoculum would be in the waste water itself or separately added. If the treatment process has been planned so that it favours acinetobacters, the inoculum could enhance the recovery of suitable bacterial flora after a disturbance.

In the enrichment cultures it was in many cases quite easy to enrich acinetobacters in aerobic conditions if these bacteria were favoured by giving them acetate for carbon and energy source, and by adding only suitable mineral nutrients. Also sludges from pulp mills could become enriched with acinetobacters. This indicates that the amounts of acinetobacters could under favourable conditions grow fairly fast even in the treatment plants of pulp mills.

Optimal growth conditions of polyphosphate bacteria with respect to carbon (acetate), nitrogen, phosphorus, potassium and magnesium were studied by using acinetobacters isolated from the sludges as model organisms. A factorial design of experiments was used.

Best carbon and energy sources for acinetobacters are short chain, volatile fatty acids and alcohols. Concentrations of volatile fatty acids were very low (5% of the total concentration of dissolved carbon) in the influents to the treatment plants of pulp mills. It is obvious that lack of suitable carbon sources is one of the factors limiting the growth of acinetobacters in the pulp mill treatment plants. In the influents to the treatment plants of paper mills the concentrations of fatty acids were higher (from 30 to 40% of the total concentration of dissolved carbon). The sludge consumed the fatty acids very fast to levels of 3 to 5 mg C l⁻¹. The most common fatty acid was acetic acid.
The C:N:P ratio giving optimal growth was 100:14:1.5 on an average, or if carbon is converted to chemical oxygen demand (COD), COD:N:P = 100:5:0.5. The ratio C:P was almost the same (69) for all the studied Acinetobacter strains. The ratio C:N varied from 6 to 8 and the ratio N:P from 8 to 12 being 10 on an average. It has to be pointed out that the COD as measured from the waste waters contains all inorganic and organic compounds oxidizable with dichromate, and is not then fully comparable to the theoretic COD value of acetate. The bacteria cannot utilize all COD in the waste waters.

For acinetobacters the best growth was obtained with the N:P ratio of 10. The result indicates that the growth of acinetobacters could be enhanced with a higher nitrogen to phosphorus ratio than is usually applied (5) in waste water treatment.

Potassium (K), magnesium (Mg) and calcium (Ca) are important to many functions in the cells. Potassium is likely to be important in the regulation of the energetic state of the cell in the polyphosphate metabolism. Magnesium functions as the positive counterion of the polyphosphate anion. As a counterion magnesium can be replaced by calcium.

The temporal variations in the potassium and magnesium concentrations (soluble fractions) as well as the variations in different parts of the treatment plants were fairly small. But there were significant differences between the treatment plants. Every treatment plant seemed to have its typical potassium and magnesium level. The small variations of concentrations in the different parts of the treatment plant may indicate that either these ions are not biologically very active, or that their biological cycle is very fast.

Potassium and magnesium had a different effect on the growth of Acinetobacter strains. One strain grew best with concentrations of 6 mg K l^{-1} and 6 mg Mg l^{-1}, the other one did not react to potassium and magnesium additions, and the third one grew best at a concentration of 12 mg Mg l^{-1} and the better the more potassium was added. According to this study there is enough of potassium and magnesium in the pulp and paper waste waters (influents) for the needs of polyphosphate bacteria, although some strains might benefit from somewhat higher concentrations. The calcium concentrations in the treatment plants were always very high relative to the needs of the bacteria. Because calcium apparently can replace magnesium as a counterion a low magnesium concentration would not suppress polyphosphate formation in bacterial cells.

For good phosphate uptake both a sufficient amount of polyphosphate bacteria and high phosphorus uptake rate per biomass unit are needed. The phosphate uptake kinetics of polyphosphate bacteria was studied with two different methods. The first approach was to study short term batch cultures so that all or at least most of the phosphate uptake was excess uptake relative to growth requirements (model 1). In the second approach phosphate uptake was followed as a function of growth, ie. both phosphorus needed for the formation of biomass and excess uptake were included (model 2). Acinetobacters isolated from the sludge were used as model organisms. In the concentration range of 1 to 4 mg PO_{4}^{3-}P l^{-1}, which is typical for the influents to the treatment plants of forest industry, both models give the same result. For instance with initial concentrations of 1.5–2 mg PO_{4}^{3-}P l^{-1} the phosphorus uptake rate was from 2 to 3 mg (g DW)^{-1} h^{-1}. 
Based on the incoming phosphorus load, phosphate concentration of the influent and average flow of the waste waters it was calculated how big acinetobacter biomass it would be needed to remove the daily load of phosphate phosphorus. It was assumed that phosphate uptake would follow our kinetic models, and that the biomass would be evenly distributed in the aeration basin. The calculations were made with the data from a paper mill and a pulp mill. The result was in both cases that it would be needed an acinetobacter biomass of the order of $10^7$ ml$^{-1}$ in the aeration basin to remove the daily phosphorus load. The concentrations of acinetobacters in the aeration basins of both plants were of the order of $10^5$ to $10^6$ ml$^{-1}$. This biomass could then at the most remove 10 % of the phosphate. The good phosphorus removal capacity of these activated sludges is most likely not due to acinetobacters. Other heterotrophic bacteria, maybe other polyphosphate bacteria than acinetobacters, so called overplus phenomenon, physical and chemical adsorption and precipitation are responsible for the phosphorus removal in the aerobic treatment plants.

In biological phosphorus removal both phosphorus uptake and release are important phenomena. In anaerobic conditions polyphosphates are degraded to orthophosphate, which is released to the growth medium. Phosphate release was different for the Acinetobacter strains studied. The results support the theory stating that the significance of anaerobiosis for phosphorus release is indirect (formation of fermentation products, maybe decrease in pH). In anaerobic conditions also the enrichment of polyphosphate bacteria in the sludge is possible.

According to theoretical calculations the volatile fatty acids in the paper mill waste waters (influents) could sustain a big acinetobacter population. E.g. the fatty acid concentration of 170 mg C l$^{-1}$ could sustain an acinetobacter concentration of $8 \times 10^7$ ml$^{-1}$ presumed that there would not be any other bacteria assimilating these acids. In reality, however, there are many other bacteria, e.g. denitrifying bacteria, competing for fatty acids. Paper mill waste waters could be suitable to sustain an acinetobacter population big enough to remove all phosphate if the treatment plant would be built so that it would favour the growth of acinetobacters, and limit the growth of other heterotrophic aerobic bacteria. In practise this would require an anerobic zone.

In the waste water from a pulp mill there seemed to be a lack of suitable carbon sources for acinetobacters. There were enough of cations important for polyphosphate formation. If biological phosphorus removal based on acinetobacters would be applied to the treatment of pulping waste waters, the high molecular carbon compounds of the influents should be degraded to short chain fatty acids and alcohols (fermentation). For this an anaerobic reactor would be needed. The fermentation products should not be in contact with zones containing denitrifying bacteria. The anaerobic phase would be important also to enrich acinetobacters.

In conclusion we can ask if it is worth while to strive for enrichment of polyphosphate bacteria in the present activated sludge plants? Maybe not if the operation of the plants can otherwise be optimized, e.g. by better control of the nutrients in the plants (see SYTYKE 15). But it could be worth while to utilize polyphosphate bacteria in new types of treatment plants, where the waste waters are treated as separate fractions (e.g. nutrient rich and/or volatile fatty acid rich fractions), and where the conditions can from the very beginning be planned appropriately. If it is possible in the future to recognize the part of the bacterial genome that is responsible for polyphosphate formation, or to show the formation to be plasmid dependent, one could even think of using genetically manipulated bacteria to treat suitable waste water fractions.
SYTYKE 2

TREATMENT OF PULP MILL EFFLUENTS BY WHITE-ROT FUNGI AND THEIR ENZYMES

Summary

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SYTYKE 2
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TREATMENT OF PULP MILL EFFLUENTS BY WHITE-ROT FUNGI AND THEIR ENZYMES

Summary

The aim of this study was to elucidate possibilities for the treatment of pulp mill effluents to further develop a biological purification method which would be based on the ability of lignin-degrading white-rot fungi to remove chlorinated organic compounds and color. The production and properties of enzymes associated with lignin modification were studied using fungi grown in the presence of effluent. Influence of cultivation medium on the enzyme production and on the removal of color and chlorinated compounds was also investigated.

Activated sludge plants are commonly used in Finland to treat pulp mill effluents. In this process part of the organically bound chlorine is removed but neither high molecular weight structures nor color are acted by bacteria in sludge. Compounds which are formed during combustion of sludge may also create problems. Therefore, it would be most desirable that organic chlorine would be transformed to an inorganic form in the biological purification process.

Two biological processes for the treatment of bleach plant effluents, MyCoR in the USA and later MYCOPOR in Austria, have been developed. Both processes are based on the ability of the white-rot fungus *Phanerochaete chrysosporium* to remove color and chlorinated organic compounds (usually determined as adsorbable organic halogen, AOX) from effluents. A process utilizing enzymes would be more easily regulated than processes using whole cultures, and might also be more stable. However, the formation of ligninolytic enzymes in the presence of effluent has not previously been investigated. Their involvement and role must be studied before any evaluation of the potential and usefulness of enzyme reactors is possible.

First, the ability of selected white-rot fungi to grow in the presence of effluent and especially to remove color and organically bound chlorine were compared. In addition, fungi were screened in order to select for specimens which would consume as little as possible extra carbon source (glucose). The potential of lignin-degrading white-rot fungi other than *P. Chrysosporium*, which is used in MyCoR process, was also studied. Five fungi were compared. The most efficient fungi for color removal were *P. chrysosporium*, two *Phlebia radiata* strains and *Coriolus versicolor*. The ability to decolorize effluent seems to be a common characteristic of white-rot fungi, although with laccase-producing fungi the color actually increased in the beginning of the cultivation, probably due to the formation of quinones. Color removal after ca. two days was in the same range as with *P. chrysosporium*. *P. radiata* and *P. chrysosporium* were cultivated in shake flasks and in 2 l bioreactors, the enzymes produced purified and some enzymatic properties investigated. Experiments were designed so that statistical analysis of the results using response surface methodology was possible. Independent variables in the cultivations were the amounts of nutrient glucose (0.05 – 0.5 % (m/v)) and total effluent (20–80 % (v/v)). The dependent variables were the decrease of AOX and color, and various ligninolytic enzyme
activities during several sampling times. In addition, correlations between various factors were calculated.

In *P. radiata* cultivations the best AOX removal (57%) was obtained in the culture medium which contained 0.275% glucose and 20% effluent. In contrast, color removal was lowest in this cultivation. The dry weight of *P. radiata* mycelium significantly correlated with glucose concentration. Color removal (4 d) slightly correlated (not significantly) with glucose concentration. Thus, the higher the glucose concentration in the beginning of the cultivation, the more color was removed. In later stages of the cultivation the amount of glucose did not significantly influence the color removal. *P. radiata* produced rather a low amount of mycelium, and glucose consumption was also low. However, slightly more mycelium was formed in media containing higher amounts of glucose. With the lowest amount of glucose tested (0.05%), the least amount of mycelium was formed. In addition, lignin peroxidase activity was low although the removal of color and AOX were relatively high (i.e. in 6 days almost all the color was removed). In the beginning of the cultivation the color in some cultivations increased, probably because of the oxidation of phenols to quinones by laccase, the first enzyme produced by *P. radiata*.

In *P. radiata* cultivations the removal of AOX (mg l\(^{-1}\)) was greatest in culturrs containing the highest concentration of effluent. According to the regression equation, the higher the concentration of the effluent in the medium, the more AOX was removed in mg per day. However, AOX removal in percentage did not significantly correlate with the concentration of glucose or effluent.

In these cultivations laccase activity (6 d) negatively correlated with AOX removal (8 d) (confidence level 99 %). the higher oxidase (laccase) activity in 6 days, the lower the AOX removal in percentage. Lignin peroxidase activity (11 d) slightly correlated with AOX removal (8 d, in percentage).

*P. radiata* produced lignin peroxidase, laccase and manganese peroxidase in media which contained effluent. The production of laccase was higher when the effluent concentration in the medium was high. In *P. radiata* cultivations the amount of glucose correlated (but not significantly) with laccase (4 d) and lignin peroxidase activities (15 d). All laccase activities determined (4, 6, 8, 11 d) slightly correlated (not significantly) with effluent concentration. There was no correlation between effluent concentration and lignin peroxidase activity. In all experiments the maximum laccase activities occurred in 4–6 days. The more effluent in the medium, the higher were the activities. This was also observed in the equations obtained by regression analysis.

According to the regression analysis, dry weight of the mycelium depended on both glucose and effluent concentrations in *P. chrysosporium* cultivations. More mycelium was formed at higher glucose concentrations. The greatest amount of mycelium was formed at high glucose concentrations. The greatest amount of mycelium was formed at high glucose concentrations in cultivations where the amount of effluent was either under 34% or over 60%. Relatively large amounts of mycelium were present in cultures when compared with *P. radiata* cultivations, and *P. chrysosporium* rapidly assimilated the supplied glucose. This may be useful in effluent treatment since concentrated effluents disturb the growth of the fungus. Reuse of the mycelium in MyCoR process is possible, although it was not investigated in the present study.
Dry weight of *P. chrysosporium* mycelium correlated with color removal (6 d, 99% confidence level) which means that the more mycelium present, the more color removed. Color removal (4 d) correlated with AOX removal (4 d). The good correlation between AOX and color removal indicate that in *P. chrysosporium* cultivations dechlorination and color removal appear to be metabolically connected.

During the growth of *P. chrysosporium*, up to 81 mg l\(^{-1}\) inorganic chlorine was released. The release of chloride was the highest in higher glucose and effluent concentrations.

*P. chrysosporium* produced lignin peroxidase and manganese peroxidase in media containing pulp mill effluent. In a series of experiments designed for use with response surface methodology, the independent variables were glucose and effluent concentrations and dependent variables were lignin peroxidase (2–8 d) and manganese peroxidase activities (2–8 d). Multiple regression analysis gave first and second degree polynomials for the dependent variables. However, no clear results were obtained for optimum conditions. The amounts of effluent or glucose did not significantly explain different enzyme activities during the cultivations. Lignin peroxidase (6 d) and manganese peroxidase activity (6 d) correlated with glucose concentration, but not significantly in the confidence level which was used.

Lignin peroxidase activity was difficult to detect when determined directly from the cultivation medium of *P. radiata*. However, after the purification of enzymes using anion exchange chromatography relatively high enzyme activities were obtained. This may indicate that some compounds in the effluent inactivate lignin peroxidase. Manganese peroxidase activities appeared simultaneously or somewhat earlier than lignin peroxidase activities, and were quite high in all cultivations. Enzyme proteins were purified at the end of cultivations from culture liquors which contained different glucose and effluent concentrations. In all enzyme profiles two peaks, h1 and h2, were clearly separated. Peak h1 consisted of manganese peroxidase and h2 comprised of lignin peroxidases LiP2 and LiP3. The molecular weights of the proteins in the peak h1, obtained in denaturing acrylamide gel electrophoresis (SDS–PAGE), varied between 47.5–49 kDa and the peak h2 between 45–46 kDa. Laccase activity was no longer present in these 18 day old cultivations. After purification, the highest lignin peroxidase activities in peak h2 were obtained from cultures which were supplied by high amounts of glucose and relatively small amounts of effluent. The lowest activities were obtained in cultures which contained low amounts of glucose and larger amount of effluent.

In *P. chrysosporium* cultures in media containing pulp mill effluents, lignin peroxidase activities were again difficult to detect, but the purification of enzymes revealed that culture liquors contained relatively large amounts of active lignin peroxidase. The most dominant isozyme was LiP2 (H2). Another important isozyme was LiP1 (H8). When glucose concentration was low in the medium the relative amount of LiP2 (H2) was rather high.

There was a slight (not significant) correlation between the maximum activity of manganese peroxidase and the removal of color in 6 days. This connection, although not strong in the present work, may be important since according to recent reports, manganese peroxidase (but not lignin peroxidase) may play a key role in color removal from effluents.
In the case of both fungi, the connection between lignin peroxidase activity and the concentration of either glucose or effluent could not be reliably evaluated without a purification step since effluent interfered the enzyme assay. However, this became evident only during the study, and filtration or any other simple method to remove the inhibition was not found. For practical reasons, it was not possible to purify enzymes from every sample during the cultivations. However, one of the most important results found with the purified samples was the finding that in both *P. radiata* and *P. chrysosporium* cultivations the amount and quality of the effluent strongly influenced the apparent activity of lignin peroxidase. In spite of apparent inactivity in many culture liquors there was a lot of lignin peroxidase which was active after purification.

Enzymes produced in fungal cultures in the presence of effluent did not notably differ from enzymes obtained from cultures from which effluent was omitted. The results did not indicate occurrence of extracellular enzymes specific for dechlorination. Because fungi produced rather large amounts of lignin peroxidase, as estimated after purification, this enzyme may be important for the removal of AOX and color. Manganese peroxidase production and color removal correlated slightly in *P. chrysosporium* cultivations. In *P. chrysosporium* color removal and AOX removal seemed to be connected, but in *P. radiata* there was no clear connection. Laccase does not seem to be important enzyme for color removal or AOX decrease.

In conclusion, both *P. chrysosporium* and *P. radiata* more than 50% of AOX and almost all of the color. Growth rate, the amount of mycelium, consumption of glucose and the rate of AOX removal were higher in *P. chrysosporium* cultivations than in *P. radiata*. AOX decreased and color was removed using a relatively low amount of glucose by both fungi. Although the fungi produced different enzymes, both were almost equally efficient with respect to color removal. Response surface methodology did not reliably reveal the role of lignin peroxidase since in many *P. chrysosporium* and *P. radiata* cultivations lignin peroxidase activity was zero or very low in medium containing pulp mill effluent. However, after enzyme purification higher activities were obtained in these samples than cultivations without effluent. Effluent contained compounds which either inactivated lignin peroxidase or interfered with veratryl alcohol oxidation in lignin peroxidase activity assay. The most dominant lignin peroxidase isozyme in *P. chrysosporium* was LiP2 (H2), the relative amount of which increased with decreasing glucose concentration. The next dominant isozyme was LiP1 (H8). In *P. radiata* the most dominant isozyme at all glucose concentrations was the complex of LiP2 and LiP3. The other important enzyme was manganese peroxidase. Because both fungi readily produced ligninolytic enzymes in the presence of effluent they may be involved in the removal of organically bound chlorine and color. The results may be used in the development of enzyme reactors and also in the studies aimed for chlorine—free bleaching.
SYTYKE 3

THE EFFECTS OF NITROGEN NUTRIENT ADDITIVE ON OPERATIONS OF AN ACTIVATED SLUDGE EFFLUENT TREATMENT PLANT

Summary

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THE EFFECTS OF NITROGEN NUTRIENT ADDITIVE ON OPERATIONS OF AN ACTIVATED SLUDGE EFFLUENT TREATMENT PLANT

Summary

Even though the effluent was deficient in nitrogen, the activated sludge process functioned relatively well when the sludge life was long, about 16 days in age.

Adding urea to the effluent significantly improved the results, particularly in terms of COD, AOX, and phosphorous removal.

If the pulp mill effluent does not contain enough usable nitrogen, the microbes are able to bind nitrogen in the atmosphere. In this case as well, the treatment plant functions well, especially in the reduction of biological oxygen demand.

As the sludge age increased, from about 11 days (F/M ratio 0.14) to about 16 days (F/M ratio 0.14), the treatment results improved also in terms of phosphorous removal. In this case, larger COD reduction resulted in more excess sludge per cubic metre of effluent, and thus more phosphorous was bound to the sludge. The general opinion is that prolonging the life of the sludge reduces the amount of excess sludge. This is true when treating organic compounds which decompose easily. Pulp mill effluent contains generous amounts of compounds which decompose slowly. Prolonging sludge life promotes decomposition of COD, resulting in greater formation than decomposition of biomass.

Because of the addition of urea, sludge settling properties improve considerably. Consequently, a higher sludge content can be maintained in the aeration basin and clarification is improved.

Nitrogen originating in wood is principally organic nitrogen (over 90%), 50 to 60% of which can be decomposed and utilized by the activated sludge process. The remainder goes through the process in organic form, which cannot be removed by the nitrification–denitrification method. If the outgoing effluent contains significant amounts of NH₄ and NOₓ, excess amounts of nitrogen have been fed into the process. Excess ammonia may be oxidized in the process into nitrite alone. Some 40% of the nitrogen in this type of effluent can be removed by the activated sludge process.

BHK₇ does not give an accurate picture of the amount of decomposing organic material in the biological treatment of pulp mill effluent. Measurement of the activated sludge process in terms of oxygen and nutrients needs as well as sludge yield should be based on COD reduction instead of BHK₇.
SYTYKE 4

BIOSLUDGE FROM THE PULP AND PAPER INDUSTRY

Summary

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BIOSLUDGE FROM THE PULP AND PAPER INDUSTRY

Summary

Background and aims

In Finland's pulp and paper industry, about 200,000 – 300,000 t/a (dry matter) of sludges requiring treatment (primary sludges + biosludges) are formed. The amount of wet sludges is as high as 1.5 – 2 times that formed at municipal purification plants. Sludge treatment in an environmentally satisfactory way represents a problem in the pulp and paper industry. At present, part of the sludge is burnt together with bark waste, whereas part is disposed to dumps. Regardless of the main destruction method of sludges in the future, the sludges should be dried to as high a dry matter content as possible.

The composition and dewatering properties of the activated sludges formed in the pulp and paper industry differ from those of municipal sludges. These sludges contain more wood-derived components (lignin, cellulose, carbohydrates) and ash, and less fat-derived components than the municipal sludges. In addition, the composition of wastewater (i.e. the high C/N ratio) contributes to an abundant formation of exocellular polymers, which can make the sludges viscous and difficult to dewater. In practice, the drying of biosludge, for example in a band filter press, does not succeed without adding fibre or bark sludges or without the use of polyelectrolytes. The polyelectrolytes are unreliable if the quality of the sludge varies, and inefficient if the sludge contains an abundance of exocellular polysaccharides. The polyelectrolytes are also expensive.

In an earlier investigation performed at VTT and partly financed by industry, the chemical composition of activated sludges from the pulp and paper industry, and the effects of chemical, biochemical, physical and thermal treatment methods on the composition and water retention capacity of sludges were studied. However, no significant correlation was obtained between the chemical composition of sludges and their dewatering properties and no unambiguous theoretical mechanism was found to describe the two treatment methods developed in the project.

The present study was initiated to continue research on phenomena related to water retention. An object of particular interest was the significance of exocellular polysaccharides in water retention. Another aim was to study surface chemical phenomena related to water retention, such as physico-chemical changes on the surface of the sludge particle during dewatering.

In addition, a techno-economic assessment of different sludge treatment methods was carried out. On the one hand, costs of sludge combustion were compared with those of dump disposal, and on the other hand costs of different conditioning methods were compared with those of combustion in a bark boiler. The sludge conditioning methods studied were so-called Fenton treatment, integration of sludge dewatering to black liquor evaporation and Carver-Greenfield multistage evaporation by mixing sludge with crude tall oil.

Materials and methods

The significance of polysaccharides in water retention was first studied using microbe
populations separated from activated sludge and from circulation water of paper machines. These microbe populations were grown both in shaking cultures and in a fermentor on different substrates, and the amount and composition of the polysaccharides produced were determined. The effect of polysaccharides on water retention was studied by measuring the filtration resistance of the microbe suspension prior to and after the extraction of polysaccharides.

Surface chemical characteristics of activated sludge, chemical composition of flocs and the significance of polysaccharides in water retention were studied with samples taken from various purification plants (Table 1). The sludges were conditioned with the oxidizing Fenton treatment (0.1% H₂O₂, 0.5 mM FeSO₄, 70 °C, 2 h). Filtering resistance was used mainly as the measure of water retention, although some laboratory scale press tests were also carried out. The polysaccharides were separated by centrifugation. The zeta potential and contact angle were measured prior to and after the Fenton conditioning. The effect of conditioning on the surface-chemical composition of sludges was studied by FTIR analyses, and the size of external floc polymers by gel filtration (GPC). The conditioning mechanism was also studied by treating and analyzing pure sludge components in the same way as the samples. Effects of conditioning on filtrates were determined (BOD₇, COD, AOX, total P).

Results

Growing conditions (substrate, shake flasks/fermentor) affected crucially the amount of polysaccharides produced by the isolated microbes. The isolates originating from circulation waters of paper machines produced 300 – 1500 mg/g polysaccharides in shake flasks, whereas the amount of polysaccharides produced by activated sludge populations was rather small (50 – 300 mg/g). In the fermentor, the production of polysaccharides was very low for all the tested isolates, and the flocculation capability of the populations disappeared. This may indicate that extracellular polysaccharides are of significance in microbial flocculation.

The sugar composition of polysaccharides was typical for each population. The removal of polysaccharides reduced and the addition of xanthan (0.1 %) clearly increased the filtration resistance.

The floc structure and filtration resistance of sludge samples from different purification plants varied greatly. The floc structure of sludges from highly loaded plants was very loosely aggregated and viscous at the beginning of the investigation, prior to process changes in the plants concerned, whereas after the process changes the floc structure resembled more and more that of sludges from the low-loaded plants (Table 1).

The filtering characteristics of untreated samples correlated well with the loading of the plants: a high load resulted in a poorly filtering sludge and vice versa. The specific filtering resistance of all sludges was reduced by conditioning. The greatest changes were observed in sludges from the Metsä-Serla Mänttä Pulp Mill and Savon Sellu Pulp Mill. Changes in the sludges from low-loaded plants were in practice insignificant (Table 2).

For comparison, a number of sludge samples were also conditioned with a commercial polyelectrolyte (P44K). The filterability values were comparable with those of the Fenton conditioning, although the polymer consumption was higher than normal, 10–33 g/kg sludge.
Table 1. Data on wastewater treatment and on the floc structure of activated sludge.

<table>
<thead>
<tr>
<th>Plant and process</th>
<th>Waste water amount, ( m^3/d \times 10^3 \text{kg} )</th>
<th>Estimated org. load ( \text{BOD}_7/m^3 \times \text{d} )</th>
<th>Floc structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metsä–Serla Oy, Kuopio/NSSC</td>
<td>10</td>
<td>3.3</td>
<td>Gelatinous</td>
</tr>
<tr>
<td>Metsä–Serla Oy, Mänttä/si,</td>
<td>20 – 35</td>
<td>2.6</td>
<td>Loosely aggregated deinking plant</td>
</tr>
<tr>
<td>Metsä–Serla Oy, Aänekoski/sa</td>
<td>45</td>
<td>1.2</td>
<td>Compact</td>
</tr>
<tr>
<td>Kymmene Oy, Kuusankoski/sa</td>
<td>90</td>
<td>0.4</td>
<td>Compact</td>
</tr>
<tr>
<td>United Pulp Mills Kaipola/TMP</td>
<td>26</td>
<td>0.8</td>
<td>Very compact</td>
</tr>
</tbody>
</table>

Table 2. Filtrability of sludges prior to and after Fenton (F) and alkali–acid (a–a) conditioning.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Control</th>
<th>F/a–a conditioning</th>
<th>Control</th>
<th>F/a–a conditioning</th>
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<td>&lt;10</td>
<td>114</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>/III</td>
<td>2720</td>
<td>&lt;10</td>
<td>237</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>/IV</td>
<td>80</td>
<td>10/9</td>
<td>45</td>
<td>4/18</td>
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</tr>
<tr>
<td>MÄ</td>
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<td></td>
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<tr>
<td>/I</td>
<td>6660</td>
<td>70</td>
<td>11</td>
<td>5</td>
<td></td>
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<tr>
<td>/II</td>
<td>4450</td>
<td>720</td>
<td>146</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>/III</td>
<td>725</td>
<td>105</td>
<td>82</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>/IV</td>
<td>1815</td>
<td>85</td>
<td>210</td>
<td>14</td>
<td>8(10)</td>
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<tr>
<td>ÅK</td>
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</tr>
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<td>/I</td>
<td>60</td>
<td>20</td>
<td>124</td>
<td>106</td>
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</tr>
<tr>
<td>/II</td>
<td>70</td>
<td>20</td>
<td>130</td>
<td>59</td>
<td>30(33)</td>
</tr>
<tr>
<td>/III</td>
<td>100</td>
<td>190</td>
<td>138</td>
<td>71</td>
<td></td>
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<tr>
<td>/IV</td>
<td>1630</td>
<td>250/40</td>
<td>186</td>
<td>21/44</td>
<td></td>
</tr>
<tr>
<td>KN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>/I</td>
<td>30</td>
<td>10</td>
<td>54</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>KA1</td>
<td>/I</td>
<td>15</td>
<td>12</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>/II</td>
<td>28</td>
<td>10/6</td>
<td>13</td>
<td>8/10</td>
<td></td>
</tr>
<tr>
<td>KA3</td>
<td>/I</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>/II</td>
<td>10</td>
<td>5/2</td>
<td>8</td>
<td>6/7</td>
<td></td>
</tr>
</tbody>
</table>


A positive correlation was found between the polysaccharide content of sludges and the specific filtering resistance (Figure 1). In the highly loaded plants the polysaccharide contents varied within a wide range (100 – 300 mg/g) compared with the values of the low-loaded plants, which produced activated sludges with rather similar compositions. The polysaccharide contents of sludges from the United Paper
Mills Kaipola Works were also relatively high in some samples, although no problems occurred in filtering the sludge.

Compress tests were carried out with one series of samples of activated sludge–fibre sludge mixture (1:1) using a laboratory–scale compressing device to simulate real conditions of a filter belt press. The mixture was conditioned by the Fenton treatment and with polyelectrolytes according to dosing instructions obtained from different plants. On the basis of dry matter content and residue, the best results were obtained by the polyelectrolyte conditioning, although the Fenton conditioning also gave a satisfactory result for readily filterable samples. It should also be borne in mind that the Fenton conditioning had not been optimized for different sludges and that the results were based on only a few tests (variations between replicate tests were considerable).

Surface–chemical characteristics of sludges before and after the Fenton conditioning are presented in Table 3. The greatest changes were observed in samples from Savon Sellu Mill and Mänttä Mill, in which the surface charge became clearly less negative and the hydrophobicity of the floc increased (the contact angle increased). The changes in the surface properties of stable sludges from the United Paper Mills Kaipola Works were insignificant. The high filtering resistance of samples from Savon Sellu Mill and Mänttä Mill were probably at least partially due to the surface properties of the sludges: a high zeta potential and a small contact angle (hydrophilicity) prevent efficient flocculation. A small contact angle may be due to a high extracellular polysaccharide content, which is also seen as a high filtering resistance. No correlation was found between the sugar composition of the polysaccharides separated from the sludges and the filtering resistance.
The Fenton conditioning clearly changes the surface characteristics of sludges, although the reaction mechanism is still unknown. Hydroxyl groups of polysaccharides may possibly oxidize into carbonyl and carboxyl groups, which are more hydrophobic at low pH. FTIR analysis indicated that the amount of these groups was slightly increased, but other mechanisms may also be possible.

In the treatment of pure sludge components it was found that amorphic cellulose, hemicellulose and bacterial polysaccharides were at least partly depolymerized during the Fenton conditioning. This was seen as a decrease in viscosity and in the formation of reducing sugars. The molecular weights of the polymers separated from the sludges were rather low (\( M = 1000 - 5000 \)), which was also reflected by low viscosity values.

The Fenton conditioning increases the contents of BOD\(_7\), COD and total phosphorus in the filtrates, and reduces AOX contents of the conditioned sludges (Table 4). From earlier investigations it is known that the amount of soluble organic matter can be reduced without any significant reduction in the conditioning effect, for example by optimizing the temperature and reducing the H\(_2\)O\(_2\) content.

Table 3. Surface characteristics of sludges after the Fenton conditioning. The contact angle values of the alkali–acid conditioned samples are given in parentheses.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Zeta potential, mV</th>
<th>Contact angle, °</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Conditioned</td>
</tr>
<tr>
<td>SS</td>
<td>/I</td>
<td>-24</td>
</tr>
<tr>
<td></td>
<td>/II</td>
<td>-18</td>
</tr>
<tr>
<td>MÄ</td>
<td>/I0</td>
<td>-24</td>
</tr>
<tr>
<td></td>
<td>/II</td>
<td>-</td>
</tr>
<tr>
<td>ÄK</td>
<td>/I</td>
<td>-19</td>
</tr>
<tr>
<td></td>
<td>/II</td>
<td>-14</td>
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<td></td>
<td>/IV</td>
<td>-17</td>
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<td>KN</td>
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<td>-19</td>
</tr>
<tr>
<td></td>
<td>/II</td>
<td>-14</td>
</tr>
<tr>
<td>KA/A</td>
<td>/I</td>
<td>-14</td>
</tr>
<tr>
<td></td>
<td>/II</td>
<td>-14</td>
</tr>
<tr>
<td>KA/B</td>
<td>/I</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>/II</td>
<td>-13</td>
</tr>
</tbody>
</table>


Table 4. Effect of Fenton conditioning on the properties of the filtrate.

<table>
<thead>
<tr>
<th>Sample</th>
<th>BOD(_7), mg/l</th>
<th>COD, mg/l</th>
<th>Total phosphorus, mg/l</th>
<th>AOX(^1), %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Treated</td>
<td>Control</td>
<td>Treated</td>
</tr>
<tr>
<td>SS</td>
<td>5</td>
<td>190</td>
<td>730</td>
<td>780</td>
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<tr>
<td>MÄ</td>
<td>100</td>
<td>610</td>
<td>750</td>
<td>2100</td>
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<tr>
<td>ÄK</td>
<td>410</td>
<td>1600</td>
<td>1100</td>
<td>2900</td>
</tr>
<tr>
<td>KA</td>
<td>340</td>
<td>110</td>
<td>80</td>
<td>640</td>
</tr>
</tbody>
</table>


\(^1\) Net reduction in the whole sample, % of control.

\(^2\) Percentage of released phosphorus of the total phosphorus of the sample.

Thermal treatment methods can be applied if combustion of the wet sludge involves...
high costs or causes emissions to the environment, or if the efficiency of the combustion process can be increased. In practice, these methods must be used if the dump disposal costs of the sludge increase to such an extent that destruction of the sludge by combustion is the only economic alternative and if minimization of emissions and costs is essential. Thermal conditioning of sludges reduces the levels of emissions and avoids technical problems in the subsequent combustion, although from the point of view of the overall energy balance of the mill, the combustion process has little significance.

In the first part of the cost assessment, the costs of dump disposal and combustion were compared when using chemical conditioning and mechanical compression of sludges.

In the second part of the cost assessment, the profitability of each thermal treatment method was compared with that of the conventional chemical conditioning. The utility price of the steam generated in sludge combustion was used as a variable.

Sludge combustion proved superior to dump disposal even at rather low dump costs. The dump disposal was a too costly alternative for high sludge amounts. Discharge problems from dumps will also favour sludge combustion, and the dump disposal of sludges will most probably be prohibited in the near future. However, the feasibility of combustion is affected crucially by the utility price of additional steam production (Figure 2). Certain mills are more self-sufficient with regard to both electricity and heat requirements, whereas the others are compelled to buy energy.

![Figure 2. Cost savings due to combustion of waste sludge as a function of dump disposal costs and utility price of steam production.](image-url)
Technical problems of sludge combustion are highly dependent on the plant concerned, and hence are not assessed in detail in this study. Estimation of additional costs or savings related to emissions would require a more extensive study of thermal treatment processes in pilot and industrial scale, and a cost assessment of emission impacts.

In this study, the economic feasibility of different thermal treatment methods was assessed on the basis of investments required for the intensification of steam generation.

Tall soap conditioning and integration of sludge dewatering to black liquor evaporation proved to be the most feasible treatment method. However, the process can be applied only in sulphate cellulose mills. Possible impacts of sludge in the black liquor evaporation plant also require additional research.

The Fenton treatment and the Carver–Greenfield process are more feasible alternatives than the standard chemical treatment at steam prices of more than FIM 20/MWh (Figure 3). The technical applicability of the Fenton treatment is well known, whereas the increase of COD, BOD, and nutrients to the effluents due to the treatment, and on the other hand the reduction of AOX in the sludge require further studies. Their economic effect on the profitability of the process concerned may be significant. Only very limited research results are available concerning the suitability of the Carver–Greenfield treatment for biosludges, and hence the economic assessment of this process can be regarded as only tentative.

Figure 3. Costs of alternative thermal sludge conditioning processes compared with those of conventional chemical conditioning.
SYTYKE 5

COMBUSTION OF BIOSLUDGE

Summary

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COMBUSTION OF BIOSLUDGE

Summary

The activated sludge treatment of waste waters from kraft pulp mills produces large amounts of biosludge. Of the total sludge produced annually by the Finnish pulp and paper industry — some 350,000 tonnes in terms of dry weight — around 50,000 tonnes is biosludge. By the year 2000, when almost all pulp and paper mills in Finland will be using activated sludge treatment, this figure will rise to around 100,000 tonnes a year. Just over one-third of all biosludge will come from the treatment of waste waters at mills producing bleached kraft pulp.

Before disposal, biosludge from activated sludge treatment is mixed with the fibre-containing sludge from the mechanical clarification of waste water. The only feasible way to dispose of this mixed sludge is to burn it together with bark. However, little is known about the emissions to the air caused by burning sludge. Although the chlorine content of pulp mill biosludge is lower than that of community waste, burning biosludge can result in the formation of chlorinated compounds such as chlorinated phenols, benzenes and dioxins. The biosludge from paper mills has such a low chlorine content that such compounds are unlikely to be formed when it is burned.

Against this background, the Finnish Pulp and Paper Research Institute (KCL), in conjunction with the Technical Research Centre of Finland, manufacturers of bark-fired boilers and mills at which sludge is burned, investigated the burning of kraft pulp mill biosludge in bark-fired boilers. The main aim was to study the gaseous emissions from combustion, with special emphasis on chlorinated compounds, and to determine safe combustion conditions.

The study

The combustion of a mixture of bark and biosludge from a bleached kraft pulp mill was studied under controlled conditions. Emissions from three different types of bark-fired boiler were compared: bubbling fluidized bed, circulating fluidized bed and grate. During the tests, samples were taken from the flue gases, from the ash in the electrostatic precipitator and from the grate/bottom ash. These were analysed for chlorinated dioxins, phenols and benzenes, PCBs and PAHs, and heavy metals. The usual flue gas emission parameters SO₂, NOₓ and particulates were also measured.

Combustion tests were conducted on the pilot scale and full mill scale in order to determine safe combustion conditions.

Results and conclusions

Measurements revealed that burning a mixture of bark and biosludge from a bleached kraft pulp mill can give rise to small amounts of chlorinated compounds. When the dry weight of fuel mix contained 5–14% sludge, the flue gases had a higher content of these chlorinated compounds than when bark alone was burned. This is probably due to the chlorine present in the sludge.
Figure 1. Chlorinated dioxins formed by burning bark together with kraft pulp mill sludge.

BFB1 = bubbling fluidized bed, test 1
BFB2 = bubbling fluidized bed, test 2
CFB = circulating fluidized bed
bESP = before hot electrostatic precipitator

However, it was clearly shown that the chlorinated dioxins introduced into the fuel mix with the sludge did not explain the amounts of chlorinated dioxins found in the flue gases and ash samples.

Measurements on the bubbling fluidized bed boiler, however, indicated that burning wet bark containing a high proportion of sludge (c. 20% dry weight) does not cause any greater emissions than burning a normal mix, provided proper combustion conditions are maintained in the boiler.

The amount of chlorinated dioxins in the flue gases varied from 0.07 to 1.2 ng/m³ as expressed in Eadon equivalents according to international practice. The three boilers studied gave rise to different emissions, as shown in Fig. 1. In the case of the circulating fluidized bed boiler, most of the dioxin formation took place in the hot electrostatic precipitator, which is rarely used in conjunction bark-fired boilers. The results lead to the assumption that the chlorinated dioxin levels in the flue gases can vary from one boiler to the next, although they probably fall within the range of values measured in this study.
Table 1. Burning pulp mill sludge together with bark. Results of mill-scale trials.

<table>
<thead>
<tr>
<th></th>
<th>Bubbling fluidized bed</th>
<th>Grate</th>
<th>Circulating fluidized bed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td></td>
</tr>
<tr>
<td>Boiler output MW</td>
<td>65</td>
<td>84</td>
<td>47</td>
</tr>
<tr>
<td>Furnace temp. °C</td>
<td>830</td>
<td>883</td>
<td>898</td>
</tr>
<tr>
<td>Elec. precip. temp. °C</td>
<td>150</td>
<td>170</td>
<td>155530</td>
</tr>
<tr>
<td>Flue gases:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dioxins, Eadon ng/m³n</td>
<td>0.14</td>
<td>0.39</td>
<td>1.09</td>
</tr>
<tr>
<td>Cl–phenols µg/m³n</td>
<td></td>
<td>0.38</td>
<td>0.19</td>
</tr>
<tr>
<td>Cl–benzenes µg/m³n</td>
<td>0.61</td>
<td>0.27</td>
<td>0.54</td>
</tr>
<tr>
<td>PCBs µg/m³n</td>
<td></td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>PAHs µg/m³n</td>
<td>8.3</td>
<td>20.9</td>
<td>5</td>
</tr>
<tr>
<td>SO₂ ppm</td>
<td>10</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>NO₂ ppm</td>
<td>162</td>
<td>150</td>
<td>80</td>
</tr>
<tr>
<td>Particles mg/m³n</td>
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<td>HCl mg/m³n</td>
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</tr>
<tr>
<td>Fuel:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine mg/kg</td>
<td>1340</td>
<td>1300</td>
<td>1000</td>
</tr>
<tr>
<td>Dioxins, Eadon pg/g</td>
<td>99</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Ash:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine mg/kg</td>
<td>5600</td>
<td>9030</td>
<td>6400</td>
</tr>
<tr>
<td>Dioxins, Eadon pg/g</td>
<td>96</td>
<td>106</td>
<td>1208</td>
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</tbody>
</table>

a) 0.15 ng/m³n before hot electrostatic precipitator

The emissions fell between the target values set in Sweden for waste incineration, namely 0.1 ng/m³n for new plants and 1 ng/m³n for old ones. In assessing the emissions measured in the present study, it should be remembered that all three bark-fired boilers were old and that the fluidized bed boilers had originally been designed to burn spent liquors. New boilers employing more sophisticated combustion techniques can be expected to produce lower chlorinated dioxin emissions than those measured here. Fluidized bed boilers provide more uniform combustion conditions than grate boilers, and therefore are presumably less likely to cause the formation of chlorinated dioxins.

As can be seen from Table 1, the ash from the electrostatic precipitator of the grate boiler had a much higher chlorinated dioxin content than was the case with the fluidized bed boilers. In the flue gases from the grate boiler, a much higher proportion of the chlorinated dioxins was bound to solid particles than with the fluidized bed boilers.

The levels of chlorophenols, chlorobenzenes and PCBs shown in Table 1 were low compared with those measured for waste incineration. The PAH levels were also low,
with the exception of those measured for the circulating fluidized bed boiler, where combustion was incomplete.

The pilot tests revealed no correlation between the combustion conditions and the formation of chlorinated compounds; the discrepancy with the results obtained from mill-scale measurements indicates that the results of pilot-scale tests are not relevant to industrial practice.

In assessing the emissions of chlorinated compounds found in this study, it should be remembered that the measurements were made at a time when pulp mills were using almost the traditional amounts of chlorine. This means the sludges had higher chlorine contents than is at present the case. In the future, as bleaching processes change, sludge chlorine levels are likely to become very low indeed, which means the emission of chlorinated compounds from burning sludge will also be very low.

The heavy metal contents of the flue gases from burning sludge were about one-tenth of the limits allowed for waste incineration plants. Although the sludges generally contained higher levels of heavy metals than bark, the inclusion of sludge in the fuel mix was not reflected in the levels found in the ash from the electrostatic precipitator, with the exceptions of chromium, nickel and iron.

The inclusion in the fuel of normal amounts of sludge did not cause SO\textsubscript{2} emissions to rise above the very low level resulting from burning bark alone. On the other hand, the nitrogen oxide content of the flue gases rose by about 20 mg NO\textsubscript{2}/MJ.
SYTYKE 6

THE STATE OF THE FINNISH FOREST INDUSTRY IN 1995

Summary

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THE STATE OF THE FINNISH FOREST INDUSTRY IN 1995

Summary

Production, Raw Material, Energy, Emissions, Waste

Development of world markets

The production development of the Finnish forest industry depends on the development of the world markets, the quality level of the products and their price competitiveness in the open markets. The production of the world forest industry is forecast to grow in the medium term, since the raw material of this industry is an effectively renewing natural resource with a secure supply. Also the following factors have a positive effect on consumption:

- population growth
- increased number of households
- higher educational level
- bigger industrial production volume
- increasing advertising

The recycling ability of the forest industry products is good and the average energy self-efficiency rate of production is high.

Table 1–1 presents a forecast of world consumption of paper and paperboard in 1995 and a growth forecast until the year 2005.

Table 1–1. Forecast of World Consumption of Paper Products in 1995 and Its Growth During the Period 1995–2005

<table>
<thead>
<tr>
<th>Paper and board grade</th>
<th>Consumption 1995 (mill. tons)</th>
<th>Growth %/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newsprint</td>
<td>38.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Uncoated mechanical paper</td>
<td>14.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Coated mechanical paper</td>
<td>13.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Uncoated fine paper</td>
<td>39.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Coated fine paper</td>
<td>13.4</td>
<td>4.0</td>
</tr>
<tr>
<td>Soft tissue</td>
<td>16.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Corrugated fibreboard</td>
<td>75.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Interior package board</td>
<td>27.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Sack paper</td>
<td>6.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Other paper and board grades</td>
<td>28.9</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>273.5</strong></td>
<td></td>
</tr>
</tbody>
</table>

The forecasts of the consumption of papermaking pulp can be derived directly from the forecasts of the consumption of paper and board. There will be no significant
changes in the pulp grade composition of the products. The share of recycled fibre from waste paper will, however, grow in newsprint, mechanical paper, soft tissue and corrugated fibreboard. Recycled fibre will primarily replace mechanical pulp, viz. refiner groundwood and groundwood pulp. In some products also the share of fillers and binders will grow somewhat.

The major part of the production of papermaking pulp is integrated with the production of paper and board, i.e. pulp is made in connection with the paper mill. However, part of it is so-called market pulp, which is dried and packed in bales at the pulp mill and then taken to paper mills located elsewhere and used there as raw material. The consumption and growth forecasts of market pulp are given in Table 1–2.

Table 1–2. Forecast of World Consumption of Market Pulp in 1995 and Its Growth During the Period 1995–2005

<table>
<thead>
<tr>
<th>Pulp grade</th>
<th>Consumption in 1995</th>
<th>Growth</th>
<th>%/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical and semi-mechanical pulp</td>
<td>2.55</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Unbleached sulphate pulp</td>
<td>17.24</td>
<td>-0.2</td>
<td></td>
</tr>
<tr>
<td>Bleached softwood sulphate pulp</td>
<td>12.97</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Bleached hardwood sulphate pulp</td>
<td>2.53</td>
<td>-4.3</td>
<td></td>
</tr>
<tr>
<td>Sulphite pulp</td>
<td>4.36</td>
<td>-0.6</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>41.42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1–3 presents a forecast of world consumption of the products of the mechanical forest industry until 1995, i.e. sawnwood and different types of boards, and their estimated, annual average growth.


<table>
<thead>
<tr>
<th>Product</th>
<th>Consumption 1995</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawn softwood</td>
<td>394.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Plywood and veneer</td>
<td>52.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Fibreboard</td>
<td>57.4</td>
<td>1.6</td>
</tr>
<tr>
<td>MDF</td>
<td>5.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Hardboard</td>
<td>8.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Development outlook for the Finnish Forest Industry

Structural changes take place slowly within the highly capital-intensive forest industry. Therefore the existing plants and equipment will be used during a long time to come, and no great changes can be expected in the production structure of the Finnish forest industry in the medium term.

Table 2–1 shows a forecast of the paper and board production of the Finnish forest industry for 1995 and 2005. Like all the figures for the Finnish forest industry also
these forecasts are so-called trend forecasts, with do not take into account the general trend fluctuations in production figures.

Table 2-1. Forecast of the Production of the Finnish Paper Industry for 1995 and 2005

<table>
<thead>
<tr>
<th>Paper and board grade</th>
<th>Production 1995 1000 t</th>
<th>Production 2005 1000 t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newsprint</td>
<td>1 430</td>
<td>1 530</td>
</tr>
<tr>
<td>Uncoated mechanical paper</td>
<td>2 250</td>
<td>2 500</td>
</tr>
<tr>
<td>Coated mechanical paper</td>
<td>1 870</td>
<td>2 500</td>
</tr>
<tr>
<td>Uncoated fine paper</td>
<td>1 250</td>
<td>1 600</td>
</tr>
<tr>
<td>Coated fine paper</td>
<td>620</td>
<td>1 000</td>
</tr>
<tr>
<td>Soft tissue</td>
<td>190</td>
<td>220</td>
</tr>
<tr>
<td>Corrugated fibreboard</td>
<td>820</td>
<td>850</td>
</tr>
<tr>
<td>Interior package board</td>
<td>1 180</td>
<td>1 480</td>
</tr>
<tr>
<td>Sack paper</td>
<td>185</td>
<td>175</td>
</tr>
<tr>
<td>Other paper and board grades</td>
<td>785</td>
<td>860</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10 580</strong></td>
<td><strong>12 715</strong></td>
</tr>
</tbody>
</table>

The production in the table for 1995 will be achieved with already existing equipment or equipment now being constructed. There will hardly be any important new investments in paper production before 1995.

The production of pulp and paper in Finland is to a high degree integrated and market pulp is exported to mills abroad owned by Finnish companies. Table 2-2 shows forecasts of the Finnish forest industry's production of papermaking pulp in 1995 and 2005.

The production in Table 2-2 will not be achieved with the production equipment that exists or is being built. The production capacity both for mechanical and chemical pulp should be increased by 1995. The implementation of such a capacity increase will depend on the recovery of the pulp and paper markets and on the financing possibilities of the Finnish forest industry.

Table 2-2. Forecast of Market Pulp Produced in Finland 1995 and 2005

<table>
<thead>
<tr>
<th>Pulp grade</th>
<th>Production 1995 1000 t</th>
<th>Production 2005 1000 t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical and semi-chemical pulp</td>
<td>4 040</td>
<td>4 775</td>
</tr>
<tr>
<td>Unbleached sulphate pulp</td>
<td>710</td>
<td>700</td>
</tr>
<tr>
<td>Bleached softwood sulphate pulp</td>
<td>2 920</td>
<td>3 350</td>
</tr>
<tr>
<td>Bleached hardwood sulphate pulp</td>
<td>2 475</td>
<td>2 785</td>
</tr>
<tr>
<td>Sulphite pulp</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Dissolving pulp</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Recycled fibre</td>
<td>580</td>
<td>700</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10 775</strong></td>
<td><strong>12 360</strong></td>
</tr>
</tbody>
</table>

As to raw material supply and know-how, the possibilities of increasing capacity after 1995 are extremely good, under the following conditions:
The raw material, labour and capital costs of the forest industry are reduced to a competitive level.

The supply of electric power and fuel of the forest industry is secured.

No limitations weakening the competitiveness of the forest industry operating in Finland compared with that of other countries are imposed through laws.

If these conditions are met, the production figures in Table 2–1 and 2–2 can be reached in the year 2005. Otherwise, the danger is great that the Finnish forest companies will invest more and more abroad and Finland is left with an obsolete production machinery which gradually is taken out of use.

Table 2–3 indicates the production forecast of the Finnish mechanical forest industry for the years 1995 and 2005. A drop in production is expected during the next 15–year period within all product groups, mainly due to the unsatisfactory price competitiveness.

Figure 2/1 shows Finland's market shares in the international export markets by main product. Finland's share of the mechanical printing paper market was substantial in 1988. The country belongs also to the world's most important exporters of uncoated fine paper and interior package board grades.

Table 2–3. Forecast of the Production of the Finnish Mechanical Forest Industry in 1995 and 2005

<table>
<thead>
<tr>
<th>Product</th>
<th>Production 1995</th>
<th>Production 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000 m³</td>
<td>1000 m³</td>
</tr>
<tr>
<td>Softwood sawnwood</td>
<td>7 300</td>
<td>6 700</td>
</tr>
<tr>
<td>Plywood and veneer</td>
<td>590</td>
<td>550</td>
</tr>
<tr>
<td>Particleboard</td>
<td>620</td>
<td>590</td>
</tr>
<tr>
<td>Softboard</td>
<td>150</td>
<td>130</td>
</tr>
<tr>
<td>MDF</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hardboard</td>
<td>87</td>
<td>77</td>
</tr>
</tbody>
</table>
Figure 2/1. Finland's Market Share in the World Markets by Product in 1988

**Raw materials and chemicals of the Forest Industry**

A forecast of the forest industry's wood consumption is presented in Table 3–1. It is based on the production forecasts given above and on the assumption that there will be no change in the amount of wood consumed by the production unit. However, a slightly improved board yield has been assumed for sawnwood.

**Table 3–1. Forecast of the Forest Industry's Wood Consumption in 1995**

<table>
<thead>
<tr>
<th></th>
<th>Softwood 1000 m³/s</th>
<th>Hardwood 1000 m³/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical forest industry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– mechanical pulp</td>
<td>10 300</td>
<td></td>
</tr>
<tr>
<td>– chemical pulp</td>
<td>21 880</td>
<td>12 630</td>
</tr>
<tr>
<td>Total raw material use</td>
<td>32 180</td>
<td>12 630</td>
</tr>
<tr>
<td>Chips from the mechanical forest industry</td>
<td>–6 740</td>
<td></td>
</tr>
<tr>
<td>Stemwood for the chemical forest industry</td>
<td>25 440</td>
<td>12 630</td>
</tr>
<tr>
<td>Stemwood for the mechanical forest industry</td>
<td>17 170</td>
<td>1 885</td>
</tr>
<tr>
<td>Total</td>
<td>42 610</td>
<td>14 515</td>
</tr>
</tbody>
</table>
Table 3–2 gives a forecast of the forest industry's consumption of other raw materials than wood for the year 1995. The recycled fibre yield has been assumed to be 85%, the rest being paper fillers and fibre losses in the process. The amounts have been given as absolutely dry.

Table 3–2. Forecast of the Raw Material Consumption of the Forest Industry in 1995

<table>
<thead>
<tr>
<th></th>
<th>1000 t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste paper</td>
<td>655</td>
</tr>
<tr>
<td>Fillers and coating materials</td>
<td>1730</td>
</tr>
<tr>
<td>Glues and binders</td>
<td>298</td>
</tr>
</tbody>
</table>

It is assumed that the recycled fibre will come from domestic waste paper. The domestic paper consumption in 1995 has been calculated at 1 470 000 tons, which means a recycling degree of 45% of the paper consumed in Finland. However, it is possible that the share of recycled fibres in paper products must be increased due to trade politics, which means that the recovery degree of the waste paper has to be raised considerably or bigger volumes of this product must be imported to Finland. This would correspondingly decrease above all the use of spruce as raw material in mechanical pulp.

Table 3–3 presents a forecast of the chemical forest industry's consumption of chemicals in 1995. The use of certain chemicals is much influenced by the way the pulp mills control the sulphur/sodium ratio in their cooking liquor. The efforts to reduce emissions have led to bigger amounts of sulphur being returned to the chemicals circulation. At the same time, the increased use of chlorine dioxide brings more sulphuric acid to the mill. Everything indicates that the introduction of modern technology will accumulate sulphur in the chemicals circulation of all pulp mills in 1995. It must be possible to reduce the use of sulphuric acid or the sulphur must be eliminated from the mill, either in the form of sodium sulphate or possibly calcium sulphate. Since there are many alternative solutions and each mill is developing its own, it is impossible to forecast consumption of sulphuric chemicals in 1995 in a reliable way. The figures given in the table are based on the assumption that the specific consumption of sulphuric chemicals will be on the same level as today, which, however, leads to an unbalanced sulphur/sodium ratio.
### Table 3-3. Consumption of Chemicals of the Forest Industry in 1995

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Amount (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphuric acid</td>
<td>129,400</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>540</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>11,900</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>57,300</td>
</tr>
<tr>
<td>Elementary sulphur</td>
<td>22,200</td>
</tr>
<tr>
<td>Calcium oxide</td>
<td>49,600</td>
</tr>
<tr>
<td>Ammonia</td>
<td>8,790</td>
</tr>
<tr>
<td>Oxygen</td>
<td>89,900</td>
</tr>
<tr>
<td>Caustic soda</td>
<td>208,000</td>
</tr>
<tr>
<td>Chlorine gas</td>
<td>70,400</td>
</tr>
<tr>
<td>Sodium chlorate</td>
<td>138,000</td>
</tr>
<tr>
<td>Hydrogen peroxide</td>
<td>35,900</td>
</tr>
<tr>
<td>Dithionite</td>
<td>12,600</td>
</tr>
<tr>
<td>Sodium silicate</td>
<td>58,400</td>
</tr>
<tr>
<td>DTPA</td>
<td>11,500</td>
</tr>
</tbody>
</table>

### Production and consumption of energy

The forecasts of the consumption of fuel and electric power of the forest industry in 1995 are based on the production forecasts for the same year. The specific consumption of both heat and electric energy of each product has been defined on the bases of statistical data. The production of back-pressure energy of the mill has been calculated based on the process heat requirements. Burning of black liquor and bark at the non-integrated pulp mills will produce a surplus of steam, which could be used to generate condensing power.

It has been assumed in the forecast that all the wood residues and black liquor of the mills are used as fuel. Fossil fuels are purchased in the same proportions as today. Table 4–1 indicates the amounts of energy which are assumed to be obtained from fuel in 1995. Statistical data for the period July 1, 1989 to June 31, 1990 are also given for comparison. The figures are fit for comparison with the reservation that the energy content may have been calculated using different calorific value definitions.

### Table 4-1. Use of Fuel in the Forest Industry in 1989–90 and 1995

<table>
<thead>
<tr>
<th></th>
<th>1989 - 1990</th>
<th>1995</th>
<th>Increase %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy PJ</td>
<td>Share</td>
<td>Energy PJ</td>
</tr>
<tr>
<td>Spent liquor</td>
<td>90.0</td>
<td>45.5</td>
<td>121.3</td>
</tr>
<tr>
<td>Woodfuel</td>
<td>38.6</td>
<td>19.5</td>
<td>48.9</td>
</tr>
<tr>
<td>Peat</td>
<td>11.8</td>
<td>6.0</td>
<td>13.7</td>
</tr>
<tr>
<td>Domestic fuels, total</td>
<td>140.4</td>
<td>70.9</td>
<td>183.9</td>
</tr>
<tr>
<td>Earth gas</td>
<td>28.9</td>
<td>28.9</td>
<td>22.2</td>
</tr>
<tr>
<td>Coal</td>
<td>13.8</td>
<td>7.0</td>
<td>9.6</td>
</tr>
<tr>
<td>Fuel oil etc.</td>
<td>14.9</td>
<td>7.7</td>
<td>17.6</td>
</tr>
<tr>
<td>Imported fuels, total</td>
<td>57.6</td>
<td>29.1</td>
<td>49.4</td>
</tr>
<tr>
<td>Total</td>
<td>198.0</td>
<td>100.0</td>
<td>233.3</td>
</tr>
</tbody>
</table>
The electric power consumed and produced by the forest industry in 1988 according to the statistical data and the corresponding forecast for 1995 are presented in Table 4.2. The consumption forecast is based on specific consumption figures.

The opinions whether the forest industry is able to reduce the specific energy consumption diverge very much. Some potential saving possibilities have been found, but up to 1995 there is no technical method which in a decisive way would reduce the electric power consumed when manufacturing e.g. mechanical pulp grades.

Table 4–2. Electric Energy Balance in 1988 and 1995

<table>
<thead>
<tr>
<th></th>
<th>1988</th>
<th>1995</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GWh/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Consumption</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical pulps</td>
<td>6 992</td>
<td>7 626</td>
<td>+14.0</td>
</tr>
<tr>
<td>Recycled fibre pulps</td>
<td>53</td>
<td>118</td>
<td>+122.6</td>
</tr>
<tr>
<td>Chemical pulps</td>
<td>3 850</td>
<td>4 606</td>
<td>+19.6</td>
</tr>
<tr>
<td>Paper and board</td>
<td>6 052</td>
<td>7 404</td>
<td>+22.3</td>
</tr>
<tr>
<td>Mechanical industry</td>
<td>1 045</td>
<td>984</td>
<td>-5.8</td>
</tr>
<tr>
<td>Mechanical conversion</td>
<td>562</td>
<td>618</td>
<td>+10.0</td>
</tr>
<tr>
<td>etc.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total consumption</strong></td>
<td>18 254</td>
<td>21 356</td>
<td>+17.0</td>
</tr>
<tr>
<td><strong>Own production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic power</td>
<td>1 995</td>
<td>1 900</td>
<td>-4.8</td>
</tr>
<tr>
<td>Back-pressure power</td>
<td>6 210</td>
<td>7 475</td>
<td>+20.4</td>
</tr>
<tr>
<td>Condensing power</td>
<td>128</td>
<td>107</td>
<td>-16.4</td>
</tr>
<tr>
<td>Gas turbines etc.</td>
<td>176</td>
<td>176</td>
<td>+0.0</td>
</tr>
<tr>
<td><strong>Total own production</strong></td>
<td>8 509</td>
<td>9 658</td>
<td>+13.5</td>
</tr>
<tr>
<td><strong>Purchased energy</strong></td>
<td>9 745</td>
<td>11 699</td>
<td>+20.1</td>
</tr>
</tbody>
</table>

The production of the hydraulic power stations of the mills in Table 4–2 is according to the average in the 1980s. The figure given for back-pressure production assumes a total utilisation of the forest industry's back-pressure capacity. The forest industry has an installed condensing power capacity of over 1500 GWh. The table includes, however, only the condensing power which would be produced by the surplus steam of the pulp mills. No changes have been forecast in the production of electricity based on gas turbines and on the district heat production of the mills. According to these assumption, the forest industry's need for purchased energy would grow by 2.6 %/a.

**Forest industry's emissions into the receiving water**

The forest industry's emissions into the receiving water have been calculated by evaluating separately the effluent volumes of each mill and then totalling the results. The most likely external treatment method has been estimated for each mill for 1995 and the calculation is based on these estimates. For the mechanical pulps and paper grades the calculation is based mainly on specific discharge figures according to experience. The amount of contaminants originated in the production of chemical pulps has been estimated taking into account the different production methods of the mills, based on the production forecast of each mill for 1995.
Table 5–1 presents the calculated total annual effluent volume from the Finnish chemical forest industry's mills and from their external treatment plants, and the amount of contaminants discharged into the receiving water. The figures are given separately for mills located inland and on the coast and then added up to get the situation for the whole country.

### Table 5–1. Discharges of the Chemical Forest Industry into the Receiving Water

<table>
<thead>
<tr>
<th>Effluents from mills</th>
<th>Inland mills</th>
<th>Coastal mills</th>
<th>Whole country</th>
</tr>
</thead>
<tbody>
<tr>
<td>volume $1000 \text{m}^3/a$</td>
<td>349 000</td>
<td>185 000</td>
<td>534 000</td>
</tr>
<tr>
<td>suspended solids t/a</td>
<td>137 000</td>
<td>58 400</td>
<td>195 400</td>
</tr>
<tr>
<td>COD t/a</td>
<td>366 000</td>
<td>166 000</td>
<td>532 000</td>
</tr>
<tr>
<td>BOD t/a</td>
<td>138 000</td>
<td>56 400</td>
<td>194 400</td>
</tr>
<tr>
<td>organic chlorine compounds t/a</td>
<td>6 290</td>
<td>5 400</td>
<td>11 390</td>
</tr>
<tr>
<td>phosphorous t/a</td>
<td>310</td>
<td>140</td>
<td>450</td>
</tr>
<tr>
<td>nitrogen t/a</td>
<td>1 085</td>
<td>225</td>
<td>1 310</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effluents from waste water</th>
<th>Treatment plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>volume $1000 \text{m}^3/a$</td>
<td>349 000</td>
</tr>
<tr>
<td>suspended solids t/a</td>
<td>15 700</td>
</tr>
<tr>
<td>COD t/a</td>
<td>196 000</td>
</tr>
<tr>
<td>BOD t/a</td>
<td>11 200</td>
</tr>
<tr>
<td>organic chlorine compounds t/a</td>
<td>3 430</td>
</tr>
<tr>
<td>phosphorous t/a</td>
<td>177</td>
</tr>
<tr>
<td>nitrogen t/a</td>
<td>1 030</td>
</tr>
</tbody>
</table>

Chlorinated organic compounds are formed in chemical pulp bleaching only. The figures in Table 5–1 are the result of combining the production forecasts of sulphate pulp with the estimates given in Table 5–1 of how much organic chlorine compounds pulp mills after waste water treatment discharge into the environment.

According to Table 5–2 the AOX discharges of the coastal mills per ton of pulp would be higher than those of the inland mills, principally because the inland mills would produce proportionally more hardwood pulp. For some coastal mills investments that would reduce AOX discharges are being considered. However, these investments have not been taken into consideration in the calculations, since it is doubtful whether they will be carried out before 1995.

No breakdown of AOX into different substance groups has been made. However, the major part of the organic chlorine compounds will probably also in the future occur in aliphatic molecules with a quite high molar mass, originated in the lignin degradation process. A small part of the organic chlorine compounds are chlorinated phenols, i.e. low–molecular compounds with a tendency to bioaccumulate. The foreseen and already started shift to a higher substitution of molecular chlorine with chlorine dioxide in bleaching will reduce the amount of tri– and tetra–chlorinated phenols, but at the same time the relative amount of mono– and di–chlorinated phenols will grow. Experimental results indicate, however, that the chlorinated phenols are almost completely decomposed in the activated sludge plants. Since it is foreseen
Table 5–2. AOX Discharges of the Forest Industry in 1995

<table>
<thead>
<tr>
<th>Bleached production</th>
<th>Inland</th>
<th>Coastal</th>
<th>Whole</th>
</tr>
</thead>
<tbody>
<tr>
<td>softwoodsulphate pulp</td>
<td>1000 ADt/a</td>
<td>1 480</td>
<td>1 440</td>
</tr>
<tr>
<td>hardwood sulphate pulp</td>
<td>&quot;</td>
<td>1 700</td>
<td>770</td>
</tr>
<tr>
<td>sulphite pulp</td>
<td>&quot;</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1000 ADt/a</td>
<td>3 180</td>
<td>2 210</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total production</th>
<th>Inland</th>
<th>Coastal</th>
<th>Whole</th>
</tr>
</thead>
<tbody>
<tr>
<td>softwood sulphate pulp</td>
<td>1000 ADt/a</td>
<td>1 760</td>
<td>1 770</td>
</tr>
<tr>
<td>hardwood sulphate pulp</td>
<td>&quot;</td>
<td>1 700</td>
<td>790</td>
</tr>
<tr>
<td>sulphite</td>
<td>&quot;</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1000 ADt/a</td>
<td>3 510</td>
<td>2 560</td>
</tr>
</tbody>
</table>

AOX PER TON OF PULP

| bleached production | kg AOX/ADt | 1.08 | 1.68 | 1.30 |
| total production | " | 0.98 | 1.39 | 1.39 |

that almost all bleached pulp mills will have effective biological effluent treatment plants in 1995, the amount of chlorinated phenols will probably be much smaller than today.

Table 5–1 presents the amounts of phosphorous and nitrogen discharged into the receiving water. If there is not enough of these substances in the effluent from the mill to the activated sludge plant, the nutrients needed by the biological treatment plant to eliminate the BOD must be added. In some mills the amount of nutrients present in the effluents is not enough while in other mills exceeds the minimum amount. The surplus cannot, however, compensate for the mills with too little nutrients. A significant part of the solids from the mills discharged into the environment consists of biosludge from the activated sludge plant discharged with the effluents into the receiving water. Since the phosphorus and nitrogen content of the biosludge is relatively high, the elimination of solids from the water discharged from the treatment plants would also reduce the nutrient load of the residual waters.

Forest industry's emissions into the atmosphere

The atmospheric emissions of the chemical forest industry have been calculated together with the mills' consumption and production of energy, since the main part of these emissions originate from energy production. The figures of the atmospheric emissions are thus based on the production forecasts presented earlier and specified mill by mill, and on the assumptions leading to the fuel consumption figures given in Section 4.

Table 6–1 is a calculation of the amount of flue gas of all mills within the chemical forest industry. The amount has been specified as dry gas and water vapour. The figures are calculated according to the estimated amount and moisture of the fuel used and the assumed combustion parameters. The amount of carbon dioxide in the dry flue gases has been calculated in the same way. The emissions of pollutants – particulates,
sulphur dioxide and nitrogen dioxide – have been calculated. A rough estimate of the pulp mills' emissions of reduced sulphur compounds has been made.

The table indicates that the Finnish forest industry will discharge approximately 23 million tons of carbon dioxide into the atmosphere in 1995. However, it should be pointed out that the major part of the carbon which produces carbon dioxide at combustion comes from living biomass, i.e. wood, which has assimilated a corresponding amount of carbon dioxide from the atmosphere. Part of the forest industry's fuel demand is met by fossil fuels, but, on the other hand, part of the carbon present in the wood remains in the products of the forest industry. Table 6–2 illustrates the forest industry's carbon balance for 1995.

### Table 6–1. Atmospheric Emissions from the Chemical Forest Industry in 1995

<table>
<thead>
<tr>
<th>Gas from combustion</th>
<th>t/a</th>
<th>10⁶ m³/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>dry flue gas</td>
<td></td>
<td>74 350</td>
</tr>
<tr>
<td>steam in flue gas</td>
<td></td>
<td>19 350</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>93 700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In the flue gas</th>
<th>t/a</th>
<th>10⁶ m³/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon dioxide</td>
<td></td>
<td>23 100 000</td>
</tr>
<tr>
<td>sulphur dioxide</td>
<td></td>
<td>25 000</td>
</tr>
<tr>
<td>nitrogen oxides (as dioxide)</td>
<td></td>
<td>24 200</td>
</tr>
<tr>
<td>solid particles</td>
<td></td>
<td>46 100</td>
</tr>
<tr>
<td>Reduced sulphur compounds</td>
<td></td>
<td>1 700</td>
</tr>
</tbody>
</table>

### Table 6–2. Carbon Balance of the Chemical Forest Industry in 1995

<table>
<thead>
<tr>
<th>Carbon to the mill</th>
<th>tC/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>With wood raw material</td>
<td>9 830 000</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>1 230 000</td>
</tr>
<tr>
<td>Total</td>
<td>11 060 000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Carbon from the mill</th>
<th>tC/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>To the atmosphere as flue gas</td>
<td></td>
</tr>
<tr>
<td>- biofuel</td>
<td>4 950 000</td>
</tr>
<tr>
<td>- fossil fuels</td>
<td>1 230 000</td>
</tr>
<tr>
<td>In products</td>
<td>4 880 000</td>
</tr>
<tr>
<td>Total</td>
<td>11 060 000</td>
</tr>
</tbody>
</table>

The carbon dioxide emissions of the mills have been estimated based on the amount of fuel used and on its sulphur content. If a sulphur–containing fuel has been used together with wood fuel, the ability of wood ash to catch sulphur dioxide has been
taken into account. The effect of the high dry content of the black liquor on the sulphur dioxide content of the flue gas has been considered when calculating the sulphur dioxide emissions from the recovery boiler.

The amount of nitrogen oxides generated when different fuels are burnt in different types of combustion equipment has been calculated based on literature and information from suppliers. All the nitrogen oxides have been estimated as the corresponding amount of nitrogen dioxide. In the forecast it is assumed that no equipment reducing nitrogen oxide from the flue gases will have been taken into use by 1995.

**Solid waste from the forest industry**

Solid waste from the chemical forest industry consists mainly of fibre and lime rejects from the processes, ashes from energy production and sludge from the activated sludge plants. The amounts of other solid material are much smaller. Table 7–1 presents the estimated volume of solid wastes in 1995.

<table>
<thead>
<tr>
<th>Table 7–1. Chemical Forest Industry's Production of Solid Waste in 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solid waste from the mills</strong></td>
</tr>
<tr>
<td>Ashes</td>
</tr>
<tr>
<td>Fibre rejects</td>
</tr>
<tr>
<td>Lime rejects</td>
</tr>
<tr>
<td>Total from the mills</td>
</tr>
<tr>
<td><strong>Solid waste from effluent treatment plants</strong></td>
</tr>
<tr>
<td>Dry matter from sludge</td>
</tr>
<tr>
<td>Water from sludge</td>
</tr>
<tr>
<td>Total sludge</td>
</tr>
</tbody>
</table>

According to the table, the sludge volume from the external effluent treatment plants of the mills is big. A major part of the sludge can, however, be eliminated by burning and would not end up as landfill. The sludge from the effluent treatment plants of the pulp mills is contaminated with chlorine compounds. It is still unclear whether this sludge can be burnt at the mills, e.g. together with the bark, because of the possible risk of generating hazardous substances in the flue gases. It is calculated that about 130 000 tons of the dry matter of the sludge are contaminated by chlorine compounds.

**Investments in environmental protection**

During the course of the work information was collected about the investments by the companies in environmental protection in 1985–1988. In addition, the corresponding investments for the period 1989–1995 were estimated.

The Finnish forest industry has invested and will be investing during the next few years most in water pollution control. During the years 1985–1995 the investments in
this sector will amount to FIM 4800 million. In 1985–1989 the total value of the investments was FIM 2000 million, while the investments in 1990–1995 were calculated at FIM 2800 million. The share of process–internal measures is around 60% of all the investments in water pollution control in the period 1985–1995.

Within the same period about FIM 1700 million will be invested in air pollution controlling measures. In 1985–1989 the investments amounted to about FIM 500 million, and it is calculated that the future investments in 1990–1995 will total about FIM 1200 million. The measures focus on reducing the emissions of sulphur and malodorous gases in the production of chemical pulp.

The investments in solid waste management from 1985 to 1995 are calculated at FIM 1200 million. In 1985–1989 a total of FIM 500 million, approximately, was invested, while the calculated investments for the period 1990–1995 are about FIM 700 million.

Thus the investments within these three sectors have amounted to FIM 3700 million, approximately, during the period 1985–1989, while it is estimated that the future investments to 1995 will total FIM 4000 million. This amounts to a total investment cost of FIM 7700 million during the years 1985–1995. The development of the investments during the period is shown in Figure 8/1.

Figure 8/1. Investments in Environmental Protection in 1985–1995

Figure 8/2 shows the investments by main sector. The operating costs of the environmental protection measures were in 1985 calculated at about FIM 220 million/a, in 1990 at FIM 320 million/a while they in 1995 will total FIM 460 million/a. About 60% of the operation costs are originated by water pollution control measures. The breakdown of estimated operating costs by main sector is presented in Figure 8/3.
Figure 8/2. Breakdown of Investments in Pollution Protection Measures by Sector in 1985–1995

Figure 8/3. Breakdown of Operating Costs of Environmental Protection Measures in 1985–1995
SYTYKE 9

THE ENVIRONMENTAL LOAD OF DEINKING PROCESS

Summary

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THE ENVIRONMENTAL LOAD OF DEINKING PROCESS  

Summary  

Introduction  

In order to study the environmental impact of deinked pulp production, a co-operative project of three Finnish deinking plants (United Paper Mills Ltd., Nokian Paperi Oy and Keräyskuitu Oy) and Ahlstrom Ecomachinery was started together with the University of Technology in May 1990. The project was financially supported by the environmental program of the Finnish pulp and paper industries (SYTYKE-program). The major purpose of the project was to characterize the waste streams of deinking processes, and to find environmentally acceptable methods for the purification, handling or disposal of these waste streams. The purpose of the project in its first phase was to characterize deinking sludge in detail. The second part of the project consisted of a waste water study. The third phase of the project concentrated on leachability properties of deinking sludge ash. Sampling was decided to carry out in three Finnish deinking plants: United Paper Mills Ltd., Keräyskuitu Oy, and Nokian Paperi Oy.

Deinking sludge characteristics  

In this study the fuel properties, the metal content, and the polychlorinated biphenyls (PCBs) content of the deinking sludge from three Finnish deinking plants were characterized. The sludge samples were characterized in terms of proximate analysis, ultimate analysis, heat values, ash properties, thermogravimetric analysis, metal analysis, and PCB analysis.

The results of the proximate and the ultimate analyses are quite uniform concerning all the samples analyzed. The variation between the samples collected from one plant is very small, and no big differences exist between the sludges collected from different plants. The dry solids content is on the average over 40 % while the ash content in dry solids varies between 30 – 60 % depending on the quality of the raw material, waste paper, and on the deinking technique. Due to the high ash content, the heat values are very modest being at the highest only 15 MJ/kg d.s.. The sodium content in the deinking sludge is 0.1 – 0.3 % in d.s., and the potassium content 0.2 – 0.5 % in d.s., respectively. The chloride content is relatively low, only 0.1 – 0.4 % in d.s.. The variations in the ash properties, such as chemical composition and ash melting point, between the three deinking mills are insignificant. No serious slagging or corrosion problems are thus to be expected when the sludge is incinerated.

The amount of trace elements and PCB in the deinking sludge are relatively small. Deinking sludge has a lower content of trace metals than sewage sludge. The difference is even bigger when compared to municipal solid waste. The PCB content was between 1.1 – 1.4 mg/kg d.s. determined as Arochlor 1242 and 1254. No special requirements are set for the handling and disposal of deinking sludge because of the metal or the PCB content.
The properties of deinking sludge hardly cause any serious environmental threat when sludge is disposed of by landfilling. The trace metal content and the PCB content are at a low level and the moisture content of sludge is sufficient for the handling operations (transportation, etc.). A modern landfill, where 1) rainwater is lead away from soil layers by a drainage system, 2) leachate is collected, and when required, purified, 3) liners are used (plastic or clay liners), 4) filling is done properly and finally the place is landscaped, and 5) the quality of groundwater and leachate is monitored, fulfills the strict environmental requirements established by the authorities. The landfill disposal of deinking sludge is, however, becoming more and more difficult for several reasons. Siting of new landfills is extremely difficult, and also the building and maintaining of a landfill are very expensive (tipping fees). In Scandinavia, especially in Sweden and Finland, the landfilling of different types of waste is still a relatively easy disposal method. It is expected that in the future the landfill disposal of waste sludges will be as problematic as it is already in Central Europe, North America, and Japan. In those areas the siting of a new landfill is almost impossible, and more stringent land disposal regulations are resulting in the closing and phased abandonment of many sludge disposal sites. Therefore, the incineration of the sludge is gaining more acceptance. The remaining ash can be further used as a raw material of other industries, such as the building material industry (cement, concrete), or it can used in road building.

The successful incineration of a sludge of high moisture and ash content sets some requirements for the combustion technique. The quality of sludge makes the combustion in grate boilers difficult. Fluid–bed systems offer an attractive and cost–effective means of disposal. The deinking sludge samples analyzed in this study possessed no such properties that could prevent the incineration of the sludge in fluid–bed boilers. Neither serious sintering problems nor emission problems are to be expected. Even if the incineration could result in very low energy production or no energy production, at least the amount of waste material is decreased and it is deactivated.

The characteristics of waste water from deinking operations

In the second part of the project the waste water originating from deinking operations was characterized in terms of 1) total, volatile, and suspended solids, 2) chemical and biological oxygen demand, 3) phosphorus and nitrogen, 4) pH–value, 5) trace elements, 6) polychlorinated biphenyls (PCBs), 7) fatty and resin acids, 8) organically bound chlorine, and 9) toxicity. The samples were collected in United Paper Mills Ltd., Nokian Paperi Oy, and Keräyskuitu Oy in Finland. The samples were collected before any external purification stages, i.e. after the microflotation stage of the deinking process.

A few general conclusions can be drawn of the quality of the waste water. The specific pollution load of the waste water depends on the process design of the deinking line, on the raw material, and on the quality requirements of the produced pulp. The load of suspended solids varies within wide limits. The inorganic and organic load of the waste water is high. The organic load measured as COD is higher than the organic load measured as BOD. The ratio between the parameters (BOD/COD) is about 0.45. The specific load of COD, when the process conditions are considered to be stable, is 30 – 35 kg/ADt. The specific loads of phosphorus and nitrogen vary clearly between the waste waters from different mills. The average phosphorus load varies between 20 and 60 g/ADt, and the nitrogen load between 175
The concentration of organic chlorine is extremely low. Also, fatty and resin acids are observed in the waste water in very small amounts. Only traces of PCB are found in waste water samples. The concentration of trace elements is extremely low. Especially the concentrations of the most toxic trace elements are insignificant. Furthermore, none of the samples was acute toxic.

The results clearly indicate that the waste water from deinking operations possesses no such properties that could prevent the purification in biological effluent treatment plants.

The leaching properties of deinking sludge ash

The aim of the third phase of the project was to characterize the leaching properties of deinking sludge ash. The major purpose was to evaluate the maximum leachability potential of trace metals, and to estimate the long-term leaching properties. To do this, deinking sludge ashes were leached using two different leaching tests: a German test called DEVS-4, which has been developed by the Environmental Authorities in Nordrhein-Westfalen, and the so called TCLP test (Toxicity Characteristics Leaching Procedure) developed by the Environmental Protection Agency in the U.S.A.

According to the results obtained only very small amounts of chromium and vanadium dissolved from the ash samples to the leachate prepared using the DEVS-4 test. In most cases the trace metal content in the leachates were found to be below the detection limits. All the samples fulfilled the requirements set for the landfill for municipal waste, and the ash sample from Keräyskuitu Oy even the requirements set for the landfill for mineral waste.

Only very small amounts of chromium and zinc were found to dissolve from the ash samples in acidic conditions according to the TCLP test. The concentrations of trace metals were in most cases below the detection limits. Furthermore, the concentrations of trace elements were also clearly below the limits set for hazardous waste by EPA.
SYTYKE 10

EFFECTS IN MESOCOSMS EXPOSED TO UNTREATED AND TREATED TOTAL MILL EFFLUENTS FROM PRODUCTION OF BLEACHED HARDWOOD KRAFT PULP

Summary

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EFFECTS IN MESOCOSMS EXPOSED TO UNTREATED AND TREATED TOTAL MILL EFFLUENTS FROM PRODUCTION OF BLEACHED HARDWOOD KRAFT PULP

Summary

Abstract

This report summarizes results obtained in mesocosms exposed to effluents from production of bleached hardwood kraft pulp. The work was performed in 1990.

The total responses obtained in the experiment have been assessed according to a point-system based on a scale from 0–5, where 0 = no effect and 5 = highest effect, for every parameter considered in the assessment. In this way different process alternatives were possible to compare. The results obtained in 1990 are compared with the results from previous experiments performed in 1982–1984 and 1986.

Generally a certain correlation between effects and AOX-emissions is discernible in connection with production of bleached softwood kraft pulp. The correlation is discernible down to AOX-levels of about 2 kg/t pulp. This is an indication that non-chlorinated substances are essential contributors to the effects noted.

Regarding total mill effluents from production of bleached hardwood kraft pulp, no correlation between AOX and effects is seen. This is further strengthening the picture that non-chlorinated substances are effect-inducers as pulp mill industrial effluents are discharged in the aquatic environment.

Evidence that natural substances in the wood raw material are effective were gained in an experiment in which fish exposed to a group of sterols originating from the wood (birch) material showed very similar effects as those obtained when fish were exposed to the total mill effluents from production of bleached hardwood kraft pulp.

Introduction

The objective with the present study was, based on ecotoxicologically sound principles, to assess the effects on the shallow, rocky littoral zone of the Baltic Sea of pulp mill industrial effluents. The study was performed in land-based so called model ecosystems in which the plant and animal life of the littoral zone of the Baltic Sea are simulated. The study is a continuation of the systematic research, which started in the beginning of the 1980s within the frame of the Swedish Forest Industries Foundation for Water- and Air Pollution (SSVL). In the beginning effluents from production of bleached softwood kraft pulp were studied. The effects of different process alternatives, different bleaching technologies, with and without external treatment were compared with effects of effluents from the, by that time, conventional bleaching sequence (C95+D5)EHDED.

The results from these experiments have mainly been published under 1989–1990
The test series from 1982–1984 showed that traditional chlorine bleaching caused the most pronounced effects in the model ecosystems (mesocosms). Externally treated effluent from a mill with the sequence \textit{O(C85+D15)EDED} and untreated effluent from bleaching of softwood kraft pulp with the sequence \textit{O(C52+D48)EDED} caused least effects. All experiments were performed with two effluent dilutions, 400 and 2000 times, based on a normalized effluent volume of 50 m$^3$/t pulp.

Regarding production of bleached softwood kraft pulp, a certain correlation between biological effects and emissions of chlorinated organic material seemed to exist down to a level of about 2 kg AOX (Adsorbable Organic Halogen). Preliminary experiments indicated that no correlation existed for effluents originating from production of bleached hardwood kraft pulp, however. These preliminary experiments, using effluents from hardwood kraft pulp production, were not possible to conduct to the same extent as those from production of bleached softwood pulp. Consequently there was a need to increase the knowledge on effects of effluents from bleached hardwood pulp production.

In the present experiment in mesocosms effects, distribution and transformation of organic material from production of bleached hardwood kraft pulp production were studied. The material, upon which this summary is based is presented in Lehtinen et al. (1992 a,b).

**Experimental set-up**

The mesocosm technique used in the experiment was developed in the 1970s and has previously been used at testing oil, oil and dispersants, arsenic and trichloroguaiachol. The advantages of this technique are long-term exposure, large volume (8 m$^3$) pools allowing for subsampling, system reproducibility, controlled exposure, low realistic levels of toxic substances used and that the system are open to a flow-through of raw seawater.

The test-systems consist of out-door land-based 8000 L circular pools (1 m depth) with polyethylene liner, each containing a 3 cm thick sand base and known figures of transplanted bladder-wrack, \textit{(Fucus vesiculosus), and associated organisms. In order to enable separate studies physiological reponses in fish, a smaller pool (500 L) for rainbow trout is attached to the out-going water from each mesocosm. Survival, growth and parasite frequency are studied in a second additional pool (150 L) attached to the out-going water from the rainbow trout pool.

Brackish water (2.8 L/min) is continuously pumped from 10 m depth from a bay outside the laboratory located in Nagu, in the Archipelago sea of Turku, Finland. The water is running to a seawater tank, from where it is distributed to the mesocosms by gravity flow. Water flow is regulated with capillary tubes. The experimental set-up is presented in figure 1.
The effluents tested were sampled at the respective mill under normal running conditions. After sampling the effluents were transported to the laboratory in Nagu and stored deep frozen in 35 L polyethylene containers. Required amounts of effluents were successively thawed during the experiment. pH, dissolved oxygen and temperature were semi-continuously measured during the experimental period from the incoming and from the out-going water of the test-systems.

The structuring element of the shallow littoral hard bottoms of the Baltic is the bladder-wrack, F. vesiculosus L. Consequently, this alga is also one of the most important species in the mesocosms.

Before the experimental start bladder-wrack specimens, attached to their original stone substrata, were collected from a brackish water bay, nearby the laboratory. The associated invertebrate fauna is sampled simultaneously when a plastic bag is threaded over the alga. The algae are placed in the same sector in relation to insolation in each pool. The total volume of every specimen is determined by the water displacement technique prior to introduction in the mesocosms. Total volume is also determined at the end of the exposure.

The number of the associated invertebrate fauna is estimated and in case some pool receives a lower number of animals, more animals are added to such pools in order to obtain similar number of animals at the start of the experiment. 100 of young three-spined sticklebacks are also added to act as predators in the systems.

After addition of plants and animals the pools are left to stabilize for at least two weeks before exposure is commenced.

Fishphysiological studies are performed using rainbow trout, (Oncorhynchus mykiss),
as test organism. Exposure is maintained for totally 8 weeks. Sampling is made after 2 and 8 weeks of exposure. Samples for blood-, bile-, and tissue-analysis are taken in these occasions.

At the beginning of the experimental period two mature stickleback males and three females are placed in 150 L pools in order to produce the fish material used in the experiment on fish populations (survival, growth, tissue structure and parasite frequency). The parent fish are removed after egg hatching.

In the final assessment of the mesocosm work the effects were compared against unpolluted controls by classifying them according to their total impact on the systems based on previously published principles (Lehtinen et al. 1990).

Effluents tested

Four effluents were tested in the present work. The effluents are called Au and At (where u stands for untreated and t for treated) and Bu and Bt.

The effluents were tested at two dilutions according to the following codes:

HD = High dose; 400 times dilution
Ld = Low dose; 2000 times dilution

The Au and At effluents are untreated and treated (active sludge) total effluents from production of bleached hardwood pulp according to the sequence (D80+C20)(EOP)DED. Bu and Bt are untreated and treated (pilot plant aerated lagoon) total effluent from production of bleached hardwood pulp according to the sequence O(D27,C68+D5)(EOP)D(EP)D. Production- and processdata are presented in table 1.

Table 1. Production- and processdata from the two mills tested.

<table>
<thead>
<tr>
<th></th>
<th>Mill A</th>
<th>Mill B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production t/d</td>
<td>1 450</td>
<td>945</td>
</tr>
<tr>
<td>Effluent volume m³/t pulp</td>
<td>40</td>
<td>54</td>
</tr>
<tr>
<td>Sequence</td>
<td>(D80+C20)(EOP)DED</td>
<td>O(D27,C68+D5)(EOP)(EP)D</td>
</tr>
<tr>
<td>ClO₂ in D+C kg/t90</td>
<td>34.7</td>
<td>5.3</td>
</tr>
<tr>
<td>Cl₂ in (D+C) %</td>
<td>80</td>
<td>32</td>
</tr>
<tr>
<td>Kappa number to bleachery</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Chlorine multiple</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>Active chlorine multiple</td>
<td>0.29</td>
<td>0.13</td>
</tr>
<tr>
<td>Total charge active Cl kg/t90</td>
<td>67</td>
<td>35</td>
</tr>
<tr>
<td>NaOH E1 kg/t90</td>
<td>19</td>
<td>11.1</td>
</tr>
<tr>
<td>NaOH E2 kg/t90</td>
<td>4</td>
<td>4.6</td>
</tr>
<tr>
<td>O₂ E1 kg/t90</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>H₂O₂ E1 kg/t90</td>
<td>1.3</td>
<td>1</td>
</tr>
<tr>
<td>H₂O₂ E2 kg/90</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Viscosity</td>
<td>1080</td>
<td>1020</td>
</tr>
</tbody>
</table>
Summary of effects noted for the effluents tested in 1990

In some of the mesocosms (one control, effl. AuHD, and effl. Bt, both doses) a green alga, Spirogyra sp., occurred spontaneously. In the exposed Spirogyra-containing mesocosms the invertebrate fauna was stimulated, despite that some of these mesocosms received higher concentrations of potentially toxic substances than mesocosms without Spirogyra in which a decline of the invertebrate fauna was noted. The spontaneous occurrence of Spirogyra is an example of how a biological factor possibly may mask and modify an inhibitive effect of an effluent. In this instance it is noteworthy that exposed mesocosms containing Spirogyra were compared with the control also containing Spirogyra.

Effluent Au, bleaching sequence (D80+C20)(EOP)DED.

The effluent flow was 40 m³/t pulp. The COD was 90 kg/t, AOX 1.6 kg/t, chloaret 5.8 kg/t, chlorinated phenolics 1.8 g/t, resin acids 73 g/t and chlorinated resin acids 4.7 g/t.

After the exposure following effects were noted in the mesocosms:

- Bladder—wrack: In the low dose (2000 times dilution) a lower biomass was noted as compared with the control. In the high dose the biomass was higher than the control. No deviations of the apical (annual) growth were noted in neither dose.

- Bladder—wrack invertebrate fauna: Lower biomass and abundance in the low dose and contrary to this increased biomass and abundance in the high dose. These effects were mainly due to changes in the mussel populations.

- Sediment invertebrate fauna: Decreased biomass and abundance in the low dose and an increase in the high dose was noted. Dominating species were the blue mussel, Mytilus edulis, the heart mussel, Cardium edulis and amphipods (Gammaridae).

- Total invertebrate biomass and abundance in the mesocosms: As in the case with the bladder—wrack and sediment associated invertebrates a weak inhibition in the low dose and a stimulation in the high dose of abundance and biomass were noted.

- Growth of three—spined stickleback young: A distinct stimulation after two months exposure occurred in both doses. The stimulation was maintained until the end of the experiment.

- The content of conjugated substances in fish bile: A dose—response relationship was noted for both chlorophenolics and resin acids. The concentration of resin acids was clearly higher than that of chlorophenolics. The concentrations were similar after 2 and 8 weeks exposure.

- Hematology: No statistically significant differences as compared with the control were noted.
Liver metabolism in rainbow trout: Aside from a significantly increased liver–glycogen no differences occurred in the exposed fish.

Effluent At, bleaching sequence (D80+C20)(EOP)DED, active sludge treatment.

The effluent volume was the same as for the untreated effluent Au. COD was 39 kg/t, AOX 1.0 kg/t, chlorate < detection limit, chlorinated phenolics 0.6 g/t, resin acids 4.3 g/t and chlorinated resin acids 2.1 g/t pulp.

Following main effects were noted:
- Effects on bladder–wrack: A clear decrease of the total biomass was seen in both doses as compared with the control. No effects were noted regarding annual apical growth.
- Effects on bladder–wrack invertebrate fauna: A distinct inhibitive effect was noted in both the high and low dose. The total number of animals and their biomass were clearly lower despite that the number and biomass of crustaceans increased.
- Effects on sediment invertebrates: Both the number and biomass were lower than in the control in both doses.
- Effects on total biomass and abundance: Inhibition in both doses.
- Effects on the growth of stickleback young: Stimulation in both doses.
- Concentrations of conjugated substances in fish bile: Increased, dose-dependent concentrations were noted. The concentration of resin acids was higher than that of chlorophenolics. The concentrations decreased somewhat after 8 weeks exposure as compared with exposure for two weeks.
- Effects on hematology: No statistically significant responses were recorded.
- Effects on liver metabolism: The only statistically significant deviation from the control was an increased liver glycogen level.

Effluent Bu, bleaching sequence O(D27,C68+D5)(EOP)D(EP)D.

The effluent flow was 54 m³/t pulp. Cod was 29 kg/t, AOX 0.9 kg/t, chlorate 2.0 kg/t, chlorinated phenolics 1.4 g/t, resin acids 9.5 g/t and chlorinated resin acids 0.5 g/t.

Following effects were seen in the mesocosms:
- Effects on the bladder–wrack: A decrease of the total biomass was noted but no effects on the annual, apical growth.
- Effects on bladder–wrack invertebrate fauna: In the low dose a stimulatory effect was noted whereas in the high dose an inhibitive response was seen. Distinct species–related differences as to the responses were seen at exposure to this effluent.
Effects on sediment invertebrates: In the low dose a stimulatory effect was seen and in the high dose a weak inhibition was obtained.

Effects on total invertebrate abundance and biomass: In the low dose a weak stimulation occurred, whereas no differences as compared with the control were seen in the high dose.

Effects on the growth of stickleback young: Growth was stimulated in both doses during the course of the experiment.

Conjugated substances in fish bile: A dose–dependent increase of chlorinated phenolics and resin acids was seen. The concentration of resin acids was higher than that of chlorophenolics. An increase of the concentration of chlorophenolics was obtained after 8 weeks exposure in comparison with the concentration after 2 weeks exposure.

Effects on hematology: No statistically significant effects were noted.

Effects on the liver metabolism: A significantly increased liver–glycogen value was noted in the fish exposed to the low dose.


The effluent flow/ton pulp was the same as for Bu. COD was 17 kg/t, AOX 0.4 kg/t, chlorate < detection limit, chlorinated phenolics 0.5 g/t, resin acids 0.5 g/t and chlorinated resin acids 1.6 g/t.

Following effects were recorded:

Effects on bladder–wrack: A decline of the total biomass was seen in the low dose, but no differences as compared with the control was seen in the high dose. No effects was seen on apical, annual growth.

Effects on bladder–wrack invertebrate fauna: A clear stimulation of both abundance and biomass in both doses was induced by this effluent.

Effects on sediment invertebrate fauna: A clear decline of the number of animals was seen in both doses. On the other hand the biomass was clearly stimulated. The low dose exhibited the highest value next to the control of all doses tested.

Effects on the total invertebrate abundance and biomass: An increase was seen in both doses.

Effects on the growth of stickleback young: Significantly enhanced growth in both doses tested.

Effects on hematology: No statistically significant differences were noted in neither dose.

Effects on the liver metabolism in fish: Except for an increased liver glycogen value no statistically significant deviations from the control fish were noted.
Effects of phytosterols, natural wood compounds.

Aside from the effluents tested an additional experiment with three–spined stickleback young and rainbow trout as test organisms was performed using a powder containing phytosteriols, mainly beta–sitosterol, was used as pollutant.

Testing period and test conditions were the same as in the other exposure groups. The reasons for testing the responses of the phytosterols were several: many of the sterols present in the powder are structurally similar to cholesterol. Cholesterol is the basic compound at synthesis of several steroid hormones in organisms and the substance is a necessary compound for maintenance of the fluidity of cell membranes. If interference between steroids present in the wood raw material in fish would occur, this might possibly explain many previously noted responses in fish exposed to pulp mill industrial effluents.

Brood of three–spined stickleback were exposed via the water, initially to a 5 ug/L nominal total steroid concentration. The concentration was increased after two months to 10 ug/L. Rainbow trout were exposed both via water and food. Except for the dose obtained via water the rainbow trout were exposed to a daily food dosage of 26 ug/ind. and during the successive 6 weeks to about 45 ug/ind.

Effects noted:

- Effects on brood of three–spined stickleback: Vacuolization of the liver tissue and stimulated growth. Similar responses were also noted for the fish exposed to the total mill effluents.

- Substances in the bile of rainbow trout: Increased levels of conjugated cholesterols and phytosterol levels. The levels were practically identical with those noted for fish exposed to total mill effluents.

- Effects on the liver metabolism of rainbow trout: An increased liver glycogen value was obtained. The response was identical with that of fish exposed to total mill effluents.

Summary of the relative environmental impact of the effluents tested.

The effluents tested have been classified according to the intensity in change of the response of the parameters studied. Since a relative classification based on a scale from 0–5 (0 = no effect; 5 = highest intensity) the procedure should be regarded as a semiquantitative integration of the results obtained. The method has previously been used for evaluation of the relative environmental impact of previously tested processes (Lehtinen et al. 1991). The method must be considered as rather subjective since the significance of the responses obtained on different biological levels is still not understood. Due to the very extensive material produced it was held important to find a means to summarize the results in a comprehensive way.

The values obtained on effects on bladder–wrack, invertebrates, brood of stickleback and the physiological status of rainbow trout are summarized in table 2 – 5. A total evaluation is given in table 6 in the form of a mean "effect index".
Table 2. Effects on the growth of bladder–wrack.

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Dilution</th>
<th>2000x</th>
<th>400x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au</td>
<td>2</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>At</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Bu</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Bt</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Direct effects on the bladder–wrack invertebrate fauna.

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Dilution</th>
<th>2000x</th>
<th>400x</th>
<th>2000x</th>
<th>400x</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Biomass</td>
<td>Abundance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Au</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>At</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Bu</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Bt</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Effects on mortality, growth, liver histology and parasite frequency of the brood of stickleback.

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Dilution</th>
<th>2000x</th>
<th>400x</th>
<th>2000x</th>
<th>400x</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mortality</td>
<td>Growth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Au</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>At</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Bu</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Bt</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Liver histology</th>
<th>Parasite frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>At</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Bu</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Bt</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 5. Effects on the physiological status (hematology, enzyme activity in liver and metabolism).

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000x</td>
</tr>
<tr>
<td>Au</td>
<td>0</td>
</tr>
<tr>
<td>At</td>
<td>1</td>
</tr>
<tr>
<td>Bu</td>
<td>0</td>
</tr>
<tr>
<td>Bt</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6. Calculated effect indexes of the effluents tested.

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000x</td>
</tr>
<tr>
<td>Au</td>
<td>2.1</td>
</tr>
<tr>
<td>At</td>
<td>3.0</td>
</tr>
<tr>
<td>Bu</td>
<td>1.6</td>
</tr>
<tr>
<td>Bt</td>
<td>2.1</td>
</tr>
</tbody>
</table>

The values obtained in table 6 have been obtained by summing the points given in tables 2–5 for the respective effluent and then dividing them by the number of parameters given in the same tables.

According to table 6 effluent Bt caused the lowest impact. The effects of effluents Au and Bu were at the same level and the highest impact was induced by effluent At. Most prominent regarding effects were the effects on the growth of the stickleback brood and the increased incidence of parasites. Liver structural changes are also noteworthy. Clear correlations between the amounts of AOX dosed, concentrations of conjugated chlorophenolic substances or resin acids in bile of fish were not prevailing, however. Notable in this respect is the high effect index of effluent Bt (active sludge treatment). Reasons behind this might be of indirect biological nature or that this effluent contained other effective substances than other effluents.

The effect indexes obtained in the present work are presented in figure 2. Previously calculated effect indexes from other studies are included in the figure as well. Previously tested processes are presented in table 7.

The effect indexes in figure 2 are plotted against emitted amounts of AOX in kg/t pulp. Regarding production of bleached softwood kraft pulp, it may be noted that some correlation between decreasing AOX and decreasing effect index seems to exist down an AOX–level of about 2 kg/t pulp. At an AOX–level of 2.5 the effect index is lower than that for unbleached softwood pulp production, however. This is indicating that non–chlorinated substances induce effects noted at least at AOX–level below 2–2.5 kg/t pulp. Concerning effluents from production of bleached hardwood kraft pulp there is no correlation between effects and emitted AOX.
Figure 2. Effect indexes of different total mill effluents tested in mesocosms in the period 1982–1990. Considerations has been given to the fact that in previous studies with hardwood processes physiological studies were not included.

Table 7. Comprehensive list of effluents from different processes tested in the period 1982–1990.

<table>
<thead>
<tr>
<th>Process</th>
<th>External treatment</th>
<th>AOX kg/t pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood pulp (1982–84)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbleached</td>
<td>no</td>
<td>0</td>
</tr>
<tr>
<td>(C95+D5)EHDED</td>
<td>no</td>
<td>ca. 8</td>
</tr>
<tr>
<td>(C87+D13)EDED</td>
<td>aerated lagoon</td>
<td>2.8</td>
</tr>
<tr>
<td>O(C83+D17)EDED</td>
<td>no</td>
<td>3.5</td>
</tr>
<tr>
<td>O(C85+D15)EDED</td>
<td>aerated lagoon</td>
<td>3.25</td>
</tr>
<tr>
<td></td>
<td>(partial treatm.)</td>
<td></td>
</tr>
<tr>
<td>O(C85+D15)EDED</td>
<td>(pilot) aerated lagoon</td>
<td>2.25</td>
</tr>
<tr>
<td>O(C52+D48)EDED</td>
<td>no</td>
<td>2.5</td>
</tr>
<tr>
<td>Hardwood pulp (1986)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D92+C8)(ED)D(EP)D</td>
<td>no</td>
<td>0.6</td>
</tr>
<tr>
<td>O(C82+D18)EDED</td>
<td>no</td>
<td>1.25</td>
</tr>
<tr>
<td>O(C51+D49)EDED</td>
<td>no</td>
<td>0.9</td>
</tr>
<tr>
<td>1990–test, hardwood pulp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D80+C20)(EOP)DED</td>
<td>no</td>
<td>1.7</td>
</tr>
<tr>
<td>&quot;</td>
<td>activated sludge</td>
<td>1.0</td>
</tr>
<tr>
<td>O(C27,D68+D5)(EOP)D(EP)D</td>
<td>no</td>
<td>0.9</td>
</tr>
<tr>
<td>&quot;</td>
<td>(pilot) aerated lagoon</td>
<td>0.4</td>
</tr>
</tbody>
</table>
General conclusions

The ecosystem

Both stimulatory and inhibitory effects were noted in the exposed mesocosms. The direction of these responses may be assumed to be regulated through biological mechanisms, for instance changes in interspecific competition. This assumption is among other things based on observations made in mesocosms, in which Spirogyra occurred. The prevalence of this green alga was presumably due to the chance. In pools containing most Spirogyra, the invertebrate fauna was stimulated despite that these pools simultaneously received a higher dose of potentially toxic compounds than pools without Spirogyra. In pools without Spirogyra the invertebrate fauna was inhibited. The random occurrence of Spirogyra is an example on how a biological factor may mask and modify an otherwise inhibitive response of an effluent. In 1991 the experiment with effl. Bt was repeated, now without Spirogyra. This time the invertebrate fauna was inhibited, which further supports the assumption of the modifying effect of Spirogyra (Lehtinen et al. unpublished).

The exposure mostly induced a stimulated growth of periphytic algae. This is an indication of that substances introduced with the effluents favour growth of rapidly growing annual algal species. At the same time the bladder–wrack exhibited decreasing tissue nitrogen levels, which shows that this perennial species is unable to compete for nutrients with the annual, rapidly growing algae during the vegetation period. This is also indicating that the bladder–wrack, under the present simulated conditions, may be disfavoured in the Baltic at exposure to pulp mill effluents, but also other effluents containing nutrients, i.e. nitrogen, may act in the same way. The mode of action of the same effluents in fresh water lakes is hard to say explicitly. Presumably phosphorus is the limiting factor in limnic environments, which may mean that nitrogen has a smaller role in fresh water than in marine environments, however.

The stimulatory effects noted on amphipods (Gammarus spp.) may be due to hormone–like substances, present in the wood raw material, inducing an increased moulting frequency. The relatively specific response of this group of organisms may cause interspecific changes in competition between the bladder–wrack associated animal species. This was indicated by the decreased abundance of another crustacean (Idothea spp.) in the exposed mesocosms.

No clear correlations between levels of AOX, chlorophenolics, resin acids and effects were seen. The EOX–level increased in several cases in different compartments of the mesocosms, however. Despite of this, no signs of biomagnification was observed. In addition the analyzed EOX–levels depended little on the total amount added AOX in the mesocosms. About 1% of the total dose AOX added was traceable in sediment or organisms.

Fish studies

The experiments performed on fish with ohytosterols and total mill effluents caused very similar responses (growth, liver histology etc.).

The significance of stimulated growth is presently not understood. In field studies a connection between stimulatory effects on growth and impaired gonad development
in fish has been made. In the present work possible effective substances have been indicated.

The 8 week long exposure of rainbow trout did not cause any induction on the detoxification enzymes analyzed. The increased levels of liver glycogen and the liver histological changes noted, do indicate some kind of metabolic disorder, however. Furthermore, the increased levels of conjugated cholesterol in fish bile are an indication on that metabolic responses occurred in fish exposed to both steroids and effluents. However, no acute liver damage seemed to prevail, since the ALAT–levels in serum of fish were not elevated.

Exposure to untreated effluents induced somewhat higher levels of chlorinated phenolics and resin acids in the bile of fish than treated effluents. Generally the levels differed only slightly from natural background levels. The analyzed levels of conjugated chlorophenolics and resin acids cannot therefore be connected to the effects obtained in fish.
SYTYKE 10A

EFFECTS IN MESOCOSMS EXPOSED TO TREATED TOTAL MILL EFFLUENTS FROM PRODUCTION OF BLEACHED SOFTWOOD KRAFT PULP AND THERMOMECHANICAL PULP

Summary

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EFFECTS IN MESOCOSMS EXPOSED TO TREATED TOTAL MILL EFFLUENTS FROM PRODUCTION OF BLEACHED SOFTWOOD KRAFT PULP AND THERMOMECHANICAL PULP

Summary

Introduction

The present study is a continuation of the systematic research in Baltic Sea littoral mesocosms, which started in the beginning of the 1980s within the frame of the Swedish Forest Industries Foundation for Water— and Air Pollution (SSVL). In the beginning effluents from production of bleached softwood kraft pulp were studied. The effects of different process alternatives, different bleaching technologies, with and without external treatment, were compared with effects of effluents from the, by that time, conventional bleaching sequence (C95+D5)EHDED.

The results from these experiments have mainly been published under 1989–1990 (Lehtinen 1989; Lehtinen 1990; Lehtinen et al. 1990; Rosemarin et al. 1990; Lehtinen et al. 1991).

The test series from 1882–1984 showed that traditional chlorine bleaching caused the most pronounced effects in mesocosms. Externally treated effluent from a mill with the sequence O(C85+D15)EDED and untreated effluent from bleaching of softwood kraft pulp with the sequence O(C52+D48)EDED caused least effects. All experiments were performed with two effluent dilutions, 400 and 2000 times, based on a normalized effluent volume of 50 m³/t pulp.

In 1989 a series of experiments with bleachery effluents from mills producing softwood were performed. Effects of effluents from an old bleachery with AOX (Adsorbable Organic Halogen) emissions of ca. 4 kg/t pulp were compared with effects of effluents from bleacheries with AOX emissions of 0.24 and 1.8 kg/t pulp respectively (Tana et al. manuscript under publication). The environmental effects of the bleachery effluents did not correlate with the AOX emission, and it may be concluded that other process effluents are major contributors to environmental effects noted.

When total mill effluents from production of bleached hardwood pulp were tested in 1990, a lack of correlation between chlorinated organic material and effects was also evident (Lehtinen et al. 1992 ab). Preliminary tests with fish exposed to natural wood steroids induced quite similar effects as the total mill effluents from production of bleached hardwood kraft pulp, suggesting that compounds present in the black–liquor could be significant contributors to effects obtained both in laboratory experiments and in field studies.

In the present work the effects of externally treated (active sludge) total mill effluents from production of bleached sulphate kraft pulp (sequence: (C84+D16)(EO)DED) and
production of bleached (hydrogen sulphite) thermomechanical pulp (biological and chemical external treatment) were studied. In addition, the effects of natural wood steroids were tested upon both fish populations and on a whole mesocosm.

**Experimental set-up**

A more detailed description on the mesocosm technique and set-up is given in the detail reports (Lehtinen et al 1993ab).

The mesocosm technique was developed in the 1970s and has previously been used at testing oil, oil and dispersants, arsenic and tri-chloroguaiachol.

The advantages of this technique are long-term exposure, large volume (8 m$^3$) pools allowing for subsampling, system reproducibility, controlled exposure, low realistic levels of toxic substances used and that the systems are open to a flow-through raw seawater. The experimental set-up is schematically presented in figure 1.

![Figure 1. The mesocosm set-up](image)

1. Incoming water  
2. Seawater tank  
3. PEH-pipe to the pools  
4. Effluent container  
5. Membrane pump  
6. Siphon for out-going water  
7. PEH-pipe for out-going water  
8. Electric valve  
9. Sodage of effluent water  
10. Mesocosm pool  
11. Rainbow trout tank  
12. Stickleback tank  
13. Registration electrodes  
14. Computer

**Effluents tested**

The effluents tested in this work are called SA (Sulphate kraft pulp) and TM (thermomechanical pulp) respectively. The steroid exposed mesocosms is called Ste.

Rainbow trout were exposed in two groups, one via the water only (Ste.wat) and the other both via food and water (Ste.food). Finally one mesocosm set-up was exposed to a combination of the high dose of TM plus the same dose of steroids as the Ste-group (not presented here).
The effluents were tested at two dilutions according to the following codes:

HD=High dose; 400 times dilution  
LD=Low dose; 2000 times dilution

Production- and processdata for the two mills are presented in table 1.

Table 1. Production- and processdata from the two mills tested.

<table>
<thead>
<tr>
<th></th>
<th>Mill SA</th>
<th>Mill TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production t/d</td>
<td>1 180</td>
<td>1 030</td>
</tr>
<tr>
<td>Effluent flow m³ xadrit⁻¹</td>
<td>42</td>
<td>22</td>
</tr>
<tr>
<td>Bleaching sequence</td>
<td>(C84+D16)(EO)DED</td>
<td>Na₂S₂O₄ only</td>
</tr>
<tr>
<td>Cl₂ in C+D kg/t90</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>ClO₂ in C+D kg active Cl/t90</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>ClO₂ amount (%)</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>ClO₂ total kg/t90</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Kappa number to bleachery</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Chlorine multiple</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Active chlorine multiple</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Total active chlorine kg/t90</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>NaOH E1 kg/t90</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>NaOH E2 kg/t90</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>O₂ E1 kg/t90</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>H₂O₂ E2 kg/t90</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Viscosity dm³/kg</td>
<td>960</td>
<td></td>
</tr>
<tr>
<td>Brightness ISO D2</td>
<td>89.2</td>
<td>–</td>
</tr>
</tbody>
</table>

Summary of effects noted for the effluents tested in 1991

Effluent SA, bleaching sequence (C84+D16)(EO)DED

After exposure following effects were noted in the mesocosms:

- Bladder-wrack: In both doses a slightly higher biomass, (possibly due to lower grazing pressure by invertebrates) than the control was noted. The annual apical growth was lower in both doses, however.

- Bladder-wrack invertebrate fauna: The total abundance decreased by 40–55% from the control. The biomass was reduced by 10–40%.

- Sediment invertebrate fauna: No effect on the fauna abundance was noted in the low dose. In the high dose the abundance decreased by 18%. Biomass was unaffected. Regarding species diversity a small decrease was noted.

- Total invertebrate abundance and biomass in the mesocosms: A 15–35% decrease in abundance was noted in the low and high dose respectively. Total biomass decreased by 10–30%.
- Growth and survival of three-spined stickleback young: A 45% higher mortality was noted in the low dose, whereas the mortality was similar to the control in the high dose. The growth was inhibited in the high dose for the first two months of exposure, whereupon a stimulation took place. At the end of exposure the mean weight did not deviate from the control. The low dose fish were inhibited during the first month of exposure, whereafter a stimulation was noted. This reaction is in good accordance with previous results from experiments with total effluents from production of bleached softwood pulp (Lehtinen 1989).

- The content of conjugated compounds in fish bile: The bile content of conjugated chlorophenols, chloroguaiachols or resin acids did not deviate from controls. The content of bile cholesterol increased in the bile of fish from both doses, however.

Hematology: Several hematological responses were noted after 2 and 8 weeks exposure. The responses were most probably related to energy allocation adjustments in the fish and not of direct toxic nature.

Liver/energy metabolism: The fish in SA,LD and SA,HD consumed less food and grew less than the control. However, there was no difference in somatic weight as compared with the control. It thus seemed that the fish used visceral fat reserves in order to satisfy the energy demand. The fish in SA,HD consumed about 40% more oxygen than control fish. The liver somatic index decreased in SA,HD fish after 8 weeks exposure. No significant deviations in detoxification enzyme (EROD, UDP-GT) activities were noted.

Effluent TM, bleaching with hydrogen sulfite

Following main effects were noted:

- Effects on bladder-wrack: No decrease in total biomass was noted in neither dose, most probably due to the same reasons as for effl. SA (see above). The annual apical growth was significantly slower over the whole experimental period, however.

- Effects on bladder-wrack invertebrate fauna. A lower dose-dependent decrease of the abundance were noted (15–45%). Biomass, on the other hand, increased by 40–50%, showing that remaining organisms were few in numbers but bigger.

- Effects on sediment invertebrate fauna: A clear 40–80% decrease of the abundance was induced by this effluent. The total biomass did not change, but fewer species than in the control made up the biomass i.e. diversity decreased.

- Effects on total abundance and biomass: The total abundance decreased by 50–75%, whereas biomass increased by 10–15%.

- Effects on mortality and growth in stickleback young: Mortality was about 30% higher than in the control. Growth was initially inhibited in fish exposed to TM,LD, whereupon growth was significantly stimulated. Fish exposed to TM,HD grew like the control for two months, whereafter a significant stimulation took place.
Concentrations of conjugated substances in fish bile: no increases of chlorinated substances were detected. Neither did the level of resin acids deviate from the control. An increased level of bile cholesterol and fatty acids was detected, however.

Hematology: As with the responses seen in fish exposed to SA, the hematological deviations were most probably due to adaptational responses elicited by changes in energy demands.

Effects on liver/energy metabolism: The fish exposed to TM,HD grew less, consumed less food and had a higher food conversion rate than controls. They also consumed about 15% more oxygen than the control. Fish exposed to TM,LD grew like the control, consumed somewhat less food, had a higher food conversion rate and consumed about 15% more oxygen. The growth was not a true growth, however, since the somatic weight did not differ from the control. This indicates a storage of fat in the visceral mass instead of a build-up of musculature and length increase.

No changes in the activity of detoxification enzymes were noted except for a significantly lower UDP-GT activity of the fish in TM,LD.

Exposure to plant steroids

The exposure with TM,HD+Ste is not considered here in detail. It may be noted that the main responses observed in this group usually were between those observed in TM,HD and Ste.separately.

Following responses on the ecosystem level towards exposure to Ste. were noted:

Effects on bladder—wrack: The total volume decreased about 10%. Apical growth was stimulated under the first 10 weeks, whereupon growth retarded.

Effects on bladder—wrack invertebrate fauna: The abundance decreased significantly (60%). The biomass decreased 40%. The overall decrease was probably due to a high competition from Gammarus spp. against other species. The exposure to steroids specifically stimulated growth of gammarids.

Effects on sediment invertebrates: The total abundance was not affected per se, but some species such as Lymnaea were disfavoured. The biomass decreased somewhat (10%).

Effects on total invertebrate abundance and biomass: The total abundance (incl. animals in the bladder—wrack, sediment and the mesocosm walls) decreased by 15% and the biomass by 35%.

Effects on mortality and growth of stickleback young: The mortality did not increase at exposure to steroids in this experiment. The growth was significantly stimulated after 8 weeks exposure. This response was identical with that from a previous experiment (Lehtinen et al. 1992a).

Conjugated substances in fish bile: No increases were noted. However, there was an increased bile cholesterol level, which was higher in fish exposed to steroids.
The total fatty acid level in bile increased also as compared with control.

- Effects on hematology: Only small responses were observed on hematological indices, but they were in the same direction as in fish exposed to total effluents.

- Effects on liver/energy metabolism: Fish exposed to Ste.wat grew more than the control, consumed less food, had an about double oxygen consumption and a 96% food conversion factor. This was indicating an increased oxygen and energy demand. However, the growth was also in this case only a question of an increased storage of presumably increased visceral fat. Fish exposed to Ste.food grew less, consumed less food, had a higher food conversion factor and a lower oxygen consumption than the control over the experimental period. The route of administration of steroids or their metabolites seemed to influence upon the responses noted.

Liver glycogen decreased significantly in both groups. This was accompanied by a lower liver–somatic index (LSI). No induction of the EROD enzyme was obtained, but the activity of UDP–GT was significantly lower than the control in both groups after 8 weeks exposure. The serum ALAT activity was slightly higher than the control after 8 weeks, possibly indicating a higher turnover rate of hepatocytes.

Summary of the relative environmental impact of the effluents tested

The effluents and the phytosterols tested have been classified according to the intensity in change of the response towards the control of the parameters tested. Since a relative classification based on a scale from 0–5 (0= no effect; 5= highest intensity) was used, the procedure should be regarded as a semiquantitative integration of the results obtained, which otherwise would pose great difficulties to compare. The same approach has previously been used for evaluation of the relative environmental impact of processes tested earlier during the 1980s (Lehtinen et al. 1991). The method suffers from a certain degree of subjectivity since the responses obtained on different levels are still not understood in a broader ecological sense. On the other hand, due to the very extensive material produced it was held important to find means to summarize results in a comprehensive way for persons not actively engaged in ecotoxicological research.

The values obtained on effects on bladder–wrack, invertebrates, brood of stickleback and the physiological status of rainbow trout are summarized in table 2–7. A total evaluation is given in table 8 in the form of a mean "effect index".

Table 2. Effects on the growth of the bladder–wrack.

<table>
<thead>
<tr>
<th>Effluent/pollutant</th>
<th>Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000x</td>
</tr>
<tr>
<td>SA</td>
<td>2</td>
</tr>
<tr>
<td>TM</td>
<td>2</td>
</tr>
<tr>
<td>Ste. (10 ug/l)</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 3. Effects on the bladder–wrack invertebrate fauna.

<table>
<thead>
<tr>
<th>Effluent/pollutant</th>
<th>Biomass</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dilution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000x</td>
<td>400x</td>
</tr>
<tr>
<td>SA</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>TM</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>St. (10 ug/l)</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Effects on the sediment fauna.

<table>
<thead>
<tr>
<th>Effluent/pollutant</th>
<th>Biomass</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dilution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000x</td>
<td>400x</td>
</tr>
<tr>
<td>SA</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TM</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Ste. (10 ug/l)</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Effects on the total mesocosm invertebrate biomass and abundance.

<table>
<thead>
<tr>
<th>Effluent/pollutant</th>
<th>Biomass</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dilution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000x</td>
<td>400x</td>
</tr>
<tr>
<td>SA</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>TM</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ste. (10 ug/l)</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Effects on mortality, growth, liver histology and parasite frequency of the brood of stickleback.

<table>
<thead>
<tr>
<th>Effluent/pollutant</th>
<th>Mortality</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dilution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000x</td>
<td>400x</td>
</tr>
<tr>
<td>SA</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>TM</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Ste. (10 ug/l)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effluent/pollutant</th>
<th>Liver histology</th>
<th>Parasite frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dilution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000x</td>
<td>400x</td>
</tr>
<tr>
<td>SA</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>TM</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Ste. (10 ug/l)</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
Table 7. Effects on the physiological status (hematology, enzyme activity in liver and metabolism).

<table>
<thead>
<tr>
<th>Effluent</th>
<th>Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000x</td>
</tr>
<tr>
<td>SA</td>
<td>2</td>
</tr>
<tr>
<td>TM</td>
<td>2</td>
</tr>
<tr>
<td>Ste. (10 ug/l)</td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Calculated effect indexes of the effluents tested.

<table>
<thead>
<tr>
<th>Effluent/pollutant</th>
<th>Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000x</td>
</tr>
<tr>
<td>SA</td>
<td>1.75</td>
</tr>
<tr>
<td>TM</td>
<td>2.17</td>
</tr>
<tr>
<td>Ste.</td>
<td></td>
</tr>
</tbody>
</table>

The values obtained in table 8 have been calculated by summing the points given in tables 2–7 for the respective effluent and then by dividing them by the number of parameters given in the same tables.

According to table 8 the phytosterols caused the highest impact followed by TM, HD. Effluent SA gave the lowest effect index in this work. Effluent TM contained fairly high levels of aluminium (about 6 mg/l). An effect of aluminium cannot be excluded for the moment. Thus, the effect indexes obtained in this work should be considered as preliminary. This issue is further investigated presently.

The effect indexes obtained in the present work are presented in figure 2. Previously calculated effect indexes from other studies are included in the figure as well. Previously tested processes are presented in table 9.

The effect indexes in figure 2 are plotted against emitted amounts of AOX in kg/t pulp. At an AOX level of 2.5 kg the effect index is equal to or lower than that for unbleached softwood kraft pulp, non-chlorine bleached TM and phytosterols alone. This is indicating that non-chlorinated substances are equally or more potent effect inducers than are chlorinated compounds.
Table 9. Comprehensive list of total mill effluents from different processes tested in the period 1982–1991.

<table>
<thead>
<tr>
<th>Process</th>
<th>External treatment</th>
<th>AOX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Softwood pulp (1982–1984)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbleached</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>(C95+D5)EHDED</td>
<td>No</td>
<td>ca. 8</td>
</tr>
<tr>
<td>(C87+D13)EDED</td>
<td>Aerated lagoon</td>
<td>2.8</td>
</tr>
<tr>
<td>O(C83+D17)EDED</td>
<td>No</td>
<td>3.5</td>
</tr>
<tr>
<td>O(C85+D15)EDED</td>
<td>Aerated lagoon</td>
<td>3.25</td>
</tr>
<tr>
<td>(Partial treatment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O(C84+D16)EDED</td>
<td>(Pilot) aerated lagoon</td>
<td>2.0</td>
</tr>
<tr>
<td>O(C52+D48)EDED</td>
<td>No</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Hardwood pulp (1986)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D92+C8)(E+P)D(E+P)D</td>
<td>No</td>
<td>0.6</td>
</tr>
<tr>
<td>O(C82+D18)EDED</td>
<td>No</td>
<td>1.25</td>
</tr>
<tr>
<td>O(C51+D49)EDED</td>
<td>No</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Hardwood pulp 1990</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D80+C20)(EOP)DED</td>
<td>No</td>
<td>1.7</td>
</tr>
<tr>
<td>&quot;</td>
<td>Activated sludge</td>
<td>1.0</td>
</tr>
<tr>
<td>O(D27,C68+D5)(EOP)D(EP)D</td>
<td>No</td>
<td>0.9</td>
</tr>
<tr>
<td>&quot;</td>
<td>(Pilot) aerated lagoon</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>1991-test, Softwood</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(C84+D16)(EO)DED</td>
<td>Activated sludge</td>
<td>1.9</td>
</tr>
<tr>
<td>Thermomechanical pulp</td>
<td>Aerated lagoon+AVR</td>
<td>0</td>
</tr>
<tr>
<td>(Non–chlorine bleaching)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
General conclusions

Impact on the mesocosm level

Both effluents as well as steroids alone caused structural and functional changes of the mesocosms exposed. However, different effect triggering factors between the effluents to the changes observed were probably prevailing. The structural and functional properties of SA, HD; TM, HD and Ste. i.e. affected species diversity and increased vertical transport (leakage) of organic carbon, are summarized in appendix 1.

Effluent TM induced more pronounced changes of the structure (animal abundance, invertebrate species diversity, algal composition) of the ecosystem than did effl. SA. Steroids added alone induced structural changes of the animal communities with increased competition from Gammaridae (Crustacea) towards other crustaceans and molluscs. The plant steroids seemed to specifically stimulate Gammarus growth.

Structural changes of the algal communities were probably one reason behind secondary responses (not directly toxic) observed in grazing animals such as Theodoxus sp. and Lymnaea spp. through changed quality of the diet.

The reasons behind the pronounced decrease in total number and species in mesocosms exposed to effl. TM are not known. It is suspected that ammonium and/or aluminium possibly had some significance.

The results with plant steroids show that the wood raw material contains biologically active substances, which might at least partly have been responsible for effects noted in other experiments and field studies. However, the mode of action of plant steroids and related substances is not well understood and merits further research.

Impact on fish

Effects on survival, growth and metabolism in fish were noted at exposure to both effluent SA and TM. Plant steroids contained in wood raw material caused the most pronounced responses as compared with responses seen in fish exposed to mill effluents.

The levels of pulp mill related substances identified in fish did not serve as explanation for the effects noted. Again, it may be suspected that aluminium present i effl. TM might have had some impact on the response picture noted in the fish.

In general, when the effects on mesocosm level and the effects observed in fish are compared, it may be noted that impact on different ecosystem compartments (sediment invertebrates, algae etc) is not predictable from the magnitude of physiological effects noted in fish, or vice versa. This may be examplified by the responses noted in fish exposed to plant steroids, which were relatively regarded strongest in this experiment, whereas the effects noted on the functionality of the ecosystem were lower than at exposure to effluents.
SYTYKE 11

DECREASE AND CONTROL OF ENVIRONMENTAL LOADS OF A PULP MILL WITH A NEW MILL LAYOUT

Summary

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SYTYKE 11
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DECREASE AND CONTROL OF ENVIRONMENTAL LOADS OF A PULP MILL WITH A NEW MILL LAYOUT

Summary

Today’s typical chemical pulp mill consists of several different buildings, each accommodate one or several production departments. Main process and possible main control room are usually arranged so that they form an individual unit, i.e. the main line. Along the line and possibly on its both sides there are production departments, where auxiliary and/or subprocesses take place. As the production departments form their own whole, in several cases separate buildings, they usually have separate control rooms, although information of subprocesses would go to the main control room. Even though the buildings that contain the production departments were arranged as adequately as possible with respect to the whole process, the unity formed of the production departments is inevitably rather decentralized, it requires much area, and it is difficult to manage.

The target of the project was to develop a pulp mill model in which the duration of the process on annual level is essentially better, in which environmental loads have been decreased by integrated control and treatment of emissions into air and water, which is more economical of energy, whose total investments are smaller, whose total area is smaller and building time shorter than in present chemical pulp mills.

The first stage of the project comprised a layout model of a sulphate pulp mill designed in a circular building. 200 m was chosen as the diameter of the building, pine as raw material, modified continuous cooking as cooking type and 1000 t/d as design production. Circular shape was not a target in itself, but an efficient, centralized, cost-competitive mill. The layout design was made with a 3D-CAD computer aided design system which made it possible to take several views to the arrangements after modelling the equipment, such as sections, axonometric drawings etc. All process equipment needed in the Sellusampo project has been modelled and located on the layout.

Mainly the same equipment that represents the latest technology on commercial level was chosen to the Sellusampo model and to the conventional chemical pulp mill which was used as standard of comparison. There are considerable differences in screening, bleaching, effluent treatment and refuse incineration. The screening in Sellusampo does not contain reject refining and screening. There is no postscreening after bleaching in Sellusampo. The bleaching process of Sellusampo is a dioxide bleaching with three stages (D, EOP, D), whereas four stages (D, EOP, D, D) were chosen to the reference process. Deviating from existing mills the effluent treatment of Sellusampo contains ultrafiltration and deep tank aeration system. In addition Sellusampo is equipped with pressure sand filtration for clear filtrate. Deviating from today’s technology tall oil soap and turpentine are also burnt in auxiliary boiler units in Sellusampo. These are still at product development stage.
The more profound stage of the project stuck to the circular layout, the design production was raised to 1500 t/d, and the influences of adding a debarking plant, chip handling and paper mill were also studied.

The result of the development work is a preliminary plan for a sulphate pulp mill, basing on a round layout, sited in a coherent roofed space. The mill with a design production of 1500 t/d is accommodated in a structural steel building with a diameter of 200 m and eave height of 35 m. The soda recovery unit, auxiliary boiler and deep tank aeration system are located outside of the circular building. In this developed model the control room has a centralized location with respect to the production departments of the plant. Production departments are mainly situated sectorally with respect to the control room. Stock preparation process mostly proceeds parallel with the circumference of the circle between adjacent production departments. The production departments are inside a coherent roofed space. In the developed model the production departments have been located to allow as short transfer distances of liquids, pulp and gas as possible.

The axonometric drawing of Sellusampo is presented in Figure 1 and section drawing of Sellusampo in Figure 2.

The studies showed that this model has several advantages compared with a chemical pulp mill that has been implemented with the present technology.

**Efficiency and maintenance**

A mill built in accordance with the Sellusampo model has better chance to gain good efficiency than the present mills. The maintenance work can be done rapidly and efficiently, because all subprocesses are in the same warm building and near each other. The area of Sellusampo is essentially smaller than that of a conventional pulp mill. The centralized control room improves the control of the mill.

**Sales revenue**

The consumption of electric energy decreases by 63 kWh/ADt i.e. appr. 10 % as a result of shorter pipe lines, smaller amounts of water that need treatment, and the chosen equipment. Most of the blow off heat from the digester plant is utilized at the evaporation plant, 1.11 GJ/ADt i.e. appr. 10 % heat can thus be saved. Sellusampo produces 204 kWh/ADt more power to the market compared with a mill basing on today's technology.

If the form of the production duration curve would be more even, the annual increase in sales revenue could mean several tens of millions of FIM.

**Environment**

The model enables the treatment and control of all emissions to the environment. Ducts for collecting the emissions into the air are short. Sulphur emissions into the air are essentially lower than in present mills. Thanks to continuous cooking, oxygen bleaching, ultrafiltration and deep tank deaeration system, and well controlled process, the colour of the effluents is clearly better and the AOX- and COD-emissions clearly lower than in a conventional solution.

**Acquisition and operating cost**

On the basis of received budgetary tenders and made calculations Sellusampo is 77 million FIM i.e. about 3 % cheaper than the reference mill. The need for operating personnel is according to calculations about 210 persons, whereas the corresponding number in the reference mill is about 300. Financial advantage is appr. 20 million
FIM/a. On annual level the chemical costs of Sellusampo are appr. 24 million FIM smaller than in the reference mill as a result of process choices. Probably the most significant cost saving will, however, be gained by the decrease in the interest cost during the construction period. According to coarse estimation the time schedule for the implementation of Sellusampo may be appr. 6 months shorter than that of the reference mill due to standard solutions and modular constructions.

Figure 1. Axonometric projection of Sellusampo.
Figure 2. Side projection of Sellusampo.
SYTYKE 12

ANALYTICS AND CONTROL OF ODOROUS SUBSTANCES OF FOREST INDUSTRY

Summary

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Analysis and Control of Odorous Substances of Forest Industry

Summary

In this work FT-IR spectroscopy was applied to the detection of odorous gaseous substances emitted by the forest industry. FT-IR method has great inherent advantages: It is sensitive to all gases in question, and is very simple to automatize. Due to its extensive information contents, an infrared spectrum always contains also the information of the exact partial pressures of the constituent gases in the mixture under consideration. However, getting this information out of the spectrum requires an interferometer optimized for this purpose, as well as quite a number of computing work. The necessary computing methods were developed by ourselves, but a commercial standard interferometer had to be used as the measuring device. In spite of that the FT-IR method proved to be efficient. The analysis of one single measurement revealed all the constituent gases at one time. In several measurements, however, the tolerances were not yet satisfactory. This may arise from the non-optimal parameters of the measuring device and, possibly, from the presence of unknown components in the gas mixtures in question. This kind of situation is, anyhow, easy to recognize when encountered, so that a reliable measurement is distinguishable from an unreliable one. In case of a successful analysis it is also possible to calculate error limits for the partial pressures, which is a very remarkable possibility in practical measurements.

The measurements were carried out in laboratory conditions, but we believe the FT-IR analysis to be the optimal gas analyzing method in the field, too. Especially in automatized tracing stations it would be superior. Actually the method is already being applied to the tracing of industrial combustion gases. For this purpose a portable FT-IR gas analyzer, suitable for installation in chimneys, has been developed in co-operation with the University of Turku and TEMET Instruments Ltd.

The prototype of this device has already been tested in the Laboratory of Heating and Ventilation in the Technical Research Center of Finland, and the results are very promising. In near future the device is aimed to be used in field measurements of air pollutants, where the contents to be measured are much lower than those in the emissions.

The method has also been tested in the U.S. in measuring air pollutants. Then it was found that the method was capable of detecting air pollutants directly from open-air down to the ppb ($10^{-9}$) level of concentration.
SYTYKE 14

EVALUATION OF BENEFITS AND DISADVANTAGES IN CONNECTION WITH ENVIRONMENTAL PROTECTION MEASURES IN AN INTEGRATED PULP AND PAPER MILL – A CASE STUDY

Part I. Mill Study; development estimates on production and emissions into the environment

Summary

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SYTYKE 14
Heikki Sütonen

EVALUATION OF BENEFITS AND DISADVANTAGES IN CONNECTION WITH ENVIRONMENTAL PROTECTION MEASURES IN AN INTEGRATED PULP AND PAPER MILL – A CASE STUDY

Part I. Mill Study; development estimates on production and emissions into the environment

Summary

Estimate on production

SYTYKE 14 research report covers the study and evaluation of the present and future emissions of the operating mill and assessments of the environmental impact of emissions, as well as evaluation of the economic effects on the mill surroundings and due to environmental changes.

An estimate is given in the Mill Study Report on emissions into the environment and the required costs related to environmental protection at the following mill production situations:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphate pulp, ADt/a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– bleached</td>
<td>432 000</td>
<td>600 000</td>
<td>750 000</td>
</tr>
<tr>
<td>– unbleached</td>
<td>80 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>512 000</td>
<td>600 000</td>
<td>750 000</td>
</tr>
<tr>
<td>Paper, ADt/a</td>
<td>120 000</td>
<td>130 000</td>
<td>430 000</td>
</tr>
</tbody>
</table>

The production situation of 1989 is agreed to represent the present situation of the mill.

Estimates on emissions

The summary on the mill's emissions into the environment in the above production situations is as follows:

The research group has anticipated the following hypothesis for the future environmental emission objectives (Adt = air–dry pulp ton):

In 1995

<table>
<thead>
<tr>
<th>Wastewater:</th>
<th>AOX</th>
<th>below 1.4 kg/Adt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air:</td>
<td>SO2</td>
<td>below 3 kg/Adt</td>
</tr>
</tbody>
</table>

In 2000

<table>
<thead>
<tr>
<th>Wastewater:</th>
<th>AOX</th>
<th>about 0.8 kg/Adt</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>about 1 kg/Adt</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>about 30 kg/Adt</td>
<td></td>
</tr>
<tr>
<td>Phosphor</td>
<td>about 0.3 mg/l (purified wastewater)</td>
<td></td>
</tr>
</tbody>
</table>

| Air: | SO2 | below 2 kg/Adt |


# Wastewater loads

<table>
<thead>
<tr>
<th>Type of load</th>
<th>Present situation</th>
<th>1989</th>
<th>1995</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (through the biological treatment plant)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m³/d</td>
<td>120 000</td>
<td>120 000</td>
<td>120 000</td>
<td></td>
</tr>
<tr>
<td>m³/ADt (pulp)</td>
<td>65</td>
<td>63</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>m³/ADt (paper)</td>
<td>39</td>
<td>39</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>BOD₇</td>
<td>kg/d</td>
<td>4 100</td>
<td>4 500</td>
<td>2 200</td>
</tr>
<tr>
<td>kg/ADt²</td>
<td>2,5</td>
<td>2,5</td>
<td>1,0</td>
<td></td>
</tr>
<tr>
<td>COD₇</td>
<td>kg/d</td>
<td>65 000</td>
<td>55 000</td>
<td>51 000</td>
</tr>
<tr>
<td>kg/ADt²</td>
<td>41,6</td>
<td>30,7</td>
<td>22,8</td>
<td></td>
</tr>
<tr>
<td>Susp. solids, kg/d</td>
<td>2 500</td>
<td>2 600</td>
<td>2 300</td>
<td></td>
</tr>
<tr>
<td>kg/ADt²</td>
<td>1,6</td>
<td>1,5</td>
<td>1,0</td>
<td></td>
</tr>
<tr>
<td>N_total</td>
<td>kg/d</td>
<td>490¹</td>
<td>500¹</td>
<td>500¹</td>
</tr>
<tr>
<td>g/ADt</td>
<td>304</td>
<td>280</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>P_total</td>
<td>kg/d</td>
<td>88</td>
<td>90</td>
<td>40–50</td>
</tr>
<tr>
<td>g/ADt²</td>
<td>55</td>
<td>50</td>
<td>18–22</td>
<td></td>
</tr>
<tr>
<td>AOX</td>
<td>kg/d</td>
<td>2 100</td>
<td>2 200</td>
<td>1 000</td>
</tr>
<tr>
<td>kg/ADt²</td>
<td>1,6</td>
<td>1,2</td>
<td>0,4</td>
<td></td>
</tr>
</tbody>
</table>

¹ The nitrogen load includes about 200–250 kg N/d of load brought along by fresh water, i.e. the net nitrogen load into the sea is appx. 250–300 kg N/d in all the production options

² ratio of total load from pulp and paper production to pulp production

## Air emissions

<table>
<thead>
<tr>
<th></th>
<th>Load, t/a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989</td>
</tr>
<tr>
<td>Particulates</td>
<td>4 153</td>
</tr>
<tr>
<td>Sulphur emission (in SO₂)</td>
<td></td>
</tr>
<tr>
<td>– process–derived</td>
<td>5 500</td>
</tr>
<tr>
<td>(SO₂ + odorous sulphur, kg/ADt)</td>
<td>(10,7)</td>
</tr>
<tr>
<td>– energy production</td>
<td>940</td>
</tr>
<tr>
<td>Total (SO₂)</td>
<td>6 440</td>
</tr>
<tr>
<td>NOₓ</td>
<td>1 300</td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
</tr>
<tr>
<td>– wood derived</td>
<td>1 550 000</td>
</tr>
<tr>
<td>– fossil fuels</td>
<td>110 000</td>
</tr>
<tr>
<td>Total (CO₂)</td>
<td>1 660 000</td>
</tr>
</tbody>
</table>
In estimates on total NO\textsubscript{x} and CO\textsubscript{2} emissions and the SO\textsubscript{2} emission from energy production the fuel various characteristics are assumed to be the following:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Black liquor, C cont.%\textsuperscript{1)}</td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Bark and chips, C cont. %</td>
<td>54</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Oil, C cont.%</td>
<td>85,5</td>
<td>85,5</td>
<td>85,5</td>
</tr>
<tr>
<td>Oil, S cont.%</td>
<td>2,3</td>
<td>2,3</td>
<td>0,9</td>
</tr>
<tr>
<td>Coal, C cont.%</td>
<td>73</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>Coal, S cont.%</td>
<td>0,9</td>
<td>0,9</td>
<td>0,5</td>
</tr>
</tbody>
</table>

\textsuperscript{1)} All contents are given as per abs. dry solids.

In addition, the value of 230 mg/MJ is used as the NO\textsubscript{x} value of pulverized fuel firing in 1995 and 2000, which will require equipment—technical NO\textsubscript{x} reduction measures as early as in 1995.

Solid waste (to be conveyed to a landfill)

In 1990 the waste amounts and future estimates are:

<table>
<thead>
<tr>
<th>Waste amount, m\textsuperscript{3}/a</th>
<th>1990</th>
<th>1995</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>26 300</td>
<td>30 000</td>
<td>60 000</td>
</tr>
<tr>
<td>Green liquor dregs</td>
<td>12 600</td>
<td>15 000</td>
<td>20 000</td>
</tr>
<tr>
<td>Lime</td>
<td>740</td>
<td>1 000</td>
<td></td>
</tr>
<tr>
<td>Bark</td>
<td>28 700</td>
<td>29 000</td>
<td>20 000</td>
</tr>
<tr>
<td>Biosludge</td>
<td>16 400</td>
<td>16 000</td>
<td></td>
</tr>
<tr>
<td>Paper</td>
<td>3 700</td>
<td>4 000</td>
<td></td>
</tr>
<tr>
<td>Glauber salt</td>
<td>100</td>
<td>2 000</td>
<td></td>
</tr>
<tr>
<td>Construction waste</td>
<td>1 600</td>
<td>2 000</td>
<td>2 000</td>
</tr>
<tr>
<td>Lime mud</td>
<td>400</td>
<td>2 000</td>
<td>3 000</td>
</tr>
<tr>
<td>Mixed waste</td>
<td>15 600</td>
<td>16 000</td>
<td>15 000\textsuperscript{2)}</td>
</tr>
<tr>
<td>Total</td>
<td>106 140</td>
<td>117 000</td>
<td>120 000\textsuperscript{3)}</td>
</tr>
</tbody>
</table>

\textsuperscript{1)} Also includes the sludge from the new PM 2
\textsuperscript{2)} Space reservation for waste amounting to 140 000 m\textsuperscript{3}/a

The following can be summarized based on the tables above. Development of waste water loads:

- Compared with the present situation, a significant decrease is expected in all other emission components except suspended solids and nitrogen by the year 2000. As regards seawater area, the emissions of suspended solids do not seem to be highly significant, but the impact of nitrogen emissions remains so far partly unstudied.

- The decreases in BOD\textsubscript{5}, COD\textsubscript{cr}, P and AOX emissions have been achieved by the mill's internal measures and by making external cleaning more efficient. These measures are depicted under point 2 below in the Table "Reduction Measures of Wastewater Loads".

As for the development of emissions into the air, particulate and SO\textsubscript{2} emissions are considerably decreased, whereas NO\textsubscript{x} and CO\textsubscript{2} emissions will grow as a result of the increases in production and energy demand.
It is estimated that the amount of waste to be transported to landfill remains the same level as in the current situation, but the waste quality will change in the year 20000 so that the present bark and biosludge amounts will decrease and be replaced by an increasing amount of boiler ash which is mainly formed from increased coal combustion. In the situation of the year 2000 lime sludge will no longer be conveyed to the landfill, but the lime is planned to be utilised in wastewater neutralization. Biosludge and paper waste is assumed to be wholly burned in the old recovery boiler No. 2 which is to be rebuilt to a bark boiler. Glauber salt will no longer be formed as waste in the situation of the year 2000. It is to be underlined that the estimates on the amounts of waste to be conveyed to a landfill are order if magnitude estimates and they have been made to secure sufficient space on landfill.

**Necessary environmental protection measures**

The present and planned environmental protection measures in order to achieve the emission goals are the following:

**Reduction measures of wastewater loads**

<table>
<thead>
<tr>
<th></th>
<th>Present situation</th>
<th>1995</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Internal measures</strong></td>
<td>separate sewer system (process wastewater, clean cooling waters)</td>
<td>oxygen phase and seawater wash filter, for fibre line 2</td>
<td>extended delignification, fibre lines 1 and 2</td>
</tr>
<tr>
<td></td>
<td>dry debarking</td>
<td></td>
<td>use of 100% ClO122 substitution in bleaching, fibre lines 1 and 2</td>
</tr>
<tr>
<td></td>
<td>increase of washing efficiency and rebuild of screen room, fibre line 1</td>
<td></td>
<td>oxygen phases, fibre lines 1 and 2</td>
</tr>
<tr>
<td></td>
<td>bleaching plant with oxygen phase, seawater wash filter and MC chlorination</td>
<td></td>
<td>new dry debarking line</td>
</tr>
<tr>
<td></td>
<td>increase of washing efficiency (pressure diffuser, fibre line 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B. External measures</strong></td>
<td>Activated sludge plant</td>
<td>Activated sludge plant (increased aeration)</td>
<td>Rebuild of activated sludge plant, tertiary treatment (removal of suspended solids)</td>
</tr>
</tbody>
</table>

**Air pollution**

**Present situation**

- Recovery boilers, 2 pcs; electrostatic precipitators for flue gases
- Lime kilns, 2 pcs; Venturi scrubbers for flue gases
- Bark boiler; electrostatic precipitator for flue gases
- Collection and combustion of strong odorous gases; the gases are collected from the blow heat recovery, from the turpentine system, the vacuum pits of the
evaporator plants, 2 pcs, and from the stripper of dirty condensates, and they are burned in lime kiln No. 2, the reserve combustion place being a separate incineration unit (Volvo incinerator).

- Collection and treatment of weak odorous gases; the system covers the tall oil plant and collection of tank exhausts from evaporator plant No. 1 and washing in a weak white liquor tanks and washing filters and leading them into the Venturi scrubber of bleaching plant No. 1.

In 1995

- A separate incinerator with SO$_2$ recovery will be built for strong odorous gases. Lime kiln No. 2 functions as a reserve combustion place and, in addition, the possibility of burning odorous gases in a flare is reserved for emergency situations.
- Weak odorous gases from the black liquor tanks and the fibre lines are collected and led to be burned in recovery boiler No. 2.
- Electrostatic precipitators filters for lime kilns 1 and 2 are installed, after which the flue gases are led to a common scrubber.
- The dry solids content of black liquor is raised to a level of about 80% before combustion in the recovery boilers.

In 2000

- Strong odorous gases (from digester plants, from the vacuum system of the evaporator plant to be built in the year 2000 and the stripper of the dirty condensates) are led to the incinerator built in 1995.
- A new lime kiln to be built in the year 2000 operates as the reserve combustion place and furthermore, in emergency situations strong odorous gases can be burned in a flare.
- Weak odorous gases from a new chemical recovery plant, which is to be built in 2000, and from fibre lines 1 and 2 will be collected and burned in a new recovery boiler to be built in the year 2000.
- The new lime kiln will be equipped with an electrostatic precipitator and a scrubber.
- The dry solids content of black liquor before combustion in the recovery boiler is at the level of 80%.

Waste management

Present situation

The mill has its own landfill, which is divided into separate areas for ash, sludge, bark and other (mixed) waste. Nowadays it has been necessary to convey considerable amounts of bark and biosludge to the landfill (e.g. due to the capacity of the bark boiler). In a normal situation the aim is to incinerate this kind of waste. Boiler ash and green liquor dregs are typical waste conveyed to the landfill. It is also noteworthy in the present situation that the share of mixed waste is quite high of the total waste amount destined to the landfill. Oil waste is incinerated in a separate boiler. Hazardous waste is collected and delivered to Ekokem for disposal.

In 1995

No major changes in waste management compared with the present situation are foreseen. The amount of ash and green liquor dregs is expected to increase in relation to the mill's increased production growth. The amount of bark and biosludge to be conveyed to the landfill is estimated to remain at the current level.
In 2000
The existing recovery boiler No. 2 will be modified into a bark boiler, after which the combustion capacity of bark and sludge will be sufficient. However, there will still be a need for landfilling of bark during the e.g. maintenance periods of recovery boiler No 2 and during possible disturbances in operation. In the same connection, intermediate storing and stabilization for biosludge could be arranged (e.g. digestion) at the mill area. The majority of the waste to be conveyed to the landfill in the year 2000 will be composed of boiler ash and green liquor dregs.

Costs of environmental protection measures

The summary on costs arising from environmental protection measures is as follows:

Present situation
In the 1980s a total of about FIM 273 million has been invested in environmental protection measures (the cost level of 1989). The operating costs of environmental protection measures amount to over FIM 10 million/a.

In 1995
The required environmental protection investments come to a sum of about FIM 154 million. On the total investments, the environmental protection share of new production equipment investments is estimated at about FIM 80 million and that of new external methods at appr. FIM 74 million. The major part of investments in external methods is used for air pollution control, FIM 66 million, and the increase of wastewater treatment efficiency is estimated to take about FIM 8 million.

The operating costs resulting from environmental protection are estimated at about FIM 13 million/a.

In 2000
The required environmental protection investments are estimated at about FIM 375 million, of which the share of investments of internal measures is predicted to be some FIM 272 million and the investment share of external methods about FIM 103 million.

The operating costs are estimated at about FIM 16 million/a.
SYTYKE 14

EVALUATION OF BENEFITS AND DISADVANTAGES IN CONNECTION WITH ENVIRONMENTAL PROTECTION MEASURES IN AN INTEGRATED PULP AND PAPER MILL - A CASE STUDY

Part II. Environmental impact; area of study, impact of production and development of loading on environment, and regional preconditions and requirements for development

Summary

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EVALUATION OF BENEFITS AND DISADVANTAGES IN CONNECTION WITH ENVIRONMENTAL PROTECTION MEASURES IN AN INTEGRATED PULP AND PAPER MILL – A CASE STUDY

Part II. Environmental impact; area of study, impact of production and development of loading on environment, and regional preconditions and requirements for development

Summary

General details of study

The aim of the SYTYKE 14 study was to provide information on environmental impact for future production strategy and mill location planning within Finland's wood processing industry. In addition, the aim was to develop methods and bases of evaluation serving to benefit other equivalent environmental impact studies.

This report contains some of the results of the study on the present situation in the surroundings of the Wisaforest Oy Ab mill for evaluating the impact of developments in production and loading on the environment and establishing regional preconditions and requirements for development. The study is based both on existing material and on the production and loading alternatives presented in CTS Consulting Oy's mill study.

The development alternatives have been timed for the years 1995 and 2000. Additionally, a so-called discharge-free situation has been envisaged in which production at the mill has stopped and there are no discharges.

The angle taken by the study has been limited to the main impact at municipal and provincial levels. National and international level changes, and impact from the standpoint of urban areas and private households, remain to be evaluated in other studies.

The study area comprises the near proximity to the integrated pulp and paper mill. Zonal divisions and areas covered by the various environmental effects vary according to the material and scope of the changes.

In the study area the present impact of the mill integrate on land use, the population and labour force, traffic and natural resources, waste management and noise are being studied.

The impact of developments in production and loading of the environment by the integrated pulp and paper mill is being evaluated with respect to the marine area, shores, soil and sea bed, fish stocks and fishery, air quality, waste management and noise. The main features of the regional preconditions and requirements of the production and environmental protection activity development alternatives are presented. These provide data on which to base an evaluation of the effects on the regional economy and the economic effects of environmental changes.
General features of near vicinity of nail and study area

Wisaforest Oy Ab's mill is located on its own 200 hectare plot in Vaasa county in the town of Pietarsaari (Jakobstad), in the Leppäluoto area on the coast of the Gulf of Bothnia. The nearest industrial area is the industrial estate in the southwestern corner of Leppäluoto. The distance to the nearest residential area on the mainland is less than one kilometre. The town centre lies about two kilometres, and the camping ground in the eastern part of Leppäluoto less than a kilometre, from the mill area.

In the proximity of the mill the land is rising by isostasis by about 8 mm a year. Owing to this rapid rate of uplift, the shallowing of the sea bay and encroachment of vegetation, and the formation of a land-locked lake are taking place quickly. The distributions of the flora and fauna are in a constant state of flux due to the environmental changes wrought by the postglacial uplift.

In the Pietarsaari sea area the whitefish fishery is of economic importance. The entire area of sea adjacent to Pietarsaari comprises a whitefish fry production area. Other fish species of economic importance are salmon, trout, burbot, pike and perch. The Baltic herring fishery has drastically declined, mainly owing to the recession in the fur farm sector.

Wisaforest's purified effluents drain into the shallow bay to the north of the mill. The water in the vicinity of the mill is also loaded by, for example, municipal waste water from the town of Pietarsaari and water from Lake Luodonjärvi released from the locks at Hästgrundet and Gertrud. The marine area in front of Pietarsaari is not, by virtue of its shallowness and labyrinthine archipelago, the best possible waste water discharge area.

Lake Luodonjärvi is a fresh water reservoir separated from the sea bay by a dam. Its drainage area includes the rivers Ähtävänjoki, Purmonjoki, Kruunupyynjoki and Kovjoki. Wisaforest Oy Ab's integrated pulp and paper mill takes its supply water from Luodonjärvi.

Present situation

In winter the mill's effluents collect together with the water flowing from Lake Luodonjärvi in a layer under the ice. Large vertical differences are discernible in the water quality factors at that time of year. The quantity of Lake Luodonjärvi water to be released from Hästgrundet mainly determines the size of the area over which the effluents spread. During the time of open water, waste water movements are also affected by the wind conditions. At times of high winds, mixing conditions are better than in calm weather, with the result that the area subjected to water quality changes due to the effluents remains small. In calm weather, changes in the water quality caused by mill effluents are visible for a greater distance from the discharge point, extending to the area between Ädö and Helsingö.

The start-up of Wisaforest Oy Ab's new waste water purification plant in 1986 appreciably lowered the BOD7 and solid matter loading. As a result of the introduction of the new purification plant the nitrogen and phosphorus concentrations at some observation points have fallen. Again, in the last few years odour level fluctuations in the water have been so slight that it has not been possible to
isolate odour more precisely. An exceptional, barely detectable odour that has not been more precisely determined has sporadically appeared at points in the water close to the shore. Elsewhere in the marine area the water has been odourless.

In 1989 the average water quality in the immediate vicinity of the discharge pipe in terms of the quality classification scheme employed by the Vaasa County water protection association, was eutrophic, or extremely eutrophic, a little further out eutrophic, and in the marine area slightly eutrophic. The classification is based on the used phosphorus concentration.

In general it may be said that the deleterious effect of the mill on the sea water quality is by and large limited, owing to the mixing effect on the water, to the east of a line between Ådö and Helsingö.

The embryonic development of fish spawn in the autumn is retarded close to the mill's effluent discharge point, and valuable fish species avoid that area. The mill also has an unpleasant effect on the flavour of the fish, as well as causing fouling of fishing gear by mucilage even slightly further away. Compensation is paid by the mill to the water area owners and professional fishermen, and the plant also takes care of replacement stockings.

Air quality at Pietarsaari was last studied in 1981–82. Currently a major air quality study is under way. In measurements conducted in 1981–82 the sulphur dioxide guide values were not exceeded at any measurement point. The guide value in the case of particulate matter was exceeded at one point, due to traffic dust. Hydrogen sulphide and methyl mercaptan caused offensive odours in the surroundings of Pietarsaari. Obnoxious odours reduce human comfort. Nitrogen oxides were not measured in the 1981–82 study.

Noise measurements carried out on the planned housing exhibition area about 500 metres from the nearest mill building and around 150 metres from the mill premises indicate that mill noise levels do not exceed the current guide values. The night noise level exceeds the drafted guide value of $L_{Aeq,07-22} \leq 45$ dB.

Road and rail traffic cause noise hazards, which in some places are higher than the guide values.

**Alternative 1995**

No major production level changes will take place in 1995. Only in the area in front of the discharge pipe may increased eutrophication occur compared to the 1989 production and loading levels.

In terms of fish stocks the 1995 loading would not cause any appreciable changes compared to the present situation. The favourable change in the condition of the sea bed from the standpoint of spawn development as observed in the last few years would continue. The situation with respect to the fish stocks in Lake Luodonjärvi and the rest of the marine area may be improved by the fish channel to Gertrud which was constructed in 1991.

The state of the shores and recreational opportunities would remain at their present level.
In 1995 emissions to the air would grow by 6% in respect of sulphur dioxide, but would be about one-third less than they are now in the case of particulate matter. Air quality annual mean guide values would not be attained, assuming that other emission sources remain at their present level or decrease.

Nitrogen oxide and carbon dioxide emission levels would increase slightly above their present levels. Malodorous sulphur compound emissions would be about 25% of their present level. An odour problem would arise occasionally.

Changes in mill noise would most likely be minor compared to the current situation. Traffic noise would increase due to increases in road and rail traffic.

**Alternative 2000**

The lowering of the phosphorus loading due to the mill to a level of 50 kg kok.P/d would reduce eutrophication. Despite the reduction in loading, the waters at the given loading levels would remain eutrophicated in the vicinity of the discharge area. Elsewhere on the eastern side of the Adö – Helsingö line the water area would fall into the category of slightly eutrophic in terms of the quality classification based on phosphorus concentrations.

The significance of phosphorus at least as a growth factor would appear in the light of our present knowledge to be irrefutable in the sea area adjacent to Pietarsaari, so that with less phosphorus eutrophication would also decrease. The significance of nitrogen in the area is still not entirely known and studies are being carried out on it. In general it can be said, however, that especially in the Bothnia Bay phosphorus is clearly a minimal factor. The nutrient relations in the North Quarken are roughly comparable to the growth factor requirements of plankton.

According to model calculations, reducing the phosphorus loading from a level of 50 kg/d to a much lower level would alter phosphorus concentrations over a radius of 3–6 km from the discharge point.

Hazards to the fishery brought about by eutrophication would become reduced. Recreation opportunities on the shore would improve.

Sulphur dioxide emissions affecting air quality would be reduced by around 10%, and particulate matter by about 30%, of their 1995 levels. There would no longer be any continuous emission of malodorous sulphur. The odour thresholds of malodorous saturated sulphur compounds would be exceeded in the neighbourhood of Pietarsaari only in exceptional circumstances.

Nitrogen oxide emissions would grow by about 60%, and carbon dioxide emissions by around 45%, of their 1995 levels.

**The discharge-free alternative**

In the discharge-free alternative some of the hazards would be eliminated immediately, others gradually.
Without the influence of the mill, the water area in the language of the classification based on phosphorus concentrations would be slightly eutrophic.

The state of the sea bed would improve with reductions in solid matter and improvements in the oxygen situation in the bottom sediments. Matter consuming oxygen would lessen the chance of spawn surviving for some years to come. Damage caused to the fishery by the mill would gradually disappear. Recreation opportunities on the shore would improve in pace with improvements in the bottom sediments and water quality.

As regards emissions to the air, closing the mill would have the most marked effect in the case of sulphur dioxide. The mill's particulate matter emissions in the year 2000 would be so small as to be already insignificant. The dust hazard in the vicinity of the roads would be reduced with the closing down of operations. Shutting down the mill in the year 2000 would have no real effect on malodorous sulphur emissions. Such emissions would arise with the mill in operation only in exceptional circumstances. Temporary, but strong, odours arising a few times a year in conjunction with process disturbance and process run-up and run-down would be eliminated.

Reductions in noise level would be mainly attributable to the cessation of mill traffic.

Conclusions

The work is based to a large extent on material obtained from several sources. A major problem was the temporal, regional and factual heterogeneity of this material. In regard to the environmental impact studied, the work was confined to an investigation of the primary effects. Studying the secondary environmental effects may in some respects be justified, since in regional economic studies the mill's indirect and isolated effects, for example emissions due to transport, would also be taken into account.

When predicting the impact of the alternatives, general methodological difficulties were experienced. Aside from in the case of the water bodies, no ready-made models were handily available. Once the effects had been described, the next step was to weigh up their significance and determine their worth for the evaluation of the benefits and disadvantages. Comparing the benefits and disadvantages is a whole set of issues in itself, starting with the choice of the method to be used and the bases for the choice.

At all stages in the work general development needs were discovered in connection with the methods: the setting of problems and limiting of the task, data compilation, prediction of impact, evaluation of significance of impact, and comparison of benefits and disadvantages. The exchange of information, and cooperation, between the various parties and professional sectors could be improved by employing systematic methodology in data communications. Database systems for compiling data about the environment would play a fundamental role in this. A computer system selectively transferring data has points of contact with the rights of ordinary citizens in connection with EIA and the desire to obtain data about changes in their environment.
SYTYKE 14

EVALUATION OF BENEFITS AND DISADVANTAGES IN CONNECTION WITH ENVIRONMENTAL PROTECTION MEASURES IN AN INTEGRATED PULP AND PAPER MILL – A CASE STUDY

Part III. Economic impact; regional economic impacts and the economic impacts from environmental changes

Summary

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Summary

The purpose of the study is to assess (1) the benefits due to the improvement of the quality of the environment resulting from investments in environmental protection in 1989–2000 at the Pietarsaari factory of Wisafos Oy Ab, and (2) the regional economic benefits caused by the factory, to be compared with environmental costs.

Regional economic impacts include indirect effects (purchases of inputs) and multiplier effects (from the disposal of income). Previous input–output studies are used to estimate these impacts. The limits of the region are determined in each context, mainly by the data and previous results. The regional delimitations include Pietarsaari economic area, Middle Ostrobothnia and Vaasa Province.

All impacts cannot be counted as benefits, nor can they all be added together directly. According to an established balance of social profitableness, the items to be included in this case are
- company taxes minus public expenditures
- income taxes from employment and avoided unemployment expenses
- net benefits from direct and indirect employment effects to households
- other positive externalities.

The company has not yet paid company tax in the area. The taxes form the companies producing inputs to Wisafos were not estimated.

Public expenditure consists mainly of the services provided for the personnel of the factory, approximately 30–35 million FIM annually.

Income tax, avoided unemployment expenses, and net benefits to households are all included in the approximated annual employment benefits. These estimates are shown below as sums of their component parts (direct and indirect employment effect, multiplier effects from employment and forest income). The upper and lower estimates are due to different assumptions concerning possibilities to sell wood to other customers:

1990 252–273 + 20–22 + 20 million FIM
1995 252–273 + 20–22 + 20 million FIM
In addition, we can also count as regional income the part of forest income that is dependent on the activity of Wisaforest,

<table>
<thead>
<tr>
<th>Year</th>
<th>Income Range (FIM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>59–176 million</td>
</tr>
<tr>
<td>1995</td>
<td>141–258 million</td>
</tr>
<tr>
<td>2000</td>
<td>276–393 million</td>
</tr>
</tbody>
</table>

Other positive externalities arise from e.g. the fact that the factory brings educated personnel into the area, thus providing a mental or cultural resource. The employment at the factory is also a major factor in securing the population base of Pietarsaari, possibly also some other municipalities, and thereby contributing to their development potential.

The figures presented above are meant to show the orders of magnitude, not the precise quantities, of the regional economic impacts of Wisaforest. This is due to the availability of data and previous results. The coefficients that were used in the calculations are from input–output studies that involve certain generalizations and that cover slightly different areas at different points in time. The salary figure used in calculations probably overestimates the real mean salary. On the other hand, the coefficient used in calculating indirect employment might underestimate employment effects.

The methods for assessing the economic value of environmental changes, still in development stage, are based on revealing the consumer's willingness to pay either by contingent valuation methods or by observing such market situations where a market good is associated with non-market, environmental goods. Since no Finnish empirical results are available yet, some foreign results are used in the present context, albeit with many reservations, along with a practice adopted in Finland. All estimates indicate only order of magnitude rather than exact quantities.

The value of the local amenity increase due to the improvement of air quality is estimated to be tens of millions of FIM annually (the estimates range from 13 to 70 million). The local amenity increase from closing the factory would also be worth tens of millions (18–51). From the point of view of society as a whole (and including carbon dioxide and nitrogen oxide emissions), the change will first be positive, then negative during the years 1989–2000. The benefits from closing the factory would be about 66 million FIM annually, or less, if we take into account the fact that some of the carbon dioxide emissions are from wood. Also the emissions from the traffic induced by the activities of the factory affect air quality but are not assessed here.

The factory produces the heat for the district heating system of Pietarsaari, which means that the town's sulphur emissions are smaller than if the city had to produce the same amount of heat with fossil fuels.

As regards water quality, the main changes had already taken place by the end of the 1980s. The amenity value and the value for fishing of the observed improvement can be estimated to be at least 1,2–2,3 million FIM, assuming that only the population of Pietarsaari are counted as users. It should be noted, however, that had the water protection investments not been made, water quality would not have stayed the same but would have continued deteriorating, perhaps resulting in irreversible or very long term injuries to the renewability of the
ecosystem and thereby also disturbing many human activities. The value of avoiding this hypothetical situation has not been estimated but is likely to be manifold compared with the value of the observed amenity changes.

In the future changes at the factory will not bring about major changes in water quality, nor would the closing of the factory. Eventual changes would be so small that their value cannot be captured with the rough estimates that are available. Benefits for fishing from closing the factory would be approximately one million FIM annually.

The emissions from the factory can affect the quality of the forest. There is no data on this phenomenon at this regional scale. The impacts of the emissions on the quality of recreation areas, besides the quality of water and beaches, are likely to be small. The uses of the forest for recreation and other purposes are somewhat restricted by its use as a source of raw material. The activity of the factory and the transports of raw material and products causes noise, but very detailed data would be needed to assess its value. The activity can have impacts on soil, but future impacts are assumed to be relatively small. The scenic effect of continuing the activity are not assumed to be of decisive value in a town with a long industrial tradition. Closing the factory would enable the land to be used for other purposes, and in the long run also scenic changes could be made. Data on the values of these effects are not available. Together these impacts that are left outside calculations can hardly be as large as e.g. the value of air quality changes.

**The costs and benefits caused by the factory can be compared from many points of view.** We now choose the point of view of an inhabitant of Pietarsaari. The factory brings employment and thus income. The employment benefit is estimated to be over 330 million FIM in the year 2000. Municipal taxes have not been subtracted, because inhabitants "buy" municipal services with tax money. The forest income is also estimated to be about 300 million FIM. The indirect effects of the factory are counted for Middle Ostrobothnia, and the multiplier effects (which are much smaller) for Vaasa Province.

The factory enables many people to live in the area, which can also be thought of as a benefit. A diminishing population would cause difficulties to maintaining the level of public as well as private services. Closing the factory could also lower the general energy level of the community.

The inhabitants also experience disadvantages from the activity of the factory. The emissions into air affect their amenity levels, perhaps also health. At present emission levels the impacts concern only amenity; any health hazards have not been shown. The estimated values of the amenity impact vary widely. The largest estimate of the value of closing the factory from the point of view of air quality is about 50 million FIM annually. Only the inhabitants of Pietarsaari are included in this calculation.

Emissions into water are harmful to recreation and to the work of professional fishermen. Having improved significantly by the end of the 1980s, the water quality is not expected to change radically as the factory continues production, neither would it improve notably in case the factory were closed. Benefits to fishing would be about one million FIM annually from closing the factory.
The net benefits to inhabitants are thus hundreds of millions of FIM annually. There are other environmental effects besides those mentioned above, but their magnitudes could not be assessed. We can assume, however, that including noise etc. would not turn the positive net benefit into a negative one.

Inhabitants whose livelihood is independent of Wisaforest, directly and indirectly, could of course find closing the factory beneficial because of its environmental effects.
SYTYKE 14

EVALUATION OF BENEFITS AND DISADVANTAGES IN CONNECTION WITH ENVIRONMENTAL PROTECTION MEASURES IN AN INTEGRATED PULP AND PAPER MILL – A CASE STUDY

Part IV. Evaluation of benefits and disadvantages in connection with environmental protection measures

Summary

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EVALUATION OF BENEFITS AND DISADVANTAGES IN CONNECTION WITH ENVIRONMENTAL PROTECTION MEASURES IN AN INTEGRATED PULP AND PAPER MILL – A CASE STUDY

Part IV. Evaluation of benefits and disadvantages in connection with environmental protection measures

Summary

Comparison of benefits and disadvantages

The task of this study is the valuation of environmental measures as a cost–benefit analysis. The costs are in this case the environmental protection investments and yearly operating costs of pollution control plants of the Wisaforest mill. The benefits evaluated are due to improvement of the environment quality, and in the preceding text estimations are based upon how the inhabitants of the surrounding region value lower emissions and improved air and water quality. In this study possible immaterial benefits to the company from environmental measures have not been studied, as for instance advantages in marketing or avoiding bad reputation.

Both costs and benefits include both one–time transactions (like investments, indemnifications, increase in real estate value), and continuous yearly money flows (like operating cost of pollution control plants). It is therefore necessary to perform transformations between money flows and one–time transactions. In this summary the transformation has been made on a 10 year pay–back time and 5 % yearly real interest basis, leading to a transformation coefficient of 7,7.

The cost–benefit analysis should preferably compare different possible alternatives. In this study as alternatives to be compared have been chosen the situations before and after implementation of environmental measures in 3 scenarios, namely the periods 1980 to 1989, 1989 to 1995, and 1995 to 2000. The next table shows a summary of costs and benefits, transformed into changes in money flow in million Finnish marks per annum, for these three periods:

Table 1. The changes in money flow of costs and benefits, MFIM/a, in 1989 money

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost</td>
<td>35,5</td>
<td>20,0</td>
<td>48,7</td>
<td>49,6*)</td>
</tr>
<tr>
<td>Other costs</td>
<td>12,3</td>
<td>2,1</td>
<td>3,0</td>
<td>17,4</td>
</tr>
<tr>
<td>Benefits</td>
<td>9,2 - 18,6</td>
<td>44,0 - 57</td>
<td>-12,04</td>
<td>1,2 - 63,6</td>
</tr>
<tr>
<td>Benefits – costs</td>
<td>-38,6 - -29</td>
<td>1,9 - 34,9</td>
<td>-64,7</td>
<td>-25,8 - -3,4</td>
</tr>
</tbody>
</table>

*) Average money flow during 21 years, as the sum of yearly investment money flows multiplied by 10 and divided by 21.
value of avoided deterioration of the waters — which could not be estimated — corresponds to the difference 3 – 26 MFIM/a.

The "zero" alternative of shutting down the mill was briefly discussed, and the environmental benefits estimated to between 20 and 80 MFIM/a. But the corresponding regional economic losses because of decreased jobs and lost forest income amounted to 400 – 700 MFIM/a. Thus the alternative was not seriously studied.

Conclusions

In this study the benefits and costs of environmental measures have been compared using the following methods and assumptions:

The estimation of benefits was a clearly more difficult task than the cost estimation. Mainly two methods were used in the valuation of air quality, namely the willingness-to-pay and marginal cost of emission reduction. Using cost-benefit terminology the latter method could also be characterized as using a shadow project.

The used estimates of willingness-to-pay were based on published data from other countries, as no corresponding data from Finland were available. These data were applied by multiplying the expected increase in real estate price, as result of lower emissions of sulfur and particles, with the number of dwellings of the Pietarsaari town. Estimates according to another source, that reported enquiry results on valuation of a total air quality improvement gave similar results.

Because only these foreign base data were available, it must be regretted that these reported results can only be characterized as indicative.

The marginal cost of emission reduction method suffers from the weakness, that estimation of both benefits and costs are based upon the same data. The risk of circular reasoning, leading to benefits always being same as the costs, must be recognized. In this study the method has only been used as check and complement to the other methods. All methods, however, resulted in surprisingly similar results.

The major problem encountered in benefit valuation was, that the benefits from water pollution control are due to the avoided severe deterioration of the waters in the mill surroundings. The measures planned for 1989–2000 would not change the water quality substantially, partly because of the influence from other pollution sources.

Because of these limitations of the methods and data no such conclusions are warranted, that in the Wisaforst case the emission control requirements and corresponding measures have been overdimensioned in comparison to environmental benefits.

The valuation should in the future be developed to include estimates of a hypothetic situation, that would prevail if no pollution control measures were undertaken, and considering both emissions from the mill and from other relevant sources.

The valuation of costs were in the study based upon environmental protection costs incurred to the Wisaforst mill. The accuracy of investment and operating cost estimation is much better than regarding benefits. The main source of uncertainty was how to allocate the right percentage to environmental protection in cases, where new
processes are being installed, that serve both production improvement and environmental efficiency. In some cases (e.g. regarding bark combustion) the shadow project method was used, with the risk of circular reasoning as explained above.

It is however the opinion of the authors, that in this case the environmental protection percentage estimates are not exaggerated. Part of the planned process changes will for environmental reasons be implemented sooner than required for maintaining profitable production.

**Recommendations for further studies**

The scope of this study did not allow in-depth assessment of the state of the mill environment. The following studies would give an improved basis for environment valuation:

**Waters**
- The role of nitrogen as minimum nutrient
- Production toxicology of the area
- Balances of chlorinated organic compounds, their accumulation and spreading, and relation to smell and taste problems
- The influence of nutrients on taste problems in fish

**Air**
- Air quality study (will be ready during 1991)

**Noise**
- Measurement of the present noise level in mill surroundings

**Flora**
- Bioindicator study

**Soil and groundwater**
- Risk evaluation of wells in the mill surroundings
- Impact from the mill dumping site on surrounding soil and wells in the Hällören industry area
- In-depth soil investigation and acidification analysis of mill surroundings

**The valuation of environmental benefits could be improved by the following studies**
- Investigation of hedonic prices related to water quality in a summer cottage area; applied to the immediate mill vicinity and to a reference area on the sea coast
- Valuation of Finnish urban air quality; industrial emissions, traffic emissions
- The value attributed to avoided irreversible or prolonged deterioration of waters and shores; hedonic real estate price development history related to environmental protection decisions
Valuation of water quality real improvements + avoided deterioration compared with environmental protection cost

Other important aspects on both benefits and costs offer the following subjects:

The valuation of broader, "global" environment impacts, like acidification, greenhouse effects, or long term protection and improvement goals for the Baltic sea

Consumer and paper buyer preferences regarding chlorine free pulping, that already influence product price and profitability, and are likely to gain in importance during 1995–2000.
SYTYKE 15

OPTIMIZATION OF THE NUTRIENT USE IN THE ACTIVATED SLUDGE PLANTS OF PULP AND PAPER MILLS

Summary

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OPTIMIZATION OF THE NUTRIENT USE IN THE ACTIVATED SLUDGE PLANTS OF PULP AND PAPER MILLS

Summary

The Environmental Research and Development Programme for the Finnish Forest Industry, SYTYKE programme has included a project (number 15) which has in the years 1991-1992 studied regulation of nutrients in activated sludge treatment plants of pulp and paper mills. The project arose from proposals of the forest industry and from research ideas and needs arising during the course of SYTYKE 1 project (1990). The work of the SYTYKE 15 has been concerned with everyday problems of treatment plants. The project has been financed by forest industry companies.

The main aim of the work has been to improve the command of nitrogen and phosphorus in the activated sludge treatment plants. Experiments with sludges have been carried out in the laboratory and quantities and transformations of nutrients in the activated sludge systems have been determined. Ways of running the plants have been sought such that nitrogen and phosphorus discharges are kept as low as possible without compromising other treatment parameters.

The principle for the optimization of the nutrients is clear. The precise need for nutrients to build up biomass has to be taken account when additions are adjusted. In practice it means that additions are also minimized. So far, feeding of nutrients (N + P) has been done according to the BOD(COD):N:P ratio which is assumed to be optimal for the treatment process.

Dosing according to need is based on the monitoring of the mineral nutrients. Concentrations in the effluents are kept as low as possible. Analysis is carried out by measuring ammonium-N and phosphate-P daily at the end of aeration basin or secondary sedimentation basin. The measurements can be done quickly and reliably enough by portable meters, too. Dosing rates have to be so low as to keep the residual ammonium and phosphate to a minimum. The aim is to have zero discharges of inorganic nutrients. Dosing has also to be proportional to loading, e.g. influent COD values.

The mills which have a permanent surplus of nutrients in the influent, have to carry out optimizing before the treatment plant.

Special characteristics of the nutrients have to be considered, too. Phosphorus can accumulate in the activated sludges of the forest industry. Therefore, those mills which add phosphorus, have to measure the variation of the phosphorus content of the sludge. According to the daily values, one can estimate the phosphorus reserve and ability to adsorb phosphorus and adapt to changes in the load.

The special features of nitrogen are its many states. However, analysis of all of them is not needed. According to the results only measurement of ammonium is relevant. For example, excess addition of urea is followed by increase in effluent \( \text{NH}_4^+ \)-N.
Some mills have already started to monitor mineral nutrients. They use the monitoring data for regulating nutrient doses. Also COD load correlation is in use. Experiences are good. Nutrient additions and discharges have been reduced. The lowest state of concentrations reached in effluents from mills producing virgin pulp are 0.5 mg/l for phosphorus and 2...3 mg/l for nitrogen. Generally phosphorus discharges are smaller in paper mills and nitrogen discharges in pulp mills.

The primary means to optimize the use of nutrients are outlined above. Better control on nutrients not only leads to lower discharges but reveals other variables in the process meaningful in the running of plants e.g. occasional discharges and malfunction of equipments.

Attempting to optimize nutrients has in some cases revealed that nitrogen, as a constituent of complexing agents, forms a considerable part of nitrogen discharges in some mills.

Once better control of nutrients has been achieved, the importance of complexing agents in waste water treatment can be examined. In the near future the use of complexing agents and other additives will grow with the increasing number of chlorine–free pulping processes. On the other hand, in the running of plants, one should also prepare for changes in production, especially the closing of water circulations which will alter the quality of waste water.
SYTYKE 16

THE EFFECT OF ENZYMATIC TREATMENT ON KRAFT PULP BLEACHING

Summary

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THE EFFECT OF ENZYMATIC TREATMENT ON KRAFT PULP BLEACHING

Summary

Introduction

During the last years much attention has been paid to the chlorinated organic compounds in the bleaching effluents. The national aim is to reach a discharge level of 1.4 kg AOX/ton of bleached pulp before 1995 calculated as an annual mean value for the whole country. The AOX-discharge from the Finnish pulp industry has been reduced considerably during the last years due to decreased use of chlorine and new biological waste water treatment plants.

The formation of AOX is dependant on the consumption of chlorine chemicals in the bleaching. Methods in use to reduce the consumption of chlorine chemicals in the bleaching are modified cooking, oxygen delignification and intensified pulp washing. Chlorine dioxide substitution of chlorine gas in the first chlorination stage partly (or totally in hardwood kraft pulp bleaching) reduces also the formation of AOX.

The research work, that was started in the middle of the 1980's and the purpose of which was to investigate the use of enzymes in chlorine-free or low-chlorine bleaching, has proceeded to mill trials using xylanases.

In laboratory trials it has been found, that with enzyme treatment it is possible to reach either higher final brightness or lower consumption of active chlorine. The aim with the mill trials has for the present been first of all to minimize the chlorine consumption and the AOX-load in the effluent.

A saving of 20–30 % of active chlorine in the prebleaching has been reached in the laboratory and mill trials. Thereby it has been possible to reduce the AOX load in the bleaching effluents by 15–25 %.

The purpose of this work was to compare investment and operating costs when an enzyme treatment stage was added to a reference process. A corresponding comparison was also carried out where an oxygen delignification stage was added to the reference process.

The comparisons were made for two different mill sizes both producing fully bleached hardwood and softwood kraft pulp. One of the mill examples represent a new mill using modern technics. The other mill example represents a pulp mill that has been running for several years and where the recovery boiler constitutes a bottle neck. In the latter case no changes were made to the other departments in the reference mill.

The annual average production was chosen to 400 000 ADt ("400-mill") for the new mill. For the old mill the annual average production was chosen to 200 000 ADt ("200-mill"), which is about the average size the production of a single fibre line in a Scandicavian kraft mill.
The operating and investment cost calculations are based on specific consumption values obtained from material and energy balance calculations using the RAMI simulation program developed by PI Process Consulting Ltd.

The balance calculations cover the whole pulp mill process from debarking to pulp drying and also the chemical recovery system, energy production, production of chlorine dioxide and tall oil. The waste water treatment plant is not included. The balances have been calculated for both hardwood and softwood.

The accuracy of investment costs have been estimated on the level used in pre-engineering using the cost knowledge the PI-Group has obtained during many projects in the pulp and paper industry.

The more specified department calculations are based on budget quotations given by the suppliers during the spring of 1991. The unit prices used in the operating cost calculations are delivery prices specified in the spring of 1991 in Finland.

"400-mill"

The investigated reference mill is a new, modern Scandinavian mill with dry debarking, modified cooking (kappa number hardwood 17 and softwood 25), fresh water washer before bleaching, bleaching sequence C/D→EO→D_1→D_2. The chemical charge in the first bleaching stage is C_{SO_2}/D_{SOD} for softwood and C_{SO_2}/D_{SOD} for hardwood. Chlorine dioxide is produced by the total-HCl-method.

Kappa number after oxygen delignification is 12 for hardwood and 15 for softwood.

The total investment cost for a Scandinavian kraft pulp mill producing 400 000 ADt/a has been estimated to 2,400 million FIM. This was chosen as the base level for the calculations.

Calculating the investment costs for the mills with oxygen delignification or enzyme treatment department, the starting point was the cost level of the reference mill and to this cost alterations were made as a function of the process changes.

The addition of the enzyme stage to the reference mill causes besides addition of an enzyme dosage system and pH-adjustment system also changes in the dimensioning of the chlorine dioxide plant and chemical recovery system. The additional capacity requirement in the chemical recovery line is about 1.5 %. The capacity of the chlorine dioxide plant can be reduced 34.5 -> 27.5 t/d. The corresponding cost changes almost equalize each other. The total investment cost for the mill including enzyme treatment is only 0.3 million FIM higher than the cost of the reference mill.

The addition of an oxygen delignification stage to the reference mill causes changes, except addition of the oxygen stage, such as an increase of the chemical recovery line capacity by about 5 %. The capacity of the chlorine dioxide plant can be reduced 34.5 -> 21.0 t/d. In the investment costs the oxygen stage has been taken into account as a turn-key package and the other changes have been estimated by capacity exponents. The total investment costs are 2539.5 million FIM, which is 139.4 million FIM or 5.8 % more expensive than the investment costs for the reference mill.

The consumption of wood, chemicals and energy, which are most significantly affected
by the process alternatives are especially detailed in the operating cost calculations.

For other operating costs like water treatment costs, packaging and maintenance costs average costs from representative Finnish mills have been used. The different process alternatives affect the waste water treatment costs, but because of lacking reliable BOD₅ measurements, no cost estimations concerning this aspect were made between the different alternatives.

The changing credits for energy production have also been accounted for in the operating costs.

For fixed operating costs like labour and administration costs, average Finnish cost levels as a function of mill size have been used.

Enzyme treatment before bleaching does not, in its present stage of development, reduce the production costs of bleached kraft pulp.

The operating costs for the enzyme treatment are 16..17 FIM/ADt higher than the operating costs for the reference mill. With present enzyme prices and enzyme charges the saved bleaching chemical costs gained due to the enzyme treatment are about the same as the chemical costs for the enzyme treatment. If the enzyme price or dosage could be reduced to half of the present, the operating costs of the enzyme treatment would be only about 4 FIM/ADt higher than the operating costs of the reference mill.

Due to the yield loss of the enzyme treatment (0.5–1.0 % units higher than the reference mill) the wood raw material costs are 16...24 FIM/ADt higher than for the reference mill. This explains most of the above mentioned cost increase.

Oxygen delignification gives a clear chemical cost saving of 50...59 FIM/ADt. The increase of wood raw material costs due to yield loss are relatively small.

To get a general picture of the profitability, the operating and investment costs were summarized. The investment costs are based on a write off period of 15 years and an interest of 10 % on the fixed funds. The total costs are divided by the average annual production (1190 ADt/d for hardwood, 1105 ADt/d for softwood).

<table>
<thead>
<tr>
<th>Total costs ( FIM/ADt ) for the process alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative (code)</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Hardwood reference (K400R)</td>
</tr>
<tr>
<td>ref. + oxygen (K400H)</td>
</tr>
<tr>
<td>ref. + enzyme (K400B)</td>
</tr>
<tr>
<td>Softwood reference (M400R)</td>
</tr>
<tr>
<td>ref. + oxygen (M400H)</td>
</tr>
<tr>
<td>ref. + enzyme (M400B)</td>
</tr>
</tbody>
</table>
A comparison of total costs to operating costs shows, that the profitability of the oxygen alternative has been reduced compared to the reference mill (the change of the difference is e.g. in the case of softwood \(-46 \rightarrow -2\) FIM/ADt), whereas the difference in the enzyme alternative \(+16\) FIM/ADt) remains the same because of the investments being of the same magnitude for the enzyme alternative and the reference alternative. The differences between the investments as well as the write off periods and the valuation of capital costs have a considerable influence on the total cost estimates.

"200-mill"

In this case the investigated reference mill represents a mill that has been running for several years.

An oxygen delignification stage or an enzyme stage is added to the reference mill.

In this case the bottleneck of the chemical recovery system, the recovery boiler, is a limiting factor. In the balance calculations the dry solids amount (ton of dry solids/d) going to the recovery boiler was kept constant in all the alternatives.

The reference alternative represents a rather modern Scandinavian mill with, for instance, dry debarking, conventional cooking (kappa number for hardwood 19, softwood 30), bleaching sequence C/D – EO – D – E – D with chemical charge in the first stage C/D for hardwood and C/D for softwood. The chlorine dioxide is produced by the Mathieson-method.

After oxygen delignification kappa number for hardwood is 13 and for softwood 18.

The average production was set to 200 000 ADt/a, which is of the same order of magnitude as that produced with one fibre line in Scandinavian pulp mills.

In this case the reference mill is assumed to have been already written off already i.e. when comparing investments only the marginal new investments are considered. Neither can capacity changes of the chlorine dioxide plant nor the chemical recovery system be done in the oxygen and enzyme alternatives when it is the matter of an old mill. The changes are taken into account as different production amounts in the operating costs.

New investments in the alternative with enzyme treatment are the enzyme dosage equipment, the pH-adjustment system and the lining of the black pulp tower with acid-resistant material. These investments are estimated to cost 1.4 million FIM.

The additional cost for the oxygen stage delivered as a turn-key package is estimated to 85.0 million FIM.

The inclusion of an enzyme stage or an oxygen stage to "the 200–mill" causes changes in the operating costs that are in the same direction as for "the 400–mill".

The investment costs burden especially the alternative with oxygen delignification although only marginal new investment costs were considered.
Total costs (FIM/ADt) of the process alternatives
(written off period: 10 years, interest: 10 %).

<table>
<thead>
<tr>
<th>Alternative (code)</th>
<th>Operating cost</th>
<th>Investment cost</th>
<th>Total cost</th>
<th>Difference to reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hardwood</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reference</td>
<td>1,659</td>
<td>+ -</td>
<td>1,659</td>
<td>+ -</td>
</tr>
<tr>
<td>(K200R)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ref. + oxygen</td>
<td>1,611</td>
<td>+63</td>
<td>1,674</td>
<td>+15</td>
</tr>
<tr>
<td>(K200H)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ref. + enzyme</td>
<td>1,669</td>
<td>+ 1</td>
<td>1,670</td>
<td>+11</td>
</tr>
<tr>
<td>(K200B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Softwood</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reference</td>
<td>1,995</td>
<td>+ -</td>
<td>1,995</td>
<td>+ -</td>
</tr>
<tr>
<td>(M200R)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ref. + oxygen</td>
<td>1,931</td>
<td>+72</td>
<td>2,003</td>
<td>+ 8</td>
</tr>
<tr>
<td>(M200H)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ref. + enzyme</td>
<td>2,006</td>
<td>+ 1</td>
<td>2,007</td>
<td>+12</td>
</tr>
</tbody>
</table>

Due to different yield losses and recovered specific dry solids amounts (oxygen delignification) and due to the bottle neck in the recovery line it was necessary to make production limitations that are of different magnitude for different alternatives. This might affect the operating margin because of reduced sales volume when the business situation is good.

The limitation of the production is 4.3–6.1 % for the oxygen alternative and 1.3–2.1 % for the enzyme alternative.

The limitation of the production has an economic effect besides as losses in the operating margin as heavier burden of the investment costs per ton produced.

The annual operating margin for the old mill (calculated with 20 %) is about 76 million FIM. The lost operating margin is 1.3–6.1 % of the total operating margin, which is worth taking into account in the profitability studies, especially when the business situation is good and the whole production can be sold.

The sum of the total costs and the operating margin lost is, compared to the reference alternative, 1.7–1.9 % higher for the alternative with oxygen stage and 0.9–1.2 % higher for the alternative with enzyme treatment.
SYTYKE 17

EFFLUENT FREE NEWSPRINT MILL

Summary

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SYTYKE 17
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EFFLUENT FREE NEWSPRINT MILL

Summary

Introduction

In the first part of the project an effluent–free green–field newsprint mill was designed and studied. Capital and operating costs were calculated for the internal water treatment and for the whole mill. The costs were compared with those of a conventional green–field newsprint mill.

The mill includes a wood room, TMP and PGW lines and one paper machine. The capacity of the mill is 250,000 tonnes of newsprint per year. The mill uses 5 % of purchased kraft pulp and the mechanical pulps are bleached with dithionite.

The investigation was conducted using the RAMI simulation program developed by PI Process Consulting Ltd. Water, fibre, TOC (Total Organic Carbon) and energy balances were simulated for the whole mill, and the circulation of phosphorus, nitrogen and chloride in the processes were calculated.

The present mill takes only 140 m³/d new fresh water in to the process. The mill’s water balance is shown in the form of a Sankey–diagram at the end of Conclusions.

In the second part of the project the possibility of closing the water circulation of an existing newsprint mill was investigated.

Capital and operating costs

An effluent–free greenfield paper mill would cost about FIM 1,610 million (USD 390 million), making it only about 1 % more expensive than a conventional green–field paper mill with a modern external treatment plant for effluent water.

In the mill designed in this project, 2,600 m³/d of process water is treated in a stainless steel evaporation plant costing about FIM 15 million (USD 3.6 million).

Another 2,400 m³/d is in an ultrafiltration plant treated. The plant costs about FIM 4.5 (USD 1.1 million).

To balance the water circulation to the output of the pulp lines and the paper machine 17,000 m³ of storage tank volume is needed. This is about three times that of a conventional mill.

The capital costs of water treatment facilities for a reference mill where offment is first treated biologically and then flocked with chemicals and filtered through a sand bed filter would be FIM 40 million (USD 11 million). The total water amount treated
is 12,000 m³/d. Of this 5,000 m³/d can be reused in the mill and only 7,000 m³/d would be discharged.

The difference in operating costs arises from differences in water treatment costs. The operating costs for the conventional mill are about FIM 11.2/t (USD 2.7/t) lower, see Table I. It is assumed that the steam for evaporation is produced by burning oil.

Table I. Costs of water treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>water m³/d</th>
<th>cost FIM/m³</th>
<th>cost FIM/d</th>
<th>cost MFIM/a</th>
<th>cost FIM/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation</td>
<td>2,600</td>
<td>13.3</td>
<td>34,580</td>
<td>12.2</td>
<td>48.7</td>
</tr>
<tr>
<td>Ultrafiltration</td>
<td>2,400</td>
<td>1.2</td>
<td>2,930</td>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Reversed osmosis</td>
<td>160</td>
<td>3.0</td>
<td>480</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>5,160</td>
<td>7.36</td>
<td>37,990</td>
<td>13.37</td>
<td>53.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference mill</th>
<th>Treatment</th>
<th>water m³/d</th>
<th>cost FIM/m³</th>
<th>cost FIM/d</th>
<th>cost MFIM/a</th>
<th>cost FIM/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation</td>
<td>12,000</td>
<td>2.5</td>
<td>30,000</td>
<td>10.56</td>
<td>42.3</td>
<td></td>
</tr>
</tbody>
</table>

Dissolved organic material

Organic material like lignin, terpenes, alcohols, formic and acetic acids are dissolved from wood during production of TMP and PGW. In the balance simulation the organic load was calculated as TOC (Total Organic Carbon).

For TMP this is estimated to be 20 kg TOC per tonne of pulp and for PGW 18 kg TOC per ton of pulp. In the wood room 1 kg TOC per cubic meter of wood is dissolved.

Process waters are treated by evaporation or ultrafiltration. The concentrates from both are burned along with bark in the bark boiler.

Washing of mechanical pulps

Both mechanical pulp lines generate heat with which clean steam can be produced. Condensates from heat exchangers are sent to the evaporation plant.

Dirty condensates are removed at the rate of 3 t per tonne of TMP and 1.6 t per tonne of PGW.

After screening and reject refining, the pulps are thickened on diskfilters.
From these filters 1.8 m$^3$ of water per tonne of pulp is led to the wood room. The effluent water from the wood room is treated together with the pulp line condensates in the evaporation plant.

From the same disk filters 0.6 m$^3$ water per tonne of pulp is pumped to the ultrafiltration plant.

The TMP pulp is washed by taken away 5.4 m$^3$ of water per tonne of pulp and the PGW pulp by 4 m$^3$.

The pulps are bleached with dithionite in MC pumps after the first disk filters. The pulps are then diluted with paper machine white water and thickened again on disk filters.

Some white water from the paper machine press section is taken to the ultrafiltration unit. The total amount of water which is treated in the evaporation and ultrafiltration plants is 7 m$^3$ per tonne of paper.

**Water treatment plants**

Effluent waters from the wood room, together with condensates from the pulp lines, totalling 2,600 m$^3$/d are treated by stripping and evaporation. Other process waters (2,400 m$^3$/d) are treated by ultrafiltration. As the process waters are acid, treated water from evaporation plant has to be neutralized. The feed water to the ultrafiltration unit has to be neutralized with NaOH.

The boiling points of many of the organic compounds present (methanol, ethanol and formic acid) are below 100 °C, which disrupts the evaporation. The condensate therefore has to be stripped clean. In the simulation a 96% removal rate was assumed; as a result, the clean water in the simulation contains 120 mg TOC/l. Before the treated water is pumped to the clean water tower, air is blown through it to cool it down. This also has the effect of stripping out some of the remaining volatile organic compounds and gives the water an excess of oxygen to prevent the build-up of anaerobic bacteria. This water has to be neutralized just before it enters the clean water tower.

The effectiveness of ultrafiltration depends on the cut-off number of the membrane. For example, a cut-off number of 1,000 means that 90% of compounds with molar masses above 1,000 will be retained by the filter. Membrane manufacturing techniques are rapidly advanced, and today membranes with cut-off numbers as low as 150 are available.

In the present simulation, a removal rate of 85% was assumed, so that the treated water from ultrafiltration contains 260 mg TOC/l. Some NaCl and other salts pass through the membrane if the cut-off number is 1,000 or more. This water, too, has to be treated with air.

About 600 m$^3$ of water per day flows into the sewers from occasional use and
overflows. The capacity of the sewer water tower is 5,000 m³. This water is treated by chemical flocculation and sand bed filtration and can then be reused for wash-ups and other occasional uses. An excess of oxygen has to be maintained in this water. The remaining sewer water has to be treated by ultrafiltration.

Flue gases from the bark-fired boiler are first filtered and then washed in an alkali scrubber. Inorganic salts dissolve in the scrubbing water, which is then treated by reversed osmosis. The salts are finally concentrated and taken away from the mill. The water can be further treated and used as feeding water for the boiler. Steam production requires 160 m³/d of feed water.

**Emission into the air**

Bark and the concentrates from evaporation and ultrafiltration are all burned. In other words, all chemicals that are not retained in the paper are burned.

Emissions of nitrogen and sulfur compounds from the bark-fired boiler can be reduced in the usual way. The flue gas filter collects 50% of the fly ash salts. The alkaline scrubbing water must not have so high content of alkali to cause formation of sodium carbonate.

Ash from boiler and filter is sintered before dumping.

Odorous gases from heat exchangers in the mechanical pulping lines and evaporation plant are cooled in order to recover the remaining volatile organic compounds.

**Energy balance**

In the present model, steam consumption is 65 t/h. The paper machine uses 35 t/h and the evaporation and stripping units 30 t/h. Some steam could be saved by using hot water in the evaporation plant.

The TMP line generates 29 t/h of steam, the rest coming from the bark-fired boiler. If all the wood used by the mill is debarked in the wood room, enough steam can be produced. Burning the evaporation and ultrafiltration concentrates helps the steam production.

The energy balance for the process was also simulated. High water temperatures will be of major concern in a mill like this. Electrical energy consumption is 80 MW, while steam from the bark-fired boiler contributes an additional 23 MW to the process.

The total energy lost from the different processes was assumed to be 44 MW, because all waters are hot. If there is no call for hot water, either in the surrounding community or in the evaporation plant, 59 MW of heat must be removed in a cooling tower. Treated water is stripped with air and cooled to 40–45 °C, but this removes only 3–4 MW.
As electricity is cheaper at night, the PGW line is shut down during the day. The TMP plant cannot be shut down because it generates so much steam. With a difference between day and night prices of FIM 40/MWh, the annual saving in energy costs at the mill is only FIM 1.4 million. To justify a major energy-saving investment, the price difference would have to be much greater.

Closing the water circulation at an existing mill

The water circulation can also be closed at an existing mill, but this is unlikely to be profitable if the mill has an external effluent treatment system in operation. Some mills already treat their effluent by evaporation and ultrafiltration, and it might be cheaper to use these processes instead of expanding existing external treatment facilities or building new ones.

Evaporation is very expensive if the equipment is made of stainless steel and if the steam is generated by burning oil.

A detailed balance simulation should be made before reducing the raw water intake to the mill. The balances of water, fibre, TOC, energy, Ca, Cl etc. can be simulated using PI Process Consulting's RAMI program.

A water consumption of 7–10 m³ per tonne of paper is sufficient for a newsprint mill. However the mechanical pulp must be washed, otherwise dissolved organic material will build up in the white water, causing pitch and slime problems and disrupting the first pass retention.

Ultrafiltration of sewer water before external biological treatment is an easy, low-cost first step. The water should be screened and neutralized before filtration. If treated water is reused, air must be blown through it to ensure an excess of oxygen. Alternatively, some sewer water can be treated by ultrafiltration and then led pass the biological treatment plant. This is cheaper than expanding the treatment plant. The concentrates from ultrafiltration can be further concentrated by evaporation prior to mixing with bark for burning. The volume of these concentrates is small and they are much easier to handle than biosludge.

Further investigations

There are still some questions to be answered before the water circulation in a paper mill can be totally closed. Investigations should be done with pilot scale equipment in existing mills.

The questions are:

- What is the best way of treating the water before evaporation and ultrafiltration?
- How much of the organic compounds can be stripped out with steam or air before evaporation and ultrafiltration?
- At which point should the water be neutralized?
- What is the cheapest acceptable neutralization chemical?
- How much of the steam used in evaporation and stripping can be replaced by using hot water and vacuum?
- How should contaminated condensates be treated in the evaporation plant?
- How should cleaned waters be treated?
- What kind of concentrates are formed in evaporation and ultrafiltration?
- What is the best way of burning concentrates?

Conclusions

It is possible to build an effluent-free newsprint mill. The present theoretical study shows that there is no difference in capital costs and only a minor difference in operating costs between non-effluent mill and a conventional mill.

The use of raw materials like recycled paper does not change the conclusions of this investigation. However, the burning of concentrates and waste from a deinking plant needs to be investigated further.
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DECOMPOSITION AND ENVIRONMENTAL IMPACTS OF ORGANIC SUBSTANCES IN THE WASTE WATER OF A MILL PRODUCING BLEACHED SULPHATE PULP

Part I. Background, carrying through and conclusions

Summary

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In this study the topic "Decomposition and environmental impacts of organic substances in the waste water of a mill producing bleached sulphate pulp" is approached from the following points of view: distribution and its modelling, decomposition, environmental impacts on fish and modelling in general.

Perhaps the most important outcome of this project – besides its research merits – was the coordination carried out by an independent coordinator in order to fit the subprojects together in the best possible way. After some initial difficulties SYTYKE–18 began its activities quite alright and the entity stayed rather well within the same frames despite some occasional rushes. The task to coordinate – even if a bit heavy – was challenging and proved that this type of approach should inevitably be continued in environmental research. The topic now studied might culminate its progress best if it will be continued for another 3–4 years under a strongly coordinated program.

The subproject on distribution and its modelling (part II) did not lead to any especially new or innovative results. The modelling of distribution used earlier in context of a project funded by the Division of Environmental Sciences, the Academy of Finland was developed further and applied to describe the distribution and decomposition of slowly decomposing substances. The same coefficients of decomposition were used both for AOX (Adsorbable Organic Chlorine) and chlorophenols. It was, however, found difficult to determine the concentration of the latter – at the present low level of pollution – accurately enough for modelling purposes (cf part V). A literature review dealing with the material published (especially in Finland) on "the organic chloro compounds in the waste water of sulphate mills producing bleached pulp" was also compiled and it is published as part VI.

The main task of the subproject on decomposition (part III) was to investigate the ecological behaviour of the waste waters already biologically treated from two sulphate mills (Å and K) in large enclosures (ca 2 m³) placed into aquatic ecosystem. The enclosures were mesocosms, but considerably larger than microcosms to be operated in the laboratory. Several variables were determined at intervals on these mesocosms. However, only the AOX values served directly the goal of modelling (see below) – as was the case in subproject II as well. In fact the enclosure approach proved that several other lines can be selected to collect data for modelling (see below) but within this short time (only about 1.5 years) it was not possible to accomplish them all.

In the continuation, however, one of the most important approaches must be to collect
information about the decomposition kinetics of various individual compounds both in laboratory and in simplified enclosure tests.

The subproject on biological effects on fish (part IV) was accomplished as originally planned by exposing 2+-year old all female rainbow trout in laboratory conditions to 34DCP and 246TCP and the waste water of a mill (Å) producing bleached pulp at +14, +8 and +2 °C. The results from the controls indicate strong seasonal and temperature effects on the parameters investigated. However, in the low, near natural concentrations the toxicants applied in this investigation seem not have harmful effects on fish.

The outcome of the subproject on modelling (part V) was obviously less than originally expected. This was, however, not due to the subproject itself but the short time reserved for the whole project to produce results suitable for modelling. At any rate submodels for describing decomposition of organic chlorine (measured as AOX in the mesocosms) were developed. They can be coupled to a water quality model including a hydrodynamic compartment. Although light and temperature have a great impact on the decomposition of organic matter and chloro organic compounds, inclusion of temperature and light did not improve much the accuracy of the model.

However, in order to get forward with the modelling if and when the project is to be continued one should also be able to screen the variation of other than organochloro compounds, for instance the change in the molecular size of the dissolved organic matter, the decomposition kinetics of various compounds at the molecular level and so forth. There are also room for new innovations. Chlorophenols, at the present low level of contamination, are hardly any more the most indicative parameters for pollution and therefore for modelling – even if the problems met in their analysis could be overcome.
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DECOMPOSITION AND ENVIRONMENTAL IMPACTS OF ORGANIC SUBSTANCES IN THE WASTE WATER OF A MILL PRODUCING BLEACHED SULPHATE Pulp

Part II. The distribution of organochlorine compounds of a pulp mill bleachery into Lake Päijänne. The modelling of the distribution

Summary

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DECOMPOSITION AND ENVIRONMENTAL IMPACTS OF ORGANIC SUBSTANCES IN THE WASTE WATER OF A MILL PRODUCING BLEACHED SULPHATE PULP

Part II. The distribution of organochlorine compounds of a pulp mill bleachery into Lake Päijänne. The modelling of the distribution

Summary

This study is a part of project SYTYKE-18, which is treating the environmental impacts of the discharges of the chemical wood-processing industry. In this study the distribution of organochlorine compounds into Lake Päijänne and the modelling of their distribution by simple water quality models is discussed.

The targets of the study are the watercourse of Äänekoski and Lake Päijänne, and the effluents of the sulphate pulp mill of Äänekoski. The annual production capacity of the present pulp mill, which started in 1985, is 430 000 tons pulp. The pulp mill has a biological purification plant with activated sludge method, and extended delignification is used to decrease the organic emissions and the use of chlorine.

In order to study the distribution of chlorine compounds and AOX four sampling stations were selected, Lake Vatianjärvi just downstream the pulp mill, Ristiselkä in Northern Lake Päijänne, Judinsalonselkä in the central areas of Lake Päijänne, and Asikkalanselkä in Southern Päijänne. Asikkalanselkä is at present the raw water basin of the Helsinki Metropolitan Area.

The sampling time was between April 1991 – February 1992. The preliminary target of the studies was the distribution of organic chlorine compounds (AOX) and chlorophenols, –catechols and –guaiacols.

The BOD$_3$–loading, nutrient loadings and the general condition of the study area were described with the aid of official research reports, which base on the orders of Water Court or water authorities. Northern Lake Päijänne is still eutrophic like the watercourse of Äänekoski, although the oxygen concentrations have markedly increased since the beginning of 1980s, when the old pulp mills were processing. Judinsalonselkä is nearly in natural condition, and according to the data of primary production and phytoplankton Asikkalanselkä is in natural condition.

In 1991 the AOX–loading was 1.5 – 2.0 tons/day, and the corresponding specific loading was about 1.5 – 2 kg/ton pulp. In the beginning of the sampling year 1991 the loading of chlorophenols was 3.9 kg/d. The loading of chlorophenols decreased during the sampling time from 3.9 kg/d to 0.3 kg/d. The decrease was a result of the research work to decrease the use of chlorine in bleaching and the loading of chlorine compounds e.g. by using enzymes instead of chlorine etc.
The amounts of chlorophenols in biologically purified pulp mill sewage have significantly decreased when compared to the amounts of unpurified sewage in the beginning of 1980s. In 1980s the specific loadings were grams/ton pulp, the maximum being about 20 g/t, now the maximum amounts are some hundred milligrams per ton pulp.

A simple water quality model suitable for studying the distribution of slowly decomposable compounds was developed. The model bases on a model described in a study financed by the Finnish Academy of Sciences, Environmental Section. So the same decomposition coefficients \((K_{20})\) for AOX and chlorophenols can be used in the new model. The decomposition coefficient for AOX was 0.00474, two decomposition coefficients were determined for chlorophenols, "kerroin 1", 0.004714, and "kerroin 2" 0.02636. Decomposition coefficient \((K_{20})\) for lignins (lignosulphonates) was 0.00545.

With the aid of the model AOX— and chlorophenol concentrations were calculated for different water bodies of Lake Päijänne by using as start loadings for AOX 1.7 t/d before 1991, and 3.9 kg/d for chlorophenols before April 1991, after which measured chlorophenol loadings were used. Parallel results between measured concentrations and model calculations were searched. This way we can estimate the real age or detention time of the loading of chlorophenols or AOX in a certain place and describe roughly the way of decomposition of the chlorine compounds.

The low concentrations of chlorophenols can cause ambiguous results, sometimes "kerroin 1" gave better results, sometimes "kerroin 2". One cause for ambiguous results may be the fact that chlorophenols are a heterogeneous group of chemical compounds which can have various decomposition speed.
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DECOMPOSITION AND ENVIRONMENTAL IMPACTS OF ORGANIC SUBSTANCES IN THE WASTE WATER OF A MILL PRODUCING BLEACHED SULFATE PULP

Part III. Degradation

Summary

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The ecological behaviour of wastewaters from bleached kraft pulping was studied in freshwater ecosystem using large enclosures placed into the aqueous ecosystem. The enclosures are mesocosms, being smaller than the lake ecosystem itself, but considerably larger than microcosms operated in the laboratory. The advantage of the mesocosm enclosures is that, exposed to light and temperature similar to those prevailing in the lakewater, they approach the real lakewater ecology, while being amenable to modelling and manipulation and run with reasonable amount of work and cost. The only serious weakness encountered during the one year’s study, was wall effects, especially wall growth by planktic organisms. This handicap, added to the mechanical problems caused by ice and snow during the winter season on the enclosures in situ, did not seriously hamper achieving the targets of this study. Although originally not planned, the experiment was extended over the winter in order to reliable information concerning the seasonal degradation dynamics of organic halogens in the wastewaters, subject to changing exposure to light and temperatures. The mesocosms in two different lakes, one clearwater and the other humic, were spiked with 0%, 2% or 10% wastewater from two different mills (A, K). Parallel enclosures, similarly spiked, were covered from light to observe for the events in absence of photochemistry and primary production.

Bleached kraft pulp mill wastewaters can influence the ecosystem by i) increasing nutrient levels; (ii) by decreasing penetration of light (coloured waters) or (iii) by their organic contents, compounds that may be acutely or chronically toxic or that can be transformed into such compounds microbes resident in the ecosystem. We observed all of these effects in the present study.

The wastewaters placed in the mesocosm enclosures were already biologically treated (activated sludge plant or anaerobic-aerobic lagoon treatment). Thus the biological oxygen consuming matter (BOD) had already been removed to approx. 90%. As expected, the placement of the wastewaters into lakewater enclosures had little effect on the levels of dissolved oxygen. The enclosures with clear lakewater were oxic (5...9 mg O₂ l⁻¹) throughout the year, but the humic water enclosures exhibited a strong gradient of oxygen, and, by times, were anoxic at the bottom. The vertical temperature gradient was mild in the clearwater enclosures and very steep in the humic enclosures. In the humic enclosures also the seasonal thermocline cycle was observed in the autumn.

Concentration of inorganic phosphorus increased during the observation period in the enclosures exposed to light, especially in the clearwater spiked with effluent from mill K. From this wastewater also inorganic nitrogen was produced in the darkened
enclosures in both lakes. The level of total nitrogen remained constant excepting one enclosure, where a cyanobacterial bloom increased the nitrogen levels late in summer (mill Å, 10% wastewater).

Wastewater decreased the species spectrum of the phytoplanktic community in the clearwater enclosure, but had an opposite effect in the humic enclosure. Wastewater increased bacterioplankton in the clearwater enclosure, but had no effect in the humic water. No effects on the zooplanktic community were observed. The results indicate that the species composition of the planktic communities could divert and that the time phase of succession of the different elements of the plankton were non synchronous in the different enclosures. Because of these divergencies, several parallels of each enclosure make-up should have been run to allow for conclusions based on statistical analysis. Such was not possible in the present study.

During 9 months of observation, 30 to 80% of the organic halogen contents of the enclosures disappeared from the water column of the enclosures, and during 14 months (two growing seasons) 50 to 80%. Approximately 1% of the organic halogens, originating from the waste water, was recovered in the sediments formed on the bottom of the enclosures by 9 months. Sorption onto and into the enclosure walls (polyethylene) in 9 months, including sorption to periphyton attached to it, was found to be less than 1% of the amount introduced on day 0. Removal of organic halogens was most effective in the humic water enclosures (40...60% in 9 months), and independent of light. In clearwater enclosures clearly more organic halogen was removed in the enclosures exposed to light than in the darkened ones. Therefore the sinks of organic halogens in these lakewater ecosystems were both photochemical and biological (light independent) reactions. In dark 30...40% of organic halogens was removed in 9 months. Assay of AOX (adsorbable organic halogen) proved to be a reliable, repeatable method for the follow-up of biodegradability in freshwater ecosystem. It clearly has potential as a monitoring tool for modelling of the impact of bleached kraft pulp mill effluent on the aqueous ecosystem.

Possible changes of the molecular size distribution of organic halogen compounds were studied by ultrafiltration fractionation. The organically bound halogen was distributed in the mill waste waters into size fractions of < 1000 g mol⁻¹, 1000...10000 g mol⁻¹ and > 10000 g mol⁻¹ as 1:1:1 (by weight). Organically bound carbon (TOC) was distributed as 2:1:1 (by weight) in the same fractions, indicating that the smallest molecules were least chlorinated. After one year of incubation in the lakewater mesocosms, the size distribution was restudied. It was found that organic halogens had been removed preferentially from the largest size class (> 10000 g mol⁻¹).

Sediments that had become accumulated at bottoms of the enclosures during the observation period, were analyzed for organic halogen content. Inorganic chloride was first deliberated from the cells by ultrasonication and washed out. It was found that sediments in wastewater containing enclosures contained 1 to 14 mg of Cl per g of dry sediment, while sediments of control enclosures (0% waste water) contained only 0.2...0.8 mg of Cl. After 10 months' incubation in the enclosures, the solvent extractability of sediment bound organic halogens was studied using tetrahydrofuran (polar solvent) and heptane (nonpolar solvent). It was found that the sediments of darkened enclosures had accumulated more than twice the amount of heptane and tetrahydrofuran extractable halogen than did the sediments of the enclosures exposed to light. All enclosure sediments contained about tenfold more tetrahydrofuran extractable halogen than heptane extractable halogen, indicating relative polarity of
the sediment accumulated halogens. It thus shows that the choice of solvent is important when organic halogens are being extracted from lake sediments and the results interpreted.

Mineralization of organics from wastewater of mill Å were also studied in the laboratory by CO2 evolution tests (OECD drafted standard, 1990). The tests were run under fully aerobic conditions (aeration by carbon dioxide free air), wastewater diluted into the same lake waters (10%) as in the mesocosm study. The results showed that mineralization was equally slow at +19 °C as at +8 °C during the test of one month. For the clearwater lake, the flasks tests in the laboratory gave the same rate of mineralization as was observed in the mesocosms (approx. 10% of AOX and of TOC were removed), while in humic lakewater the mesocosms mineralized more effectively than the flasks in the laboratory. The hypochlorite dose, recommended by OECD draft protocol to assess for abiotic degradation, had little effect on mineralization with these wastewaters. This indicated relative chlorine resistance of the microbes present in the (biologically treated) wastewaters from bleached kraft pulp mills.

The OECD draft CO2 evolution test is designed for testing pure chemicals, and therefore requires modification before being applicable to monitor for the biodegradability of wastewater organic contents. For instance, it was not possible to distinguish between the inoculum brought in by the (biotreated) wastewater and that added as sludge, nor to distinguish between nutrients deliberated from the wastewater or applied by the nutrient solution used.

The various biological processes observed in the mesocosms, such as mineralization and uptake of nitrogen and phosphorus, vertical gradients of temperature and oxygen, indicated that the mesocosms closely reflected the conditions prevailing in the freshwater lake ecosystem. Therefore it may be expected that the changes observed in the mesocosms during the observation period, such as degradation, sedimentation, and changes of molecular size of the organic halogens originating from the mill wastewaters, are likely to reflect the processes that take place in the ecosystem.

This study has shown that mesocosms are a valuable tool for bringing forth data to be used for predicting wastewater impact on lake ecosystem and to design a model for predicting wastewater behavior in recipient water. We recommend their further use for such purposes. It should be added, that it was important to use two different mills with different processes and wastewaters, and two different recipient lake ecosystems. Otherwise the dominating impact of the wastewater and lakewater characteristics upon the results might have passed unnoticed.
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DECOMPOSITION AND ENVIRONMENTAL IMPACTS OF ORGANIC SUBSTANCES IN THE WASTE WATER OF A MILL PRODUCING BLEACHED SULPHATE PULP

Part IV. Biological effects on fish

Summary

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DECOMPOSITION AND ENVIRONMENTAL IMPACTS
OF ORGANIC SUBSTANCES IN THE WASTE WATER OF
A MILL PRODUCING BLEACHED SULPHATE PULP

Part IV. Biological effects on fish

Summary

The effects of 3,4-DCP, 2,4,6-TCP and waste waters of a mill producing bleached sulphate pulp on 2+ year old allfemale rainbow trout (*Onchorhyncus mykiss*, Walbaum). The exposures were conducted in laboratory scale in three different temperatures, +14°, +8° and <2 °C.

The concentration of toxicants during the exposures were selected to fit those in natural waters downstream of pulp mills (Lake Päijänne). 3,4-DCP was used in concentrations of 130 and 260 ng *1*⁻¹, 2,4,6-TCP in concentrations of 0.05 and 0.1 ug *1*⁻¹ and waste waters of the pulp mill were diluted 1:50 and 1:10. During the exposures to two higher temperatures the fish were in L:D rhythm of 8:16, and in the coldest temperature, during winter they were kept in total darkness. Each exposure had its own control group in pure water.

The physiological status of the fish was determined in addition to measuring their length and weight by estimating blood hemoglobin concentration and hematocrit value. To evaluate the status of osmoregulation plasma was assayed for Cl⁻, Na⁺, K⁺-, Ca²⁺- and Mg²⁺- ionic concentrations and osmolality. The short term stress and status of carbohydrate metabolism was estimated from the glycogen content of the liver. The liver was also assayed for UDP-GT- and BG-activities for the status of detoxification metabolism. Plasma ASAT was assayed to indicate liver tissue damages.

The results reveal some osmoregulatory lability during the short term exposure in the greater concentration of 3,4-DCP. The glycogen concentration in liver decreased and UDP-GT activity increased at 14 °C, but at the temperature of 8 °C the change was vice versa. At this temperature microbicidic activity of the neutrophiles may be weaker than normal.

A short term exposure to 2,4,6- TCP made the erythrocytes to shrink at 14 and 8 °C, which evidently decreased the oxygen affinity of the blood. At 8 °C the results reveal a contradictory osmoregulatory respons to that seen during the exposure to 3,4-DCP. At this temperature the glycogen concentration of the liver decreases and blood lumphocyte count drops.

During the exposure to waste water plasma potassium concentration increased.

During the long term exposure to 3,4-DCP at 7 and <2 °C the sodium- and at the colder temperature also CL⁻-concentrations of the plasma increased during the first month of exposure. Later the differences to the controls diappeared. At the higher
temperature GT–activity of the liver and the oxygen affinity of the blood decreased. Blood oxygen affinity increased during the cold exposure.

The amount of roe, the size of the eggs and their fat and ionic concentrations did not differ from the controls after the long exposure to 3,4–DCP. Even the hatchability was as in the controls.

The results reveal marked seasonal changes in the parameters examined. The growth of the fish reared in Hakuninmaa at the temperature of 7–8 °C was slow because of their low feeding rate. After July the hemoglobin concentration was lower in summer than in winter. Plasma Cl− and Na+–concentrations increased in July and stayed on the high level for the rest of the year. Also plasma Mg2+–concentration and osmolality behaved similarly. The blycogen concentration increased during summer and remained on this elevated level to the end of the experiments in January.

In temperatures <2 °C the protein concentration increased during the wintertime, evidently in relation to the reproduction cycle. The Hb concentration decreased in midwinter but turned to an increasing trend during spring. Between January and April Cl−, Na+– and K+– and after this Mg2+– and Ca2+– concentration increased.

The results of the controls reveal that the experimental temperature affects the physiological status of the fish. The Hb–concentration and Hct value of the controls correlated positively with the temperature when assayed at the same time of the year. The same was true for plasma protein, Mg2+– Ca2+– and liver glycogen concentrations and liver UDP–GT– activity. The ASAT–activity of the plasma correlated negatively with the temperature.
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DECOMPOSITION AND ENVIRONMENTAL IMPACTS OF ORGANIC SUBSTANCES IN THE WASTE WATER OF A MILL PRODUCING BLEACHED SULPHATE PULP

Part V. Modelling

Summary

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DECOMPOSITION AND ENVIRONMENTAL IMPACTS OF ORGANIC SUBSTANCES IN THE WASTE WATER OF A MILL PRODUCING BLEACHED SULPHATE PULP

Part V. Modelling

Summary

Introduction

Water quality models are needed in making quantitative assessments and predictions of the impact of waste water loading on lakes and rivers. Water quality models are usually based on water and material balances and the kinetic principle. According to the kinetic principle, reaction rates are proportional to a concentration or a function of a concentration. In the simplest water quality models there is only one state variable, e.g. total phosphorus or AOX, whereas in more sophisticated models there may even be several tens of state variables.

In mechanistic water quality models a hydraulic compartment and a water quality compartment can be distinguished. E.g. advection, dispersion and dilution are hydraulic processes. Among non—hydraulic processes there are decomposition, volatilization and sedimentation as well as other corresponding processes. In models, hydraulics can be described in many different ways and the choice depends on e.g. the problem to be solved and the resources available.

The aim of this study was to develop submodels describing the fate and effects of chloro—organic compounds in lakes and rivers. In the future the submodels can be coupled to a total model including a hydraulic compartment in order to study the impact of loadings in receiving waters.

Material and methods

The original purpose of this study was to develop submodels that can be used in describing the decomposition (and its dependence on different factors) of both AOX and different chloro—organic compounds, as well as the effect of organic chlorine on fish. When reporting this study, data only on AOX was available.

In the study results of mesocosm experiments carried out in two lakes (clear Lake Valkea Mustajärvi and polyhumic Lake Mekkojärvi) with effluents of two pulp mills (Aänekoski and Kaskinen) were used. There were two dilutions of the effluents in the mesocosms (ca. 2% and ca. 10%). One of the mesocosms with 10% of waste water was darkened. In addition, there were control mesocosms with only lake water.

In developing the models, data on concentrations of AOX at different times was especially used. Data on sedimentation and adsorption of AOX to the plastic material of the mesocosms was also available. The contribution of sedimentation and adsorption to the material balance of AOX was so small that it was not necessary to consider them in the model. The AOX concentrations in the control mesocosms were subtracted from the measured AOX concentrations because it was assumed that the natural AOX concentration does not reduce any longer, i.e. the most readily decaying chloro—organic compounds have already decomposed.
Light and temperature are important factors affecting the decomposition kinetics of AOX. The study proceeded in the following way: Firstly decomposition at a constant rate was considered, in the following step the effect of temperature was included in the model, after that the component of decomposition that is dependent on light was separated, and in the fourth step the reduction of the reaction rate along with time was considered. The idea in the fourth correction function is that the most readily decaying components disappear in the beginning of the experiment.

The concentrations were measured between the 4th of June, 1991 and the 6th of August, 1992. In modelling the decomposition kinetics, only the period until the 4th of March 1992 could be used because data on temperature and radiation was available for that period. In addition, AOX concentrations have been much higher in May than in March, the reasons for which have to be cleared up before the results can be utilized.

In developing the models the coefficients are searched out that produce the smallest differences between the observed and calculated values of the concentrations.

**Developing and applying the models**

**Decomposition at a constant rate**

The starting point in developing the decomposition model is to assume that the decomposition obeys first order kinetics with a constant reaction rate coefficient. The equation for the decomposition is as follows:

\[
\frac{dc}{dt} = -k \cdot c
\]  

(1)

where  

- \(c\) = AOX concentration (M L\(^{-3}\))  
- \(t\) = time (T)  
- \(k\) = reaction rate coefficient (T\(^{-1}\))

The effect of temporal variation of the environmental factors has not been taken into account in Eq. (1). It is not theoretically sound to assume that the coefficients in all the mesocosms would be the same (e.g. light/darkened mesocosm). Therefore a decomposition coefficient was calculated for each of the mesocosms separately. Because the results are the most reliable in the beginning of the experiment the calculations were made separately for the period between the 4th of June and the 21st of October, 1991, and the period between the 4th of June, 1991 and the 4th of March, 1992.

The \(k\)\(_{275}\) coefficients representing the longer period are smaller then the \(k\)\(_{140}\) coefficients representing the shorter period, which can also be theoretically based. AOX is a composition of chloro-organic compounds decaying at different rates and the apparent total decomposition rate coefficient becomes smaller when the most readily decaying components disappear. The overall applicability of Eq. (1) was better for Lake Valkea Mustajärvi than Lake Mekkojärvi. The model could be better used to describe the decomposition of AOX from the mill of Äänekoski than the mill from Kaskinen.
Calculations were also made using the same coefficients for different mesocosms, separately for light mesocosms and for darkened ones (the longer study period). The best coefficient for light mesocosms was then \( k = 0.004 \, \text{d}^{-1} \) and for darkened mesocosms \( k = 0.002 \, \text{d}^{-1} \). The fit of the model was then worse than in the case where it was calibrated for each mesocosm. When Eq. (1) was applied to different groups of the mesocosms the following coefficients (d\(^{-1}\)) were obtained: \( k_{140\text{light}} = 0.006, \ k_{275\text{light}} = 0.004, \ k_{140\text{Äänekoski}} = 0.005, \ k_{275\text{Äänekoski}} = 0.003, \ k_{140\text{Kaskinen}} = 0.007 \) ja \( k_{275\text{Kaskinen}} = 0.006 \).

The coefficients representing the shorter period are clearly greater. It was found that the AOX of Kaskinen dissappears faster than the AOX of Äänekoski, which could also be detected in the mineralization results of the effluents.

The effect of temperature

In the next step the effect of temperature was included in the model. Eq. (1) was modified as follows:

\[
\frac{dc}{dt} = - k(T_s) \cdot f(T) \cdot c
\]

where:
- \( k(T_s) \) = decomposition rate coefficient at standard temperature \( T_s \) (\( \text{d}^{-1} \))
- \( f(T) \) = temperature correction function

The general temperature correction function of Frisk and Nyholm, formed on the basis of the function of Streeter and Phelps, was used. The temperature correction parameter \( \theta \) is described as a linear function of temperature:

\[
\theta = a + b \, T
\]

where:
- \( \theta \) = temperature correction parameter
- \( T \) = temperature (°C)
- \( a \) ja \( b \) = empirical coefficients

The temperature correction function is Eq. (4):

\[
f(T) = \frac{\left(\frac{a}{b} + T\right) \ln(a + b \, T) - 1}{\left(\frac{a}{b} + T_s\right) \ln(a + b \, T_s) - 1}
\]

The values for the empirical coefficients were \( a = 1.12 \) and \( b = -0.004 \) which have been found to be applicable for BOD decay reaction. For light mesocosms the best decomposition coefficient at standard temperature was \( k = 0.007 \, \text{d}^{-1} \) and for darkened mesocosms \( k = 0.002 \, \text{d}^{-1} \).

The inclusion of the temperature correction does not much improve the applicability of the model. In some situations in Lake Mekkojärvi the differences between the calculated and observed values were even greater. At standard temperature 20°C the coefficients are smaller than the corresponding coefficients in the model with a
constant coefficient because the temperature in the mesocosms was for most of the time less than 20°C.

Light correction

In order to take into account the effect of light, the term describing decomposition was divided into two terms, one describing the reaction dependent on light and the other the reaction that is independent of light. Both components were considered as dependent on temperature:

\[
\frac{dc}{dt} = - k_v f(I) f(T) c - k_m f(T) c
\]  

(5)

where

- \( k_v \) = reaction rate coefficient of light-dependent decomposition at standard temperature (T')
- \( k_m \) = reaction rate coefficient of the component of decomposition independent of light, at standard temperature (T')
- \( f(I) \) = light correction function
- \( f(T) \) = temperature correction function (Eq. 4)

The same temperature correction coefficients as before were used (\( a = 1.12, b = -0.004, T_s = 20 ^\circ C \)).

For calculating the light correction function, data on ambient light is needed. Light at different depths was computed applying Lambert's law. Light absorption coefficient (extinction coefficient) was calculated on the basis of colour using a regression model presented by Arvola and Jones. Colour values were different in different mesocosms, due to the differences in the humus content of Lakes Valkea Mustajärvi and Mekkojärvi on one hand and different waste water dilutions on the other hand. Colour decreased along with time in the mesocosms because coloured organic substances of the waste waters decomposed during the experiment. The decrease of colour was assumed to obey first order kinetics.

Light correction function \( f(I) \) was described analogically with the Michaelis–Menten equation, as is often done in studies concerning productivity of waters. An average value integrated from the surface (\( z = 0 \)) to depth \( z \) was used:

\[
f(I) = \frac{1}{\epsilon Z} \ln\left( \frac{K_L/I_o + 1}{K_L/I_o + e \epsilon Z} \right)
\]  

(6)

where

- \( Z = \) effective depth of the mesocosm (L)
- \( I_o = \) light intensity on the surface (M T\(^{-3}\))
- \( K_L = \) half saturation constant of light (M T\(^{-3}\))
In the calculations the value for \( K_L \) was 0.7235 MJ m\(^{-2}\) d\(^{-1}\) and for \( Z \) 1.5 m.

The value for the coefficient independent of light \( k_m \) was determined taking advantage of the results from the darkened mesocosms. At standard temperature it was 0.004 d\(^{-1}\). The coefficients dependent on light were calibrated for different mesocosms separately. A coefficient representing the best fit to the whole data set was also estimated, its value was \( k_c(T) = 0.006 \) d\(^{-1}\).

The fit of the model with both light and temperature corrections was approximately as good as the model with only temperature correction. It is obvious that even light correction is not sufficient to make the results good enough in Lake Mekkojärvi.

**Time correction of decomposition rate**

Because light and temperature corrections were not sufficient to make the calculated curve completely correspond to the observed values, especially in the mesocosms of Lake Mekkojärvi, a time correction of the decomposition coefficient was included in the model. Time correction is theoretically based because the most readily decaying components decompose first and then the decomposition coefficient decreases along with time. Eq. (5) was written as follows:

\[
d\frac{dc}{dt} = - k_c f(I) f(T) f(t) c - k_m f(T) f(t) c
\]

where \( f(t) = \text{time correction function} \)

By means of sensitivity analysis it was found that the initial value of the decomposition coefficient must be about one order greater than the steady state value in order to obtain an effect great enough. The following time correction function was introduced:

\[
f(t) = 1 + e^{-at}
\]

A value of 0.1 d\(^{-1}\) was calibrated for parameter \( a \).

Because the value of the time correction function is always greater than 1 it is clear that the standard values of the coefficients are smaller than in former applications. The standard value of the coefficient independent of light was \( k_m = 0.002 \) d\(^{-1}\). The coefficients dependent on light were calibrated for different mesocosms separately. The best common value for \( k_c \) in the whole data set was 0.004 d\(^{-1}\).

Time correction of the decomposition coefficient made the general applicability of the model to the data much better. The improvement was especially remarkable in the case of Lake Mekkojärvi, whereas in the case of Lake Valkea Mustajärvi the effect was not so significant.

**Discussion**

The purpose of the modelling was to describe decomposition kinetics (and its dependence on external factors) of organic chlorine in waste waters of sulphate pulp mills. As external factors, light and temperature were considered. The experiments
were carried out using the effluents of two different mills diluted with water of two
different lakes.

The magnitude of the coefficients determined in this study correspond to the value of
0.00474 d⁻¹, computed on the basis of the mass balance studies of Lake Päijänne,
converted to temperature 20°C (Granberg). On the basis of the mesocosm experi-
ments it was found that during a shorter period the coefficients were greater than
during a longer period. This can be explained by the fact that the most readily
decaying compounds disappear first and then the apparent decomposition coefficient
becomes smaller. This phenomenon could be more exactly described by dividing the
considered substance into several components, each of which has a decomposition
coefficient of its own. In this study an empirical time correction function with
calibrated parameters was applied. According to the time correction function the rate
of decomposition in the beginning is tenfold compared to the steady state rate.

Temperature and light are important factors affecting decomposition. In summer when
temperatures are higher and there is more light energy available than in winter,
decomposition is more rapid. However, temperature and light were not sufficient to
explain the more rapid decomposition in summer 1991 and the above mentioned time
correction was needed. This is easy to understand if we think about the temporal
succession of light and temperature correction functions. Temperature was relatively
low in the beginning of the experiment. The warm water of summer became cooler
only in August–September. However, decomposition was most rapid right at the
beginning. If we think about light the situation is different. The light energy available
depends not only on incoming radiation but also on the colour of the water. Colour is
dependent on the humus content of the dilution water and on the magnitude of
dilution. In midsummer, incoming radiation is at its maximum, but colour is also high.
Later colour becomes lower when organic substances decompose. For these reasons
light and temperature that, no doubt, very much affect the decomposition rate did not
sufficiently contribute to the results so that the deviations of the first order kinetic
model from the observed values would have been corrected.

The effect of light on decomposition is apparent. Using the model the component of
decomposition dependent on light could be separated from the component independent
on light. The starting point in determining the independent component was the
decomposition of AOX in darkened mesocosms, which was much slower than in light
mesocosms. When the values of the light correction function at different times are
taken into account it can be found that the component dependent on time contributes
to decomposition slightly more that the component independent of light. However, the
experiment was not optimal for determining the light correction function. For the sake
of the great importance of light for decomposition it should be studied in experiments
that are especially designed for determining the correction function.

One of the purposes of the study was to make a calibration of temperature correction
coefficients a and b for organic chlorine. For the above mentioned reasons the
coefficients could not be calibrated on the basis of mesocosm data. Like light
correction temperature correction should also be studied making special measure-
ments.

Mesocosm experiments provide a very applicable method for determining decomposi-
tion rate coefficients. However, the simulation of experimental mesocosms is not
sufficient for testing the models. The submodels developed in this study should be
coupled e.g. to a three-dimensional current–water–quality model and the thus formed total model should be tested against empirical data. If positive results were obtained in the test the model could be reliably applied in assessing the behaviour of organic chlorine in waters. It is also very important to be able to assess the areal variation of concentrations in the study of the biological effects of organic chlorine. Due to random variation, it is not possible to determine reliably the areal variation of water quality using only measurements. In future research programmes it would be important to connect the study on the behaviour of organic chlorine in waters with the study on the biological effects of organic chlorine in the framework provided by model development. In addition to AOX different compounds should also be considered. The waste waters of mills that do not use chlorine in bleaching should also be taken into a corresponding model consideration.

The fit of the models was in general very good in the mesocosms of Lake Valkea Mustajärvi, whereas in the mesocosms of Lake Mekkojärvi it was poorer. In Lake Mustajärvi decomposition seemed clearly not to obey first order kinetics and a time correction of decomposition was needed. Additional water quality variables were not included in the model. E.g. humus may have great effects that are not known. In the polyhumic Lake Mekkojärvi decomposition was in the beginning more rapid than in Lake Valkea Mustajärvi the reasons of which are not clear.

The AOX in the effluents of the Kaskinen mill was more rapidly decomposed than that of the Äänekoski mill. The reason is that the waste waters of the Äänekoski mill are more completely mineralized. However, when time correction was applied it was found that a similar correction was needed for describing the AOX of both mills. The same correction functions could thus be applied to the waste waters of Äänekoski and Kaskinen.
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EMISSION TREATMENT OPTIONS AND COSTS IN THE PULP AND PAPER INDUSTRY

Summary

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SYTYKE 19
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EMISSION TREATMENT OPTIONS AND COSTS IN THE PULP AND PAPER INDUSTRY

Summary

Description of effluent treatment and cost calculation methods

On behalf of the SYTYKE project CTS Consulting Ltd and Enviro Data Oy have made a study on effluent treatment alternatives and their costs for the pulp and paper industry.

Production of pulp and paper entails varying amounts of effluents in the form of gases, solvents or solid wastes which are transferred as effluents into the surrounding air, soil and water. The impurities contained in the effluents originate from the raw materials used, wood and process chemicals and their reaction products. Some of the effluents develop in connection with the energy production required by the processes. The production process must therefore be seen as a balance in which all raw materials used leave the process either as products, waste or energy.

When aiming at reducing the total load of effluents in the environment, the measures are often classified as internal and external. With internal measures the efficiency and recovery grade of the production process are improved. The task of the external methods is to reduce or change the impurities of the effluents in the production process.

The aim of the present study was to evaluate the technical and economical aspects of the alternatives for external treatment of various effluents. The evaluation was concentrated on methods that are in general use in the pulp and paper industry today, or will become more general in the future. Furthermore, the study deals with some interesting processes which have not yet been applied in the wood processing industry. The evaluation contains a short description of the methods, an evaluation of their applicability, efficiency, advantages and negative influences as well as cost factors.

It has been the aim to make a uniform presentation of the cost calculations for various effluent treatment alternatives on a certain level. The costs have mainly been presented as a function of the type of production and factory size.

A data model simulating the processes has been made of each effluent treatment alternative in order to facilitate the calculation work. Starting with specific effluents from different processes and the dimensioning of the method and investment costs, the model calculates the result of the treatment, the composition of the effluents, and the treatment costs.

The model simulating the treatment process always requires as base value data describing the character and amount of effluent in the process in question. Data has been gathered by investigating the most common processes for pulp, paper and board
production now in use in Finland. The figures presented describe the effluents according to subprocesses. In the evaluation of these readily measured data has been available. There has also been effluent parameters to be calculated based on process data, for example natrium and chloride effluents which are not normally measured.

The biggest problem with the model describing the treatment method relates to parameters describing the quality of the effluent. During the control it was discovered that certain figure parameters which do not state amounts of matter or their physical-chemical nature, require additional parameters in order to describe how they behave in the process. Parameters which in themselves are appropriate for certain purposes, like COD, lead to meaninglessness or to the use of an endless number of correction coefficients for water and process in the balance sheets of effluent technology. The model shows this type of faults, especially when combined with several subprocesses. The development of effluent water parameters should have a high priority in future studies.

The principles of the dimensioning of the treatment process is based on literature and operational experience. The dimensionings used cannot be directly applied on any other than the listed examples.

The costs have been calculated in Finnish marks according to the price level of November 1, 1991. The exactness of the costs calculations is +/− 20%. The item machinery costs contains the direct cost of machinery, installation as well as start-up and training. The machinery configuration includes all devices forming a functioning unit. The machinery costs represent in general devices of an average price level.

Direct investment costs contain device, construction, electrification and automation costs subject to VAT. These costs also contain installation, start-up and training.

The portion of VAT of the tax exempt costs is 22%.

The engineering's part of the direct costs has been estimated at 6 % and the general costs at 10 %. The unforeseen part of the direct costs is 10 %.

Treatment methods for controlled effluents

The treatment methods chosen for this study have been controlled according to certain principles. In this way a uniform picture of each method has been developed, describing the most important characteristics of the method. The models developed for calculation of costs and effluent treatment results turned out to be very reliable working tools.

In the treatment of gas emissions the emphasis has been laid on particulates, sulphur dioxide and separation of simple sulphur compounds. Typical effluent sources are flue gases, odour gases and other condensates.

As concerns devices suitable for separation of flue gas particulates the electrostatic participator has turned out to be the most effective and most widely used in industry. Lime kiln flue gases are still mainly treated with wet separators.

The most significant measures regarding control and reduction of the sulphur dioxide effluents of pulp mills in the future are internal. This also includes the use of
regeneration units for treatment of chemical solutions for optimization of the S/Na balance. Of the actual external methods flue gas washers are in general use. The choice of washing solution has a big impact on the separation efficiency of the device. The main part of the bleaching plant's chlorine dioxide condensates are purified in washers.

Reduction of simple sulphur compounds, i.e. flue gas effluents require efficient collection and destruction through burning as well as washing of the flue gases.

Experiences of the possibilities to reduce flue gas nitrogen oxides with external methods are so far minimal. Possible measures to reduce nitrogen oxides are mainly related to optimization of burning conditions.

Organic and chlorinated organic compounds and nutrients are the effluent parameters which today have the greatest impact on the effluent waters. It is estimated that greater demands will be put on the treatment methods in the future with regard to efficient disposal of these parameters. The qualitative differences between various effluents with regard to these parameters are rather big. Especially, the quality of organic matter is an important factor also influencing the choice of treatment method.

Dissolved organic compounds which have a high molecule weight are most effectively separated from water by physical methods, i.e. film filtering processes. As investments these processes are so far comparatively expensive. When the degree of mill shutdowns increase and the effluent water fractions become concentrated, the competitiveness of the film filtering process is likely to increase, as the treatment costs stand almost in direct proportion to the treated amount of liquids. The chemical precipitation or adsorption, for instance the efficiency of LRP in relation to COD is somewhat lower than the physical deposit of the substances in question. The greatest deficiency in these processes is the formation of solid wastes and their secondary treatment. Uses should be found for the production process wastes. The methods based on chemical oxidation are interesting on account of the absence of wastes, but the cost efficiency is not sufficient yet. Biological methods, for examples activated sludge treatment on the other hand efficiently disposes of the most easily decomposable small molecular compounds. A varying amount of organic compounds are also adsorbed in the sludge. It would be possible to achieve higher COD reductions by making the sorption ability more effective in present activated sludge plants.

The formation of chlorinated organic compounds in most purification processes follow COD, since the separation ability is slightly better than COD in the film separating processes and somewhat inferior in the biological processes.

Phosphor emission during biological purification of effluent water is partly dependent on binding agent (solid matter). With efficient disposal of the solid matter, for instance sand filtering, the phosphor load in the watercourses can be reduced even by half. Possible measures for control of emitted phosphor are solvents related to regulating the operations of biological processes, separate treatment of fractions containing big amounts of phosphor or chemical tertiary treatment.

Among solid wastes the sludge of the effluent treatment plants have received the greatest attention in this study. The greatest part of the treatment methods consists of water separation devices which aim at reducing the effluent flows to be treated. The
obtainable end results are primarily determined by the quality of the sludge and its properties and not so much by the type of water separation device. The water separating qualities of sludge usually improve with physical and chemical improvement methods. Biological sludge is considered "difficult" with regard to water separation.

The amount of dry matter in the biological sludge can be somewhat reduced by biological methods, mouldering and decomposition. A more efficient reduction of organic substances can be achieved with wet burning. The costs, however, are very high.

Burning and transportation to landfills are today the most significant way of solid waste disposal. Various recycling methods have been investigated on a large scale, but a common feature of these methods today is their low profitability. Efforts should, however, be made to separate the solid matter of the process suitable for recycling as early as possible in the treatment phase. It should also be remembered that the amount of biological sludge deriving from the process is almost directly comparable with the organic load of the wastewater from the mill.

When evaluating the costs and treatment results of different treatment methods, an approach to the problem has been used in this study which makes it possible to control a big amount of process and emission parameters within a large load area. This control method is therefore comparatively coarse (inexact), since quite a lot of generalisations had to be made. For this reason one has to be rather critical when comparing costs and treatment methods, as local conditions and special properties favour the treatment methods in different ways for different objects. The results presented in this survey have been calculated according to these conditions and in the circumstances described in the examples.

The high integration rate of certain treatment alternatives with the production process has caused difficulties when trying to evaluate the economical benefit. A treatment process that produces energy as raw material also produces direct monetary benefits, provided that the operating costs of the mill can be reduced with these products. Because these processes require a comprehensive control, the possible benefit has not been added to the operating costs.

Production technology development outlook

The study work also included an evaluation of the changes in the production technology of pulp mills in the near future.

With regard to pulp production extensive research and testing activities have been carried out during the last 10 years. As a result of this the formerly stagnant technical situation has been developing rapidly. The "megatrends" of this development are:

- The aim of especially reducing the need for bleaching chemicals in production of sulphate pulp. At the same time one tries to get away from the use of chlorine at first by increasing the use of chlorine dioxide and oxygenous chemicals (oxygen and peroxide). So called semibleached pulp has been produced without chlorine chemicals.
- The need for bleaching chemicals has been reduced with so called continuous
cooking and oxygen delignification, and the result can be expressed in for example the softwood pulp kappa prior to bleaching. In new mills and production lines one has succeeded in reducing it in softwood pulp from the level 30–32 to the level 12–14.

- Energy conservation, signifying that the pulp mill uses process compatible fuels and produces steam and electricity for paper and board production. The reason for this is the taking into use of medium consistence (MC) technology and other partial energy saving solutions. Simultaneously air emissions have also decreased which the burning results of black liquor with dry matter content shows for sulphur dioxide emissions.

- Increased use of lower quality raw material, like sawngoods.

The consequences of this in the cooking process has been a transition to serial cooking (continuous cooking) previously connected to increased odour gas emissions. The situation has, however, improved remarkably in this respect along with the technological development.

In relation to other pulp production methods the development has been less rapid. A fact worth mentioning is the increased experimentation with organic solvents in the cooking process (i.e. MILOX).

The changes related to mechanical pulp production have so far been insignificant. With regard to environmental load increase the greatest impact has been made by the increased use of peroxide in the bleaching process. On the other hand, a reduction of the emissions affects the flow of the waters in an integrated mill from the process by way of the mechanical pulp production.

The increased use of recycled paper can also be included in the big changes. An increased domestic use of this raw material is, however, dependent on imports and there are so far no clear solution models for the organisation of it.

The greatest environmental changes on the part of paper and board production consist of increased production of coating and qualitative changes. Increased use of filling compounds and for instance carbonate will influence wastewater emissions and their treatment.

**Emission objectives and handling techniques in the near future**

Of the present emission objectives the most widely known values are at present those aimed at protecting watercourses and a decision in principle by the council of state regarding a 80% reduction of sulphur emissions. Of the stated reduction objectives regarding wastewater emission, a general objective worth mentioning is that of reducing the BOD load and the CODcr loads in sulphate pulp production, phosphor and the AOX objectives. Sulphur emission reductions into the air concerns both sulphate pulp production and other chemical pulp production methods. This study investigates the possibilities of reducing these emissions to a tenth of the present levels. Considering this, the situation varies according to product group in the light of the available treatment technology. The following can be said for the production of pulp:

- Reduction of BOD emissions from the present level will mainly be possible by making the disposal of solid wastes more effective, for instance by filtering. This
will reduce the BOD emissions by half. On the other hand the production of semibleached and bleached pulp will, however, at least in the beginning increase the emissions of the activated sludge plant before necessary operating and subprocess changes can be initiated.

- With regard to the COD emission loads, the changes in relation to the officially stated value objectives will partially take place due to improved operation of processes and activated sludge plants. Compared to that a further reduction of emissions will require such methods as special handling of bleaching waters and (ultrafiltering and LRP) or anaerobic treatment of wastewaters. The sorption of the activated sludge plant could be made more efficient with certain additional methods. During production of semibleached pulp the COD purification effect of the activated sludge plant increases. Half of the reduction objectives regarding emission levels could be achieved, if all known resources are taken into use.

- Reduction of the phosphor load is possible today through special treatment of fractions containing high levels of phosphor prior to the biological purification. Disposal of the solid matter in biologically treated water also makes the disposal of phosphor more efficient. From the present values of 1.0–2 mg P/l a level of 0.2–0.9 mg P/l can be reached by mastering the phosphor emissions of the process and water treatment.

- As regards the AOX emissions present technology could provide possibilities to achieve at least a level of 0.3–0.5 kg AOX/t pulp for hardwood and 0.5–0.8 kg AOX/t for softwood. The problem disappears with transition to the sole use of oxygenous chemicals. If the AOX values are compared to wastewater parameters which are more closely related to the environmental impact of chlorine compounds, the measures will at least partly deviate from those related to AOX.

- For sulphur emissions into air the latest emission objectives means an emission level of ca 2.5–3 kg SO₂/t. In principle one should be able to achieve significantly lower values, if one takes into use all known sulphur emission reduction methods including the regeneration of effluent oxygen. Calculated from the present level of 5.5–6 kg SO₂/t the reduction should be ca. 80%.

Regarding the mechanical pulp production a continued reduction of BOD, COD and phosphor emissions are made possible mainly by disposing of solid matters from biologically purified wastewater. Increasing the efficiency of the presedimentation of wastewater with chemicals and a possible treatment of enzymes, mainly results in an improvement of COD disposal. On the part of BOD and phosphor the reduction could be 50%. As regards the COD load the reduction possibilities are bigger for certain pulp qualities. What has previously been said about mechanical pulp also applies for recycled pulp and paper and board production.

The study also contains a short survey of the treatment technology for effluents until the end of the decade.

The year 2000 is comparatively close and significant methods in general use have already been implemented or are in the pilot stage. However, big technology changes happen intermittently. New wastewater technology could for example appear relatively soon. New ideas about biological purification have been put forward as follows:

- Increased efficiency in COD purification by using kantajia? in the aerobic treatment process
- The use of special enzymes in the pretreatment process to break up the carbohydrates
Regarding chemical purification the following processes are of interest:
- The use of peroxide in deinking.
- Application of ozone especially in breaking up organic acids and phenol.

On the part of pulp production the previously mentioned moderated regeneration of sulphur chemicals is the most interesting news.

In the sludge treatment process burning seems to be the most likely solution in most cases. Technology improvements for better solutions are presently being developed. As a new burning method one can mention that the burning of biosludge together with black liquor in a recovery boiler is being developed at present.

Data on the above described methods come primarily from laboratory and pilot tests. If something new will be developed from this only becomes clear at a later stage. A clear line of development can, however, be seen in the increased use of the much discussed special treatment of wastewater fractions in most countries. This method improves the end result significantly in most cases.
SYTYKE 20

THE POSSIBILITIES OF CONTROLLING SODIUM AND SULPHUR BALANCE IN A FINNISH KRAFT PULP MILL

Summary

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THE POSSIBILITIES OF CONTROLLING SODIUM AND SULPHUR BALANCE IN A FINNISH KRAFT PULP MILL

Summary

In the production of bleached sulphate pulp it is possible today to go below the given limits of environmental load by means of several technical solutions. The usage of chlorine gas in the bleaching can be abandoned and one can change over to a 100 percentage chlorine dioxide bleaching plant, when the affecting process variables will be correctly optimized.

The development of the bleaching of sulphate pulp is now very rapid. It would seem to be so that also of chlorine dioxide could be abandoned totally. The most promising are the bleaching sequences developped to the chemicals based on oxygen, like molecular oxygen, ozone and peroxide.

The technical development of bleaching will be strived at the reduction of the usage of chemicals based on chlorine and also at the diminishing of the amount of waste water. Already now in new sulphate pulp mills that are being planned the waste water amount from the fiber line will be lower than 5 m³/TS₉₀, when in the functioning Scandinavian mills it is typically of the range 20 m³/TS₉₀.

The technical development of bleaching will reduce the amounts of waste water and thus will make the process a more closed one. In the long run the consumption of chlorine dioxide will get lower that will ease the problems connected with the handling of side products.

On the other hand the technical development of the recovery island, especially the rise of solids content of black liquor, has considerably reduced its gas like sulphuric emissions both sulphuric dioxide and reducible sulphuric compounds. The partial emissions of the recovery island have been made small by using electrostatic precipitators and alkaline scrubbers.

The above described technical development of fiber line and chemicals' recovery is very significant from the point of view of the chemical balance, especially of sodium and sulphur balances. When the air and water emissions are reduced, both sodium and sulphur tend to gather in excess to the chemical balance, if the processes are not opened e.g. by abolishing fly ash.

Of the Finnish kraft pulp mills five use oxygen delignification and two have made a decision to instal it. The usage of chlorine gas is continuously deminished, but the consumption of chlorine dioxide is for the moment growing. Chlorine dioxide is still produced in most of the mills by Mathieson–method, the side product of which is, as well known, difficult to set back to the process. The reduction of the usage of chlorine gas means the diminishing of the production of chlorine–alkaline factories and the loss of economical alkaline coming from this source.
When new mills are built and the old ones are modernized also the control of sodium and sulphur balances and both the consumption and supply of alkaline have to be resolved.

The production process of chlorine dioxide affects mostly sodium and sulphur balances because of its side product, and the production of tall oil due to the sulphate brine produced through this process.

In this report has been studied various alternatives in order to solve the control of the sodium and sulphur balances in a Finnish kraft pulp mill producing bleached sulphate pulp.

As the ways of controlling the balances has been studied the change of chlorine dioxide process, the separation of the sulphur and sodium from fly ash by means of an electrohydrolysis, the recovery of sulphur from flue gases, the carbonization of green liquor, the handling of soap, the use of chlorine–alkaline factories, the separate causticizing, the use of oxidized white liquor and the absence of chlorine dioxide.

By changing the production process of chlorine dioxide the amounts of side products from the process can be reduced and thus amend the sodium and sulphur balances. However, only the production processes of chlorine dioxide that are under development work like R9, will bring a considerable amelioration to the balance problems, because as side products from these will be created products like sodium hydroxide that are substitutes of purchase chemicals. The production processes of chlorine dioxide that are integrated to chlorate electrolysis are progressive solutions in case there will be usage for gas chlorine, but as large investments they will be actual only when a new mill is being built.

Fly ash from a soda recovery boiler is formed very much, about 80 kg/TS, and in theory its separation, e.g. to sodium hydroxide and sulphur acid, would be enough for the control of sodium and sulphur balances. The electro–hydrolysis of fly ash which is studied in this report is, however, not yet a ready commercial solution. As a problem in this method is among other things a mild 10 %-sulphuric acid which is generated in this process and which appears to be not very useful. There would also be large usage costs from the change of bipolar membranes. Since there will be such a large amount of fly ash and it is easy to abolish the recovery island, it offers a potential continued target of study in order to control sodium and sulphur balance.

The recovery of sulphur from gases that release as sulphuric compounds for instance from evaporation, from cooking and the heat treatment of black liquor, offers an interesting solution for the control of sulphur balance. In this report has been studied the recovery by means of an absorption and a vaporization to sulphuric dioxide and by wet catalysis method to sulphuric acid. Both of the methods are applied after the gases have first been burnt to sulphuric dioxide. There will be found several natural goals of usage both for sulphuric dioxide and sulphuric acid in a kraft pulp mill where they substitute purchase chemicals. The recovery of sulphur from flue gases may in some cases be even economically profitable.

As one object of a continued study might be to scrutinize the soap acidulation by sulphuric dioxide.
The carbonization of green liquor e.g. by Stora— or Tampella—method is as a totality a large investment, because to this has to be attached a separate causticizing and a plant for producing sulphuric dioxide. Both of the methods are considered as complicated and space demanding solutions and thus they have not been generalized.

The soap acidulation by sulphuric acid or by a side product from the production of chlorine dioxide would be a bad solution when regarding sodium and sulphur balance. Further the handling of sulphate brine generated may cause additional problems e.g. in an evaporation plant. When regarding the chemical balance it would be wisest to burn the soap, either inside the process or in a separate burning system, and to recover the quite large amount of energy. Especially in a new mill this solution would be profitable to consider.

The usage of current chlorine alkaline factories bychanging them into e.g. electrohydrolysis factories handling fly ash or the side product from producing chlorine dioxide may first seem to be tempting as a solution of one country as a whole, because the transportation and a part of the electricity systems already exist. The mildness of the chemicals generated makes, however, this solution economically unprofitable.

A separate causticizing, departing from purchased sodium carbonate, would be economically profitable only if the price of sodium hydroxide will rise around 2000 FIM/t NaOH. As a problem in this solution is further the cleaness of the sodium hydroxide generated and considerable carbon dioxide emissions.

Oxidated white liquor is widely used in the connection of oxygen delignification. When the sulphate process is closed for the part of actual bleaching, it might be wise to study the usage of oxidated white liquor also there. As for the quality of the pulp and the consumption of bleaching chemicals the oxidation would evidently be good to extend until generating sulphate.

In bleaching concepts having no chlorine dioxide, alkaline is needed, in some of them even more than in traditional methods, as well as sulphuric acid or sulphuric dioxide as an inhibitor. If these chemicals cannot be regenerated from somewhere else in the kraft process e.g. by means of the above mentioned methods, they will be an excess in the sodium and sulphur balance. Therefore the absence of chlorine dioxide is not solely a solution to the chemical balance problems.

On the basis of this study it would seem to be so that the sulphur excess of the mills can be abolished from the balances and thus correct the sulphur balance by means of known methods and with quite reasonable investments. The economically wisest solutions seem to be those, where sulphur is recovered from the gaseous sulphuric compounds of the kraft pulp mill e.g. as sulphuric dioxide. Instead there will remain as a problem further the sodium excess in the balance, to which not even this study brought any natural solution excluding the electro— hydrolysis of fly ash.

The sodium and sulphur balance problems of various mills and their solutions can considerably deviate from one another and one cannot give any general solution.

When the mills are continuously isolated from their environment by diminishing the waste streams coming from them, the elements coming to the recovery island and their mutual relations, e.g. because of corrosion problems, will become more significant than earlier. The handling of different waste streams separately from the main
process so that energy and pure mineral compounds are generated in order to be recovered and the wastes will be separated, is one direction to a development.

The isolation of mills from their environment will make them more independent when considering their chemical maintenance. The necessary chemicals will be produced more and more in a kraft pulp mill itself.
SYTYKE 21
ORGANOSOLVPULPING

Summary

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SYTYKE 21
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ORGANOSOLVPULPING

Summary

Introduction

Fractionating wood with organic acids or solvents (organosolv-methods) has been studied since the beginning of this century, but only during the last decade the pulpresearchers have taken an active role in the studies. For this reason not until lately the pulp properties have been taken into consideration, earlier the importance of two byproducts; ie. lignin and sugar, have been preferred. Even today many scientists do not perceive that papertechnical properties of pulp have a great importance when they compare different organosolv methods.

The SYTYKE-program ordered from Rintekno Oy November 24, 1991 a project called SYTYKE 21 "Organosolv cooking". The goal for the project is to prepare a technical and economical study of the different organosolv processes. The limiting factor was set so, that the pulp from these processes must have good pulp characteristics. It was also assumed that in the future, if not yet possible, both soft- and hardwood can be cooked with these processes, and processes using chlorine and sulphur were excluded from this paper. For economical calculations the capacity of these mills was decided to 100,000 t/a and the time limit was set to the year 2010.

Selecting processes

Using literature and archives such organosolv-processes were looked for, which have pulp as a main product and have been mentioned in the literature during the last five years. This way 14 different methods were found. Using special criteria six processes were chosen and these have realistic development possibilities and they represent different methods.

Cooking with alcohols:

1  Methods with natural pH
   *  Alcell      Canadian method using ethanol, pilot mill producing 35 tp/d
   *  n-butanol   only in laboratory

2  Methods with pH-buffer
   *  NAEM        Canadian method, only in laboratory.
                 Uses methanol, adding alkali earth salts

3  Alkaline methods
   *  Organocell  German method using metanol. A mill for 150,000 tp/a is being built in Kelheim, Germany.

Cooking with acids:

4  Organic acids
* cook with acetic acid A pilot plant is being designed in Germany

* Milox method using hydrogen peroxide and formic acid (peroxide acid), developed by the Finnish Pulp and Paper Research Institute (KCL) and a pilot plant built by Kemira in Oulu.

5 Adding inorganic acids (HCl)
- no method was chosen for this category

Technical comparison

The following deductions can be drawn from the cooking conditions and pulp properties in the above mentioned categories:

1 Alcohol cooking

There is no significant difference between methanol and ethanol. The cooking temperature is about 200 - 210°C and alcohol-water ratio is 70:30. The pressure sets to 28 - 32 bar and the pH for hardwood is 3.8 - 4, which is a result from the acids liberated from the wood. The alcohol recovery is rather uncomplicated. These processes work only for hardwood, because the pH for softwood cooking drops under the point, where the lignin starts to condensate. The pulp cooked like this has similar properties than the sulphate pulp.

Butanol-cooking was left out of this paper later in the study because n-butanol has a boiling point higher than water, which makes the recovery difficult, and is also even more poisonous than methanol. There is no knowledge of the pulp properties.

2 Methods with pH-buffer

With soda cooking (20 % NaOH calculated from wood) using alcohol : water ratio = 50% : 50% it is possible to get a soft- and hardwood pulp having as good properties as the sulphate pulp has. The cooking temperature is about 160°C and the recovery process for alcohol is rather uncomplicated. The high amount of sodium hydroxide in the process needs a recastizicizing process in recovery.

3 Alkaline methods

Methanol-cooking, alcohol:water ratio :: 50% : 50 % and adding 0.05 % alkali earth salt (NAEM), has a boiling point of 200 °C. Pulp can be produced from softwood as well as from hardwood. The process may be called as a modern version of Alcell but, unfortunately, it has been tested only in laboratories. One disadvantage of the process is that about 15 kg of alkali earth salt per ton pulp gets in to the system.

4 Organic acids

Acetic acid makes it possible to cook both soft- and hardwood pulp at 180° C. The optimal concentration in cooking with acetic acid is about 87 %, which makes it possible to prevent carbon hydrates to be extracted from wood and spoil the pulp properties. The recovery process is also difficult and the chips must be dried before cooking. The pulp properties are similar to those with sulphite pulp, but they have a low tearing strength.

Milox is a three stage peroxide/formic acid cooking at temperature 80 - 100° C. In the acid cookings the formic acid must have a concentration of at least 85 %. Because of the corrosion problem, most of the equipment must have a zirconium-coating inside.
The recovery distillation is difficult because the boiling points of formic acid and water are close to each other. The pulp properties are similar to sulphite pulp, but the tearing strength is 10 - 20% lower.

5 Adding inorganic acids (HCl)

It has been proved that when adding hydrochloric acid to the cook (for example phenol-cooks or organic acid-cooks like Acetosolv) it decreases the cooking temperature to about 100°C, but at the same time chlorine gets in to the system. At the very best the pulp properties are equivalent to poor sulphite pulp and the fibre is fragile and breaks easily. In this study no methods were chosen from this category.

There is no good documentation of bleaching the organosolv pulps. The alkaline pulps are bleached mainly as sulphate pulps, but a little lighter. The acidic pulps are bleached as the sulphite pulps. The Milox-pulp is a special case, because it is bleached by peroxide in 4 - 5 stages.

The technical level of these methods is usually poor. The Organocell method makes a distinctive difference since the production is starting in the near future. According to estimations the Alcell is a rather well developed process, but the information published is quite simplified and gives easily a distorted picture of the process level.

Economic calculations

The ethanol process with non-chlorine bleaching was chosen as a reference process, the material and energy balances were simulated, and the investment costs were calculated. This simulated process was based on realistic unit operations as much as possible. From this base the six chosen processes were evaluated and the price of the products were calculated.

It must be taken into consideration that the by-products cannot be given any market price, because there is no buyer of lignin or wood sugars. The quantities of formic or acetic acid produced in cooking are too low to be recovered economically and to be sold on the world market. In this study it has been chosen to burn all by-products to obtain energy for the system.

A common fact for all the non-alkaline ethanol processes is that the investment costs are lower than with the sulphate process. This is due to the uncomplicated regeneration of cooking liquid and the chemical recovery systems. As the investment and labour costs are lower than the ones for the sulphate process, a mill of 100,000 - 150,000 t/a capacity could be economically feasible.

The costs of an acetic acid method are considered to be similar, but the demand on the high acid concentration in cooking can rise the investment costs.

The level of the investment costs of an alkaline Organocell method is the same as in the sulphate process. This is because two separate recovery systems are needed, one for alcohol and one for sodium hydroxide. The latter chemical needs a whole recausticising process including a soda recovery boiler.

For Milox, which uses the peroxyformic acid, it is difficult to estimate any investment costs at this time. There are three factors, which will rise the costs, zirconium or glass coatings in process equipment, high concentration in cooking liquid and difficult conditions in the formic acid recovery distillation.

The operating costs differ between the different organosolv-methods because of the variations in pulp yield, need of energy and use of bleaching chemicals. The costs vary around the costs of the sulphate process.
Future development

The future problems of the pulp industry are reason for the fast development of organosolv processes. In most countries all around the world the infrastructure and financing of the pulp industry do not have enough strength for big modern sulphate mills. This affects most the European industry. In the future the extensive use of recycled fibre sets demands for a high quality of papertechnical properties for virgin stock. The environmental consciousness of people in the market areas will more and more have effect on the pulp manufacturing processes.

There are many reasons why the alcohol processes will lead the development work at least at this stage. The whole concept of alcohol cook gives wide possibilities to optimize, because in an alcohol cook the pH can be varied in a more diversified way than in acidic cooking. Along with the pH the optimal cooking temperature and the alcohol concentration can also vary. So there will be many process technical possibilities to optimise pulp properties in alcohol cooking.

When alcohol cooks, or generally organosolv cooks, seize a larger part of the pulp production, it also effects the chemical market. The chlorine chemicals will disappear in spite of organosolv and the use of sulphur will diminish, which will lead to long term storing of elemental sulphur. Also the use of sodium hydroxide will probably be less than today.

From the environmental point of view the organosoly processes will decrease unorganic emissions to the sewers. The noncondensable gas emissions will disappear almost totally. The total amount of emissions will decrease significantly, but on the other hand the emissions from the sulphate mills will also decrease. It is worth mentioning that ethanol is not considered as a poison.

Presumably during this decade a few softwood and hardwood pulp mills using alcohol as a solvent will be designed in Europe. In August 1992 an alkaline metanol process has started in Kelheim, Germany. This will put some pressure on the competition, a trend, which is noticeable even now.

In Canada, Repap will carry through their Alcell process as soon as this period of depression is over. They have also tried to market their process abroad, recently in Lithuania.

In Finland as well as in the Scandinavia the ethanol process will be realized probably near the turn of this century. Most probably the first production line will be a side line to an existing sulphate mill or a small separate unit producing "environmentally safe pulp". The ethanol's biological background, a good workspace hygiene, a high level of technology in Finland, and domestic raw materials makes it a considerable candidate for cooking solvent.

Finally, it is worth mentioning that non-wood plants may be used as raw material in alcohol cooking. In this case the ethanol process is much more suitable than the more commonly used soda cooking.
SYTYKE 22

SCENARIO ANALYSIS OF THE DEVELOPMENT OF FINNISH PULP INDUSTRY UP TO THE YEAR 2010

Summary

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SCENARIO ANALYSIS OF THE DEVELOPMENT OF FINNISH PULP INDUSTRY UP TO THE YEAR 2010

Summary

Background and aims

The Finnish Pulp and Paper Research Institute (KCL) has studied different scenarios depicting the development of the Finnish pulp and paper industry, and their effects on discharges up to the year 2010. The study encompassed both chemical and mechanical pulping as well as the use of recycled fibre. The study did not cover papermaking, because its environmental impact is small compared with that of pulp production, nor did it address the effect of the closure of paper mill circulations because of the lack of sufficiently accurate data, and also because this subject is dealt with in other SYTYKE projects.

The purpose of the project was to identify options for the technological development of the Finnish pulp industry with particular reference to ways of reducing discharges from pulp and paper mills. The aim of the scenario analysis was to show to what extent the discharges from pulp and paper production could be reduced if the scenarios were implemented, the effects on the consumption of wood, chemicals and different forms of energy, and to make an estimate of the cost of the related investment in environmental protection. For this purpose, forecasts were made for the output of paper and pulp, and four scenarios were produced depicting the technological development of pulp production. These scenarios were based on different situations with respect to market demand for "environmentally friendly" pulp and paper on the one hand, and on the industry's profitability on the other. It was assumed that the latter will be determined by the rate at which new technology is introduced.

This report summarizes the results of the project. The assumptions on which the scenario analysis is based are presented in Section 2 (technical options) and Section 3 (production volumes). Section 4 presents specific discharges for the different process options calculated per product, and Section 5 discusses what the effects of four different scenarios would be at the national level. The prospects for the economic development of the Finnish pulp and paper industry are dealt with in Section 6. Finally, we present the conclusions drawn from the scenario analysis about the different options for the future development of pulp production.

Production processes and effluent treatment

Pulp production

Chemical pulp

In Finland, almost all chemical pulp is produced by the kraft process, and it is assumed in this study that this situation will not change by the year 2010. The advantages of the kraft process are its suitability for a wide range of wood raw
materials, the excellent quality of the pulp, and the economical use of chemicals and energy. One disadvantage is that chemical pulp is difficult to bleach. Bleaching has demanded the use of chlorine chemicals, which has given rise to chlorine compounds in the waste waters.

Two methods which, in principle, complement each other are available for reducing discharges from kraft pulping to below their present levels: maximizing lignin removal (delignification) in combination with efficient washing prior to open-circulation bleaching, and closure of the water circulations, which is facilitated by the use of smaller amounts of chlorine-containing bleaching chemicals.

Delignification can be stepped up by modifying the cooking process (Super Batch or Modified Continuous Cooking, MCC), which is increasingly being followed by oxygen delignification. However, pulp delignification is limited by pulp quality, strength and yield requirements. After cooking, a residual lignin content (Kappa number) of 15–20 can be obtained for softwood and of 14–16 for hardwood. Effective oxygen delignification reduces the Kappa number by some 40–50%.

Kraft pulp is conventionally bleached using elemental chlorine (chlorine gas) and chlorine dioxide. The use of chlorine gas has decreased sharply in recent years, and in 1991 averaged only 19 kg per tonne of pulp produced. This can be attributed to the lower residual lignin content of the pulp and to advances in bleaching technology. Chlorine gas has largely been replaced by chlorine dioxide, the average substitution rates at the end of 1991 being almost 50% for softwood pulp and over 80% for hardwood pulp.

Kraft pulp can be bleached without chlorine gas (CGF, chlorine gas free) using chlorine dioxide, at present to a brightness of 88–90% ISO. This often raises the problem of sufficient chlorine dioxide production capacity, although this is naturally eased by extending delignification and making bleaching easier by pretreating the pulp with oxygen chemicals or enzymes.

Bleaching kraft pulp without any chlorine chemicals (TCF, totally chlorine-free) is possible to 75–80% ISO brightness for softwood and to 85% ISO for hardwood. To achieve this, delignification must be extended as far as possible and peroxide must be used for bleaching. Heavy metals present in the pulp cause peroxide to decompose, and to prevent this, complexing agents must be added prior to bleaching. Ozone bleaching is at the pilot plant stage and is expected to improve the brightness of TCF pulps.

Mechanical pulp

Mechanical pulps fall into the following categories: groundwood (GW), pressurized groundwood (PGW), thermomechanical pulp (TMP) and chemithermomechanical pulp (CTMP). The processes by which these pulps are produced differ in terms of raw material requirement and energy consumption. The pulps differ considerably in their properties. The choice of process depends on these factors and on the demands placed on the end product. Chemithermomechanical pulp (CTMP) is produced at only one mill in Finland, and as there are no plans for any significant increase in capacity, it is not dealt with further.

In comparison with chemical pulps, mechanical pulps have the advantages of high
yield and low production costs, and they also give the paper good printing characteristics. After biological treatment, the effluent loads from mechanical pulping are smaller than those from chemical pulping, but are nevertheless considerable, especially when peroxide bleaching is used.

The biggest drawback of mechanical pulping is its high demand for electrical energy. Although mechanical pulping requires a smaller capital investment than chemical pulping, the capital investment it demands in energy generation has to be taken into account in any investment cost comparison of pulping processes. For both PGW and TMP, electricity consumption can be reduced by further developing the pulping technology. A potential saving of 15–20% is thought to be possible by the year 2010. Mechanical pulp quality must be taken into account in any evaluation of energy consumption. The importance of mechanical pulp quality is underscored by the fact that Finland produces and exports large quantities of mechanical papers such as SC (supercalendered uncoated) and LWC (lightweight coated).

Production of recycled fibre pulp

In Finland, almost 50% of all used paper suitable for recycling is collected. In 1990, about 450,000 tonnes of collected waste paper (about 5% of total paper production) was used to make new paper. The reason for this low percentage is that about 90% of all paper produced in Finland is exported. To increase the proportion of recycled fibre used, Finland would have to import waste paper.

Replacing some mechanical pulp with recycled fibre obtained by deinking waste paper cuts the cost of producing mechanical paper grades, provided the waste paper source is close by. The saving stems from the smaller consumption of wood and electricity. On the other hand, deinking waste paper causes some environmental problems at the mill. For one thing, the large volume of sludge resulting from the 15–35% deinking losses greatly increases the amount of solid waste. Also, the need to purchase more fuel may lead to greater emissions into the air.

Discharges to receiving waters

Decreasing effluent volumes

A pulp or paper mill with a closed water circulations is the ultimate solution to the problem of mill effluent loadings. As far as pulp mills are concerned, decreasing the use of chlorine chemicals can be considered one step towards a closed water circulation. A technique is being developed to allow chlorine-containing filtrates to be concentrated by evaporation, but not even an end to the use of chlorine chemicals would immediately allow filtrates to be taken via evaporation for burning. Filtrate volumes must first be sufficiently reduced and non-process substances must be prevented from building up in the chemicals circulation. A way also has to be found to return recoverable alkali to the bleaching process in the case of totally chlorine-free bleaching. It seems clear that by the year 2010, effluent volumes will have been reduced through partial circulation closure. At a chemical pulp mill, the first fraction to be recovered will be the alkaline filtrate from bleaching; this does not cause precipitation problems and contains a high proportion of the pulp mill's organic effluent loading. This means that the remaining effluent, which would be more acidic than at present, would continue to remove from the process inorganic substances such as heavy metals and nutrients.
External treatment

Pulp and paper mill effluents are generally treated biologically; paper mill effluent may also be treated chemically. The biological treatment in widest use today is the activated sludge process; very few mills use aerated stabilization basins, which involve less capital investment but is less effective.

Management of biological treatment processes is an area that is being further developed, allowing treatment results to be improved. One key aspect of this is management of solids without a tertiary treatment, as this particularly affects the removal of nutrients. Based on the process modifications assumed in this study, the loading to existing treatment plants can be expected to fall, thus improving the overall effectiveness of treatment. For this reason, additional treatment stages are not expected to be needed for external treatment plants.

Emissions into the air

At an integrated mill, emissions from chemical pulp production and power generation are dealt with separately. At kraft pulp mills, recovery boilers use fossil fuels only as auxiliary fuels. The airborne emissions from chemical pulp mills consist largely of sulphur and nitrogen oxides, unpleasant smelling reduced sulphur compounds, and sodium and calcium salts in the form of solid particles. Power is generated by burning wood waste but also fossil fuels, which means that the flue gases contain sulphur and nitrogen oxides, but not reduced sulphur compounds.

The main source of SO2 emissions at chemical pulp mills is the recovery boiler. Process improvements such as evaporation of black liquor to around 80% dry solids and the rapid switch over to computer—controlled combustion are two factors that have cut SO2 emissions from modern recovery boilers.

In the case of power boilers, SO2 is only released if oil or coal is burned. Burning wood waste, peat and natural gas does not produce significant amounts of SO2. In fluidized bed boilers, SO2 can be retained in the ash by absorption with lime.

Modern odour elimination involves collecting the malodorous gases, both concentrated and dilute, where they arise. The gases are then burned either in the recovery boiler or lime kiln, or in a boiler designed for this purpose and equipped with systems for heat recovery and SO2 removal.

Nitrogen oxide (NOx) emissions from pulp mills are low. For example, the NOx emission from a recovery boiler is only about a tenth of that from a corresponding coal—fired boiler. NOx emissions can be restricted either by minimizing NOx formation by modifying the combustion conditions, or else by removing them from the flue gases. NOx emissions from pulp and paper mill power boilers can be reduced by feeding ammonia into the boiler.

When discussing carbon dioxide emissions from the forest industry, it should be remembered that forests remove more carbon dioxide from the air when wood processing and forest management are carried out efficiently. The only way to reduce carbon dioxide emissions from fossil fuels is to reduce their usage.
Pulp and paper markets

World market prospects

According to present estimates, global paper demand and consumption are expected to develop favourably. Demand is likely to continue to grow at around 2.5% a year for the next 20 years. The growth in demand for printing papers is forecast to remain at 3-4% a year. Total production of paper and paperboard is anticipated to grow from 240 million t/a in 1990 to 345 million t/a by the year 2005. Demand for paper and paperboard is concentrated in North America and Western Europe, where demand will continue to grow fairly rapidly. Western Europe will remain Finland’s main market.

The proportion of recycled fibre used by the paper industry in production increased steadily up to the end of the 1980s in the countries of Western Europe and the Far East. However, environmental pressures such as the shortage of landfill sites have resulted in a call for greater recycled fibre utilization in continental Europe, but especially in North America. As a result, the use of mechanical pulp will grow more slowly than paper consumption.

Production forecasts for Finnish pulp and paper

The fairly optimistic forecast for the global paper market forms the basis for forecasting paper production in Finland. The study includes one scenario that takes into account the present market over—capacity, manufacturers’ poor profitability and the difficulty of financing investments, factors that could slow down the growth in capacity in the next few years. Some of the capital investment by the Finnish paper industry is expected to be in existing and possibly also new mills outside Finland. The Finnish paper industry will focus increasingly on high—quality paper and paperboard grades, while production of speciality papers will grow. This production forecast, too, presupposes sizable investments, and the prospects for financing these are dealt with in Section 6.

Production forecasts for the main paper grades are given in Figure 1. The main features of these forecasts are as follows:

- Newsprint production will gradually be reduced, and there will be a shift to coated magazine papers (LWC, MWC – medium weight coated).
- In addition to this, production of both coated (LWC, MWC) and uncoated (SC) mechanical papers will increase.
- Production of both coated and uncoated fine papers will increase significantly.
- Production of paperboard, especially solid bleached kraft board, will rise considerably.
- For other paper and paperboard grades, the changes will be of less significance in terms of total production.

The growth in total production forecast for 1990–2010 is around 31%, which means smaller market shares for several paper and paperboard grades. The growth in production of printing and writing papers would be about 70%.
The forecast for pulp production is based largely on the above forecasts for paper production. The forecasts are presented in Figure 2. The main features this time are:

- Production of mechanical pulp will not grow significantly in Finland. The increase in production of LWC and SC paper will compensate for the fall in newsprint production and for the smaller amount of mechanical pulp needed as more recycled fibre pulp is used. The demands placed on the quality of mechanical pulp will change.

- Production of bleached softwood kraft pulp will increase as the production of coated mechanical papers, fine paper and paperboards grows. Finland is expected to remain a producer of bleached softwood kraft market pulp. Output of softwood pulp will have to be raised by the equivalent of 2–3 pulp mills during the period under discussion.

- Demand for bleached hardwood kraft pulp will rise sharply as fine paper production grows. The rise forecast for the period up to the year 2010 is about 30,000 t/a. Output of hardwood market pulp will fall. The shortage of raw material and the growing availability of eucalyptus pulp will restrict the growth of hardwood pulp production in Finland.

- If Finland starts importing waste paper for market or economic reasons, pulp production, especially mechanical pulp production, will fall correspondingly.

- A large-scale switch over to totally chlorine-free bleaching (TCF pulps) would reduce slightly the need for hardwood pulps but cause a small increase in the need for softwood pulps.
Figure 1. Paper production forecasts in Finland used as a basis for the scenarios.
Figure 2. Trends in fibre requirement for paper and paperboard production in the extreme scenarios A and D.
Review of individual products

Starting-points

In pulp production, the only process modifications that will significantly affect effluent discharges concern kraft pulping. Closure of the water circulations at paper mills, with which mechanical pulping is always integrated, would also have some effect; however, as this is not included in the scope of this study, the results reflect only the effects of process modifications in chemical pulp production. In mechanical pulping, a small decrease in specific refining energy consumption can be expected, which in turn may be marginally reflected in emissions from energy generation but will be almost completely masked by decisions affecting basic energy production. The use of collected waste paper as a source of fibre affects discharges to both receiving waters and air as well as the volume of solid waste. Depending on the paper grade in question and on the quality of the waste paper, recycled fibre can be used in place of both chemical and mechanical pulps, and this will also affect the quantity of fuel that has to be purchased as the proportion of wood-based fuel falls.

To assess the changes due to process modifications and to the increasing use of waste paper, a computer program was used to calculate specific consumption and discharge figures for kraft pulp and for different paper and paperboard grades in certain important but hypothetical process and fibre composition situations. All effluent discharges are examined after treatment using the activated sludge method. This is because almost all pulp and paper mills will eventually have an activated sludge treatment plant. As can be seen from the values given in Table 1 for BOD (biological oxygen demand), discharges of readily biodegradable organic matter will be very low in all the cases studied, and the differences between products in this respect will be negligible.

The calculations were based on the same starting values as used later to calculate the discharges and chemical and energy consumption figures for the Finnish forest industry. The specific figures obtained thus reflect the average annual ones and also help to show what the scenario results were derived from.

Kraft pulp production

The effects on discharges and consumption figures of the following modifications were examined for both softwood and hardwood pulping:
- a substantial reduction in the residual lignin content of the pulp by means of cooking modifications and the use of oxygen delignification
- chlorine-free bleaching using peroxide and ozone
- elimination of bleaching waste waters using internal measures or removal of just the alkaline filtrate
- the effect on emissions of reducing the water content of black liquor burned in the recovery boiler and of treating the flue gases.

Discharges to receiving waters

Extending the delignification of softwood pulp to Kappa number 18 reduces mill discharges of dissolved organic matter measured as chemical oxygen demand (COD) to about 30 kg/tp (kg per tonne of pulp); for a Kappa number of 30, the figure is 45 kg/tp or higher, depending on the general condition of the mill. Changing over to totally chlorine-free bleaching does not greatly affect the discharge of dissolved
organic matter because the reduction in discharge that could be expected from the very low lignin content that would be necessary is masked by the greater amount of dissolved matter arising from the poorer yield from totally chlorine-free bleaching. An AOX value (a measure of organic chlorine) of 0.6 kg/tp is achieved when bleaching is performed without elemental chlorine; in the case of TCF pulps, no organic chlorine compounds are formed. The phosphorus discharge is 40–50 g/tp if phosphorus-containing lime is not used to neutralize the waste waters. The complexing agents needed in totally chlorine-free bleaching apparently do not decompose during activated sludge treatment and can roughly double the nitrogen discharge.

Table 1. Specific discharges from pulp and paper production

<table>
<thead>
<tr>
<th>Product</th>
<th>Waste water</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COD</td>
<td>BOD</td>
</tr>
<tr>
<td></td>
<td>kg/tp</td>
<td>g/tp</td>
</tr>
<tr>
<td>Softwood pulp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CGF18</td>
<td>31</td>
<td>1.3</td>
</tr>
<tr>
<td>TCF11</td>
<td>33</td>
<td>1.9</td>
</tr>
<tr>
<td>CGF18, 2010</td>
<td>26</td>
<td>0.9</td>
</tr>
<tr>
<td>CGF18, closed, 2010</td>
<td>4</td>
<td>0.2</td>
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<tr>
<td>Hardwood pulp</td>
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<td>CGF14</td>
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</tr>
<tr>
<td>TCF12</td>
<td>34</td>
<td>2.0</td>
</tr>
<tr>
<td>CGF14, 2010</td>
<td>24</td>
<td>1.0</td>
</tr>
<tr>
<td>CGF14, closed, 2010</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>Mechanical pulp</td>
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<td></td>
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<tr>
<td>TMP, unbl</td>
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<td>1.3</td>
</tr>
<tr>
<td>TMP, bl</td>
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<td>2.1</td>
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</tr>
<tr>
<td>TMP, bl, 2010</td>
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<td>1.4</td>
</tr>
<tr>
<td>Newsprint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMP</td>
<td>15</td>
<td>1.4</td>
</tr>
<tr>
<td>TMP+recycled fibre</td>
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<td>0.9</td>
</tr>
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<td>TMP+recycled fibre, 2010</td>
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<td>0.6</td>
</tr>
<tr>
<td>Uncoated mechanical printing paper</td>
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<td></td>
</tr>
<tr>
<td>TMP+CFG18</td>
<td>13</td>
<td>1.0</td>
</tr>
<tr>
<td>GW+CFG18</td>
<td>12</td>
<td>0.8</td>
</tr>
<tr>
<td>TMP+TCF11</td>
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<tr>
<td>TMP+CFG+recycled fibre</td>
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<td>0.8</td>
</tr>
<tr>
<td>TMP+CFG18, 2010</td>
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<tr>
<td>Uncoated fine paper</td>
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<td></td>
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<tr>
<td>CGF18+CGF14</td>
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<td>1.4</td>
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<tr>
<td>TCF11+TCF12</td>
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<td>CGF, 2010</td>
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<td>TCF, closed, 2010</td>
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</table>
The specific discharges for hardwood pulping are very similar to those for softwood pulping.

It has been assumed that management of activated sludge treatment will improve with time, and that in the year 2005 the average results will be slightly better than at present for removal of both readily biodegradable (BOD) and total dissolved organic matter (COD). Improved management will mean major reductions in the nitrogen and phosphorus levels of the treated effluent and in the amounts of biomass removed as solids, both of which will lead to lower nutrient discharges in the years 2005 and 2010.

If the obstacles to closure of bleaching plant water circulations (reducing the volume of water, preventing the build-up of foreign substances, finding a way to return recovered alkali, and treating chlorine-containing effluents from bleaching with chlorine chemicals) are removed and the circulations are closed, the pulp mill's waste waters will consist of debarking waste waters and miscellaneous minor discharges (MMD). In the near future it may also be possible to close debarking plant water circulations, but this is not dealt with here. It has been assumed that, after the year 2005, pulp mills with closed circulation bleaching plants will correspond to today's best mills in terms of general condition and MMD, bringing total discharges down to
a very low level. However, because closed circulation processes are more difficult to control, MMD could be much higher than this, Fig. 3. If only the alkaline filtrate from bleaching is recovered, the pulp mill’s discharges of dissolved matter can be cut by about a third. As most of the AOX formed during bleaching with chlorine chemicals is in the acid filtrate, recovery of just the alkaline filtrate from bleaching will reduce the AOX discharge only by about a quarter.

Emissions to the air

The carbon dioxide produced by burning black liquor and wood waste reaches about 3 t/tp for softwood pulping and about 2.5 t/tp for hardwood pulping. The amount increases as pulp yield falls with extended cooking, in which case more excess energy is produced at the pulp mill. When pulp mills begin burning black liquor of about 75% dry solids, SO2 emissions will be 1–1.5 kg/tp. If the mill also has a flue gas scrubber in operation, SO2 emissions will fall to 0.5 kg/tp or below. These figures do not include sulphur dioxide escaping during the burning of malodorous gases.

The NOx emissions from a pulp mill are around 2 kg NO2/tp, but vary with the amount of wood-based fuel burned. The combustion technique used in the recovery boiler can be further developed to give a small decrease in NOx emissions, whereas raising the black liquor dry solids causes it to increase to such an extent that the 10–15% reduction in specific emission that would be possible has been omitted from the scenario. Equipping the recovery boiler to reduce NOx emissions is not worthwhile. By using electrostatic precipitators the particulate emissions from the recovery boiler and bark-fired boiler can be reduced to 2–2.5 kg/t of softwood pulp and 1.5 kg/t of hardwood pulp. If the recovery boiler also has a flue gas scrubber, as many mills are expected to have in the future, particulate emissions will be halved.

Use of raw materials

The introduction into chemical pulping of methods that cause a drop in yield result in higher consumption of wood per tonne of pulp. For example, bleaching without chlorine chemicals requires the pulp to be cooked to a low lignin content before bleaching, which in turn causes a 5–8% increase in wood consumption. The energy generated at the mill then increases accordingly.

Replacing chlorine chemicals with hydrogen peroxide and ozone raises the alkali requirement per tonne of pulp. It has been assumed that this will happen also when the bleaching plant circulation is closed, as no method is currently available for purifying the recovered alkali sufficiently for peroxide bleaching. If the bleaching circulation based on chlorine chemicals were closed, it is assumed that the recoverable alkali could then be recycled.

Mechanical pulp production

No technical modifications are in prospect that would affect the specific discharges of effluent from mechanical pulping. As peroxide bleaching increases the specific discharges from mechanical pulping, the most important factor in the future will be the extent to which peroxide bleaching has to be used in response to changes in paper quality requirements and production structure. Although specific energy consumption in mechanical pulping is expected to fall 10% by the year 2005, calculated at a given pulp quality level, the average energy consumption will rise because of the trend towards higher quality paper grades. On the other hand, this trend will cause electricity consumption per tonne of paper to fall, as these papers contain less mechanical pulp.
As mechanical pulp production is always integrated with paper production, the effects of using mechanical pulp and recycled fibre on discharges to water and air are dealt with in more detail under papermaking.

Use of recycled fibre

The deinking of collected waste paper into usable recycled fibre results in smaller specific discharges (as measured by the traditional parameters) to both water and air than mechanical or chemical pulping, but produces much larger volumes of solid waste in the form of deinking sludge. However, the use of recycled fibre to replace some of the chemical and mechanical pulp in papermaking has a major impact on emissions to the air, as it leads to less wood–based fuel being burned at the mill and to a drop in the amount of heat recovered from defibration in mechanical pulping. The extent of the effect depends on how much recycled fibre is used in each particular paper. For example, by replacing some of the TMP used in a newsprint furnish by raising the recycled fibre content to 60% of the weight of the paper, wood consumption falls to one-third and purchased electricity consumption to one-half, but at the same time emissions to the air rise sharply because more purchased fuel is burned.

The chemicals used to deink collected waste paper include sodium hydroxide, hydrogen peroxide, sodium silicate and complexing agents. Thus, replacing mechanical pulp with deinked recycled fibre in products in which the mechanical pulp does not have to be peroxide bleached greatly increases the use of chemicals in production. This does not apply to paper grades containing peroxide–bleached mechanical pulp.

Papermaking

To study the combined effects of pulp and paper production involving different ways of producing the mechanical or chemical pulp and replacement of some pulp with recycled fibre, discharges arising from production of the most important paper grades were calculated assuming that the paper is made at a mill that also produces all the pulp it requires. Specific discharges were calculated for the following paper and paperboard grades:
- newsprint
- uncoated mechanical printing paper
- coated mechanical printing paper
- uncoated fine paper
- coated fine paper
- folding boxboard
- solid bleached kraft board

The specific discharges for the most important cases are shown in Table 1 for newsprint, uncoated mechanical printing paper and uncoated fine paper. The differences between the cases studied for coated papers were similar to those calculated for uncoated papers, although the specific discharges for coated papers, in terms of all parameters except solids, were lower due to the higher pigment content of these papers. In terms of emissions to the air, coated paper production requires more purchased fuel because the process produces less wood–based by–products for burning. The specific discharges for folding boxboard production correspond well with changes in specific discharges from mechanical printing paper production; a similar correspondence exists between solid bleached kraft board and fine paper.
Discharges to receiving waters

The different options for chemical pulp production and the replacement of TMP by pressurized groundwood have very little effect on the effluent loadings from the production of different paper grades. The small AOX loading disappears if TCF pulps are used. The use of recycled fibre also reduces the effluent loading somewhat.

Emissions to the air

Excluding total reduced sulphur (TRS), one-third of SO₂ emissions from the pulp and paper industry stem from process boilers and two-thirds from power generation. The latter is greatly affected by the fuel used, as shown in Fig. 4. Neither wood waste nor natural gas produces significant amounts of SO₂. Specific discharges were calculated assuming the national average consumption of the average fuel mix. The only method studied for removing sulphur dioxide from power plant flue gases was to use a lime bed, which is a possibility in coal-fired boilers.

The use of recycled fibre increases SO₂ emissions because it requires greater use of purchased fuels. Changing from TMP to pressurized groundwood also increases the formation of SO₂, because in POW production no heat is recovered from defibration, and the difference therefore has to be supplied by burning fuel.

Solid wastes

Unless it is burned, the sludge from effluent treatment forms the bulk of solid waste: 50–60% in chemical pulp production and 80–90% in paper production. The use of recycled fibre causes a significant increase in solid waste: in newsprint production, for example, the deinking waste from recycled fibre production can lead to five times the amount of solid waste. Burning can reduce the amount of solid waste from treatment plant sludges to about one-sixth and that from deinking sludges to about one-third.

![Figure 4. Sulphur dioxide emissions from power production at a non-integrated fine paper mill, effects of different fuels.](Mixture = national average CaO = lime used in fluidized bed combustion of coal).
Effects of different scenarios at national level

Scenarios and basic assumptions

Changes in the pulp and paper industry generally take place slowly because of the size of the investments involved. A particular process modification may necessitate major changes in other parts of the process, in which case it is only considered in conjunction with an extensive modernization or the installation of a new process.

The effects on Finland's total pulp and paper mill discharges of those process modifications and changes in pulp usage that are assumed possible here were calculated in four different situations. These situations differed with respect to the speed with which the technology could be introduced, the extent of recycled fibre usage and the proportion of totally chlorine-free (TCF) pulp used. The trend in Finnish paper production is assumed to be the same in all scenarios. The scenarios were:

Scenario A: Normal development
The basic premises are
- no import of recycled fibre
- no significant production of TCF pulps
- pulp mills install oxygen delignification so that by the year 2010 at least 95% of production has a Kappa number of about 18 (softwood) or 14 (hardwood)
- by 1995 all pulp mills will evaporate their black liquor to at least 75% dry solids or have flue gas scrubbers to remove sulphur dioxide, and 40% of all mills will have both by the year 2000
- removal of particulates from power plant flue gases will steadily be improved to give an average emission of 20–30 mg/m³ by the year 2010
- the proportion of sludge burned will remain at the present level of about one-half.

Scenario B: "Eco-products", poor profitability
Based on the assumption that the market will demand the use of large amounts of recycled fibre and TCF pulp, but prices and costs are such that profitability will be poor and investment low. The premises are thus
- by the year 2010, total consumption of recycled fibre will be about 1,200,000 t, over half of which will be imported
- TCF pulp will represent 40% of all bleached kraft pulp used by the year 2000
- process modifications are the same as in scenario A, except that investments in bleaching required for TCF will be made.

Scenario C: "Eco-products", good profitability
Use of recycled fibre and TCF pulp as in scenario B; good profitability, however, allows additional investments, which
- will reduce the pulp lignin content prior to bleaching; by the year 2000 some 35% of all pulp will be cooked to Kappa number 8–12
- in the year 2000, alkaline filtrates from bleaching will start to be taken to the chemicals recovery system, and by the year 2010, 70% of mills will be doing this
- air pollution control will be intensified, and by the year 2010 all recovery boilers will be burning black liquor evaporated to high dry solids and all flue gases will
be scrubbed; coal-fired power boilers will be fitted with lime beds for sulphur
dioxide removal
- by the year 2010, 80% of all sludges will be burned.

Scenario D: Rapid development
Without regard for financial constraints, this scenario looks at the discharge and
consumption figures that could result from very rapid developments. It assumes the
following
- all kraft pulp mills will have oxygen delignification by the year 2000, and 90%
of all chemical pulp will be cooked to Kappa number 8–12 by the year 2010
- TCF pulp will account for 80% of all pulp used by the year 2000
- by the year 2010, half of kraft pulp mills will have a completely closed bleaching
process, and in addition one in five will return the alkaline filtrates from bleaching
to the chemicals recovery system
- in addition to the air pollution control measures included in the other scenarios,
natural gas fired power boilers will be fitted for NOx removal by the year 2010.

The import of collected waste paper would mean an increase in the use of recycled
fibre in papermaking, so that by the year 2010, the paper products containing deinked
recycled fibre would have the following share in the different paper grades: newsprint
55%, uncoated mechanical printing papers 30%, coated mechanical printing papers
15%, fine papers 10% and tissue 80%. It is also assumed that 20–25% of collected
waste paper would be used without being deinked in various paper and paperboard
products.

In the calculations, account has been taken of the changes caused by fibre characteris-
tics in the proportions of the different fibres used in papermaking; the main differences
are:
- the lower strength of TCF softwood pulp means that mechanical printing paper
  furnish will need a higher proportion of reinforcement pulp than when
  conventional pulps are used
- the lower strength of TCF hardwood pulp means that fine papers will contain less
  hardwood pulp than at present
- in mechanical printing grades, it is assumed that recycled fibre will replace mainly
  the mechanical pulp component; on the other hand, it is assumed that some
  recycled fibre will be produced from high-quality office waste paper and will thus
  replace some of the chemical pulp component. It is assumed that only deinked
  recycled fibre from office waste will be used in fine paper furnishes, so that both
  softwood and hardwood chemical pulps will be replaced in equal proportions.

Discharges to receiving waters

It is assumed that management of activated sludge treatment will improve in the
future, increasing somewhat the removal of organic matter (BOD and COD). The
biggest improvements, however, will be in discharges of solids, while treated effluents
will contain less dissolved nutrients. It is also assumed that the average water
consumption by paper mills will fall by the year 2005 to around the figure currently
achieved at the best mills. The same assumptions are included in all scenarios.

The rapid decline in effluent discharges from Finnish pulp and paper industry during
the 1980s will continue during the 1990s, even if the trend in the development of technology is merely normal. As the results of the scenarios in Fig. 5 show, effluent discharges of readily biodegradable organic matter (BOD) fall to a very low level after the introduction of biological treatment. The total discharge of organic matter (COD) will fall to two-thirds of its present value by the year 2005 because of the latest activated sludge plant installations, a slight improvement in treatment, and the lower lignin content of pulp prior to bleaching following the introduction of oxygen delignification. The AOX loading will fall to almost one-half of the present figure, i.e. to below 4,000 t/a, by the year 2000, the initial sharp reduction being attributable to an end to the use of chlorine gas in bleaching. The reduction may be even greater if mills switch over to chlorine dioxide production processes in which no chlorine water is formed. The phosphorus loading will also fall to nearly half of its present level by the year 2000. This will be due to the reduction in discharges from the pulping process as less lime mud is needed for neutralization, but largely to the introduction and improved management of activated sludge treatment, which will bring a marked improvement in phosphorus reductions.
Figure 5. Pulp and paper industry effluent discharges in the different scenarios. (COD = chemical oxygen demand; BOD = biological oxygen demand; compl. N = nitrogen of complexing agents, which do not decompose during biological treatment).
The differences between the different scenarios in terms of the change in BOD loading are extremely small.

The results in scenarios C and D show that fairly radical measures will be needed to reduce the COD loading to significantly below the level that will result from normal development. By the year 2010, the loading predicted in scenario D, in which pulp mill bleaching plants will have achieved a high degree of closure, will be 40% lower than that in scenario A. In the same year, an estimated 100,000 t of COD loading will originate from sources other than chemical pulp production.

The AOX loading will naturally fall in relation to the proportion of TCF pulp produced. Because, in the scenarios, bleaching plant circulation closure was connected mainly with totally chlorine-free bleaching, it was not the actual reason for the reduction in AOX loading.

An inspection of the scenarios indicates that phosphorus discharges from kraft pulp mills could depend partly on the ratio of BOD to phosphorus in the untreated effluent. A fall in BOD without a fall in phosphorus would result in a higher phosphorus discharge because less biomass would be formed to adsorb phosphorus. This is shown in scenarios B, C and D in Fig. 5.

In the scenario representing normal development, nitrogen discharges will fall to 1,800 t/a by the year 2000 and to 1,400 t/a by the year 2010. These figures do not include nitrogen originating from the complexing agents needed in the bleaching of mechanical pulp and in the totally chlorine-free bleaching of kraft pulp; this nitrogen source is around 300 t/a at present, but in scenarios B and C would grow to about 1,100 t/a by the year 2010 and in scenario D to around 1,200 t/a by the year 2000 after which it would decrease as a result of water circulation closure. That is the case unless some way is found to remove the complexing agents from the effluent.

Environmental impacts

Impacts of discharges to receiving waters are always local, and thus vary greatly from one mill to another. As the scenarios depict the average discharge for Finland as a whole, it is only possible to predict the general change in the state of the recipient waters. In practice, the geographical differences are usually great, and the changes will be very significant in some waters while some others remain virtually unchanged. The differences are due to differences in today's situations, differences between recipient waters and developmental differences between mills.

All scenarios (A–D) predict a large reduction in nutrient loading; the phosphorus loading will fall from the 1989 figure of 750 t/a to 250 t/a by the year 2000, i.e. to about one-third. During the same period, this will reduce the pulp and paper industry's contribution to the whole country's phosphorus discharge from 9% to 3% if other loadings were to remain at the 1989 level. This means the pulp and paper industry would be responsible for 1–2% of the total nitrogen discharge in the year 2000. The nutrient loading from agriculture is likely to fall significantly during the 1990s. If it were to fall to one-half of the 1989 level (3,400 t P/a and 32,000 t N/a) the pulp and paper industry would contribute 4% of the whole country's phosphorus discharges and 2–3% of the nitrogen discharges.

Locally, the significance of pulp and paper mill nutrient loadings is much greater than the proportion calculated for the whole country; in some cases accounting for 30% of
the recipient's phosphorus loading. The phosphorus content of receiving waters will fall by up to one-quarter from its present level merely due to the reduction in discharges from pulp and paper mills. The reduction in nitrogen discharges has less significance. By how much eutrophication of waters changes depends greatly on local factors, but to make a sweeping generalization, eutrophication can be expected to fall in all cases by 0–20% from the 1990 level merely as a result of the fall in nutrient discharges from the pulp and paper industry.

Discharges of organic matter to receiving waters fall in all scenarios. Water colouring due to discharge loadings will fall, and scenarios C and D, in particular, show a significant impact on coastal waters around chemical pulp mills from 1995 on. A very pronounced reduction in BOD will, in practice, eliminate all oxygen problems due to pulp and paper mill effluents in all receiving waters in all scenarios at the latest by the year 2000. A reduction in the suspended solids loading to one-third of its level of the early 1990s by the year 2000 will reduce water turbidity, especially around discharge points, and could lead indirectly to a reduction in the accumulation of certain compounds in aquatic organisms.

There are no grounds for predicting any overall change in the ecotoxic effects of effluents in the light of present knowledge, certainly not in terms of the scenarios based on chlorine-free bleaching. Improving the effectiveness of external treatment will lead to a clear reduction in the toxic effects of effluent discharged from several pulp mills. The use of less chlorine chemicals in pulp bleaching is not, in itself, likely to result in any significant changes in the state of recipient waters. Very little research data is available on the advantages and disadvantages of the new chemical pulping processes. In the light of present knowledge, effluent from the modern kraft pulp mill equipped with activated sludge treatment plant and carrying out bleaching with chlorine chemicals has no significant ecotoxicological effects on recipient waters that could be eliminated by discontinuing the use of chlorine chemicals.

Air emissions

As more wood-based and purchased fuels are burned, the formation of carbon dioxide will rise from the present figure of about 17 million t/a to 24 million t/a by the year 2010 (Fig. 6). There are no significant differences between scenarios in this respect. Around 80% of this carbon dioxide is derived from wood-based fuels. Sulphur dioxide emissions will fall significantly as a result of air pollution control measures currently being implemented, reaching 25,000 t/a by 1995. Only scenarios C and D provide any further reduction, the prediction being around 13,000 t/a by the year 2010. The same measures will also bring a significant reduction in particulate emissions. The scenarios differ little in this respect. NOx emissions will increase slightly in all scenarios as fuel consumption grows. Only the NOx removal in natural gas fired boilers in scenario D would reduce emissions after the year 2000.

Emissions of reduced sulphur compounds vary greatly from mill to mill, depending on the process technology and the collection system employed for these gases. These emissions cannot be estimated theoretically with sufficient accuracy, and no attempt has been made to quantify them in the present study. According to the mills' own estimates, emissions of reduced sulphur compounds from chemical pulp production were around 6,700 tonnes of sulphur (13,400 t as SO2) in 1991. Several mills have just installed, or are currently installing, new systems for the collection and disposal of malodorous gases, which means there will be a fairly sharp fall in emissions of reduced sulphur compounds in the near future.
At present, about one-third of sulphur dioxide and nitrogen oxide emissions from pulp and paper mills originates from recovery boilers, the rest coming from power production. Recovery boilers are also responsible for about 60% of particulate emissions. In the case of SO2, this situation will remain largely unchanged in all scenarios up to the year 2010. On the other hand, nitrogen oxide emissions from power production will approach those from recovery boilers when the NOx removal outlined in scenario D is introduced. Particulate emissions from power production will fall to almost one-tenth of total emissions as a result of the improvements expected in particulate separation.

![Graphs of SO2, NOx, CO2 emissions](image)

Figure 6. Air emissions and formation of carbon dioxide from pulp and paper mills in the different scenarios. (Woodb. = CO2 from wood-based fuels).

**Solid wastes**

If about half of all sludges from effluent treatment plants and the deinking of collected waste paper were burned, as is the case today, and in the absence of large imports of collected waste paper to Finland, the amount of pulp and paper mill solid waste to be taken to landfill sites will increase from the present 600,000 – 700,000 t/a to about 800,000 tonnes by the year 2010. The amount of solid waste would reach about 900,000 tonnes if total consumption of collected waste paper were to rise to 1.2 million tonnes, in which case the figure for deinking sludge would be almost 200,000 t/a. If some 90% of sludge from effluent treatment and deinking were to be burned,
the total amount of solid waste would be about 500,000 tonnes in the year 2010 (scenario D). The amount of ash produced would then rise from the present 120,000 tonnes to 200,000 tonnes in the year 2010.

Wood, energy and chemicals

The predictions for Finnish paper production mean an increase of about 35% in pulp-wood consumption from the present 35 million m³ to about 47 million m³ by the year 2010. The biggest growth would be in softwood for chemical pulping, reaching about 50% in a situation of normal development and 58% in the scenario representing rapid development in which it is assumed that the pulping process will consume more wood per tonne of pulp produced. Consumption of spruce pulpwod for mechanical pulp production will grow by about 13% by the year 2010 if the use of collected waste paper remains at its present level. On the other hand, there would be no major growth in consumption if collected waste paper were to be imported. Demand for hardwood for pulping will grow by about 30%.

The increase in wood consumption will result in more bark and black liquor being burned for energy, the latter increasing more in relative terms than the use of wood as pulping processes begin to consume more wood. In scenario D (rapid development), the amount of black liquor burned would grow by about 70% by the year 2010. On the other hand, the increase in the need for purchased fuels will correspondingly be slightly smaller in relation to the growth in production. Electricity consumption would grow by about 30% in scenario A (normal development) and by about 5% points less if there is a sharp rise in the use of collected waste paper. The production of ozone at the pulp mill, as required in scenario D (rapid development), would consume roughly the same amount of electricity, and scenarios A and D therefore do not differ greatly in terms of electricity consumption. However, changing over to using ozone would reduce the use of electricity needed elsewhere to produce chlorate. The saving would be about five times the electricity consumed in ozone production. The need to purchase electricity will grow slightly less than consumption, the result being a relatively sharp rise in energy from burning wood–based fuels.

The use of elemental chlorine will fall to a very low level in the very early part of the period reviewed, even in the case of normal development, so that the need for chlorate will grow by about 30% by the year 2010. Changing over to peroxide and ozone in pulp bleaching would substantially reduce the consumption of chlorate. However, more sodium hydroxide would be needed, especially with the introduction of totally chlorine-free bleaching and greater use of recycled fibre. With present technology, the peroxide bleaching of kraft pulp, with or without ozone, would consume so much peroxide and complexing agents that a substantial increase in their production capacity and import would be necessary.

Costs

The need for capital investment in environmental protection was also assessed for the different scenarios. This was done by calculating an average investment estimate for the different processes for a typical Finnish mill; capital investments were then summed for each scenario. The accuracy of the investment estimate for each process is ± 20%. The investment cost estimates for the different scenarios are given in Fig. 7.

In all scenarios, the focus of investment is on the 1990s, during which the annual
investment in the particular environmental protection measures expected here varies from about FIM 300 million to almost FIM 600 million. A high proportion of the investment earmarked for 1990–1995 has already been completed or is under way. The rate of investment for the period 2000–2010 is much lower in all scenarios, partly because most of the environmental investments that can be expected will be completed during the 1990s.

The capacity of the pulp and paper industry to invest over the next ten years will be limited, as will be shown in Section 6. This will have a major impact on investment in environmental protection. The industry should not, at the present time, be faced with environmental protection targets involving high capital investment. Scenario D represents one such option. Once the industry has restored its profitability, it can then be expected to show a greater commitment to environmental protection. In fact, it is highly likely that the market (recycled fibre, TCF) will force companies to invest in environmental protection, both real and imaginary.

Variable production costs (wood, chemicals, energy) have also been estimated for the different scenarios. The essential difference between scenario A and scenarios B and C, which at the present computation accuracy are virtually the same, is in the price of imported waste paper. At today's prices, the difference is FIM 200–300 million a year. The production costs for the whole country in scenario D are some FIM 500 million a year higher than in scenario A. This is significant, especially in view of the need for investment inherent in scenario D. In fact, the costs included in scenario D are extremely high.

Economic prospects for the pulp and paper industry

Pulp and paper production is an extremely capital-intensive industry. Capital intensive means the capital expenditure required for production is high in relation to the value of production and other production factors. Investment is focused on expanding production and maintaining existing capacity.

During the past 20 years, the Finnish forest industry has invested an average of 12% of its net sales in operations in Finland. The rate of investment was particularly high in the second half of the 1980s. As a result, the value added of production is extremely high and the production facilities are among the world's most modern. Investment in environmental protection has also been high.

Income from operations has only been enough to finance part of the forest industry's investments, which means that most investments have had to be financed through loans. In fact the Finnish forest industry carries a greater debt burden than its competitors. Net indebtedness in the forest industry is equivalent to net sales, and in excess of net sales in the pulp and paper industry. Some Finnish forest industry companies are so indebted that if they were operating in certain other countries they might be faced with receivership.

As the rate of inflation slowed down in the early 1980s, previously negative real interest rates became positive, thus increasing the forest industry's real interest expenditure. The benefit derived from high inflation in terms of a reduction in the real value of debts also diminished substantially.
Figure 7. The pulp and paper industry’s need for investment in process modifications and treatment plants in the different scenarios.

Finnish forest industry companies sell their products on the world market, where prices are determined by supply and demand. Being situated further from the main markets than its competitors, the Finnish forest industry suffers the disadvantage of much higher transport costs as well as higher distribution and marketing costs resulting from linguistic and cultural differences.

The main reason for the growth in the Finnish forest industry’s debt burden has been inadequate financing from operations. To overcome this requires a sufficiently high operating margin. The operating margin, in turn, is the turnover from sales less manufacturing, transport, distribution and marketing costs.

Manufacturing costs are the only costs over which the industry has total control. In order to compensate for higher transport and other costs and to achieve the same operating margin as its competitors, the Finnish forest industry must bring its manufacturing costs down to below those of its competitors. This is the only way to ensure the pulp and paper industry has an adequate operating margin, which should be at least 20–25% of net sales. This minimum figure has been reached only three times in the past 20 years. The operating margin should be enough first to pay off the interest on loans raised to expand production capacity and second to replace existing capacity, i.e. for depreciation. Any operating margin remaining is needed to repay loans raised to finance investments, for new investment in response to market demands (raising capacity, improving quality), and for defensive environmental investment and investment aimed at reducing the environmental impact of production.
The over-capacity currently on the European paper market is expected to disappear as demand picks up over the next few years. As a result, the Finnish paper industry may be able to raise its capacity utilization rates, which are currently as low as 84%, up to almost 100%. As the market balance is restored, it may be possible gradually to increase prices from their present low levels. This, together with higher capacity utilization rates, will give the paper industry the chance to improve its net sales, operating margin and financial results.

If the improved financial results achieved in this way are used entirely to repay debts, Finnish forest industry companies could reduce their indebtedness to 70–80% of net sales by the mid-1990s. In view of the increasing integration in Europe, this is not enough, and Finnish companies need to reduce their debt burden to 35–40% of net sales in line with that of their competitors.

Even under optimum conditions (full capacity utilization, improving demand, rising prices, costs under control), achieving a substantial improvement in financial solidity of this order is likely to take another 5 or even 10 years beyond the 3–4 already mentioned. In the second half of this decade, not all income from financing will be available for repayment of loans because some will be required for raising capacity and increasing the value added of production in response to growing demand. The industry will probably not be able to invest in raising production capacity in line with predicted growth in production until late this decade, when the economy recovers.

If, in the future, the European continent enacts legislation requiring all paper grades
to contain some recycled fibre and refuses to accept paper and paperboard made from Scandinavian primary fibre as "feedstock fibre" for the production of its recycled fibre-containing paper grades, the Finnish forest industry will also have to invest in widening its raw material base and perhaps even close down pulp mill capacity. It should be remembered that the export industry and particularly the forest industry have a vital role to play in reducing Finland's external debt burden and restoring a balance to the country's current account over the next 10 years.

From this, it follows that the Finnish pulp and paper industry will be able to retain its leading and exemplary position in environmental protection over the next 10 years only if the country's forest industry raises its operating margin and keeps it at a sufficiently high level throughout the period of this scenario analysis.

Conclusions

In examining the economic future of the Finnish pulp and paper industry and its prospects for reducing the environmental impact of its production, we must remember two fundamental points. First, properly managed, the pulp and paper industry involves several features of an industrial activity based on sustainable development. It processes a renewable natural resource into products that for the most part are biodegradable, and in so doing generates a high proportion of the energy it needs from a renewable biofuel—wood. Second, the industry is of vital importance to Finland, which means that a profitable basis must be found for it now and in the future.

It is assumed that exports of pulp and paper will continue to grow fairly rapidly. As a result, demand for pulpwood will increase by about one-third by the year 2010, which will still be below the production capacity of Finnish forests. However, an economic analysis reveals that the forest industry, with its high burden of debt, cannot contend with demands for even higher spending on environmental protection in the near future.

The environmental loading due to the Finnish pulp and paper industry was assessed in the following four, partly hypothetical, situations:

- Normal development, including the changes currently taking place
- "Eco-products", poor profitability
- "Eco-products", good profitability
- Rapid development

The following conclusions can be drawn:

- Despite the increase in production, discharges into both water and air will fall in all four scenarios; the only increases will be in emissions of nitrogen oxides and carbon dioxide. Effluent loadings as a whole will fall to low levels merely as a result of changes already taking place.

- The normal development scenario contains a sharp fall in discharges. In the other scenarios, the improvements that can be achieved through additional investment are not significant.

- By closing bleaching plant water circulations at pulp mills, discharges of dissolved organic matter and nutrients from the entire pulp and paper industry can be further reduced to at most one-half of what can be achieved through external activated...
sludge treatment in a situation in which specific discharges from the papermaking process remain constant.

- The normal development will bring the AOX loading down to a very low level. The technology needed to eliminate the AOX loading completely is extremely expensive, yet has no major impact on any other loading unless accompanied by closure of bleaching plant water circulations. AOX would only be eliminated if market forces demanded it.

- The reduction in effluent discharges that is currently taking place will improve the state of waters to different extents in different areas.

- In terms of air pollution control, only sulphur dioxide emissions can be reduced well below the level that will result from normal development.

- The forest industry's need for chemicals will change dramatically. The need for oxygen chemicals and imported alkali will grow as the use of chlorine is all but discontinued. These changes will demand considerable measures within the chemical industry.

- A substantial rise in capacity will increase the need for energy, most of which will be met through better energy management and the use of more wood–based fuel. The need for purchased electricity will grow more slowly than pulp and paper production.
SYTYKE 22A

GENERATION AND ANALYSIS OF SCENARIOS FOR PULP PRODUCTION IN FINLAND 1995–2010

Summary

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GENERATION AND ANALYSIS OF SCENARIOS FOR PULP PRODUCTION IN FINLAND 1995–2010

Summary

Goals

The goal for the project "SYTYKE 22", allocated to Keskuslaboratorio Oy, was to identify an amount of alternative technology choices for the Finnish pulp industry for the years 1995–2010, with special emphasis on the possibilities to reduce discharges from chemical pulp mills. As part of the project, Keskuslaboratorio Oy ordered a study from Jaakko Pöyry Consulting Oy. In it, the same territory would be explored from several different viewpoints, by combining the concepts of environmentally friendly products and sustainable development with various mathematical methods. The intention was to provide food for thought by illuminating known problems from lesser known angles. This independent whole was given the appellation SYTYKE 22a.

In this summary, the relationship to SYTYKE 22 has been taken into account in that the emphasis is on those components that differ the most from the root project. The expansive presentation of scenario results 1995–2010 in SYTYKE 22a has here been compressed more than the other parts, and instead the principles behind the calculations have been put under the magnifying–glass.

Approach

The nucleus of the approach is the use of computers for scenario generation and evaluation. The number of possible scenarios is extremely large with an even slightly more complex simulation model. When a human applies his reasoning faculties to producing a subset of scenarios, many valuable ones may go unnoticed. In order to avoid this, it is possible to use a computer in the role it should have in a decision support system: as a supremely fast, never bored assistant. The computer does the preliminary pruning and provides the human with a choice set of scenarios for further processing. The evaluation inherent in the pruning is naturally not done by the computer on its own; instead, the evaluation skills of experts must somehow be captured in numbers. Thus, in a way, pale copies of experts are sent to explore an unknown scenario space in the innards of a computer.

The Parts of the Study

The study is divided into three main parts, where aspects of scenario generation and evaluation are dealt with. These parts are the environmentally friendly product, intuitive scenarios and scenario simulation. Providing additional structuration is a framework into which factors that complicate technology choices are placed.

Scenario Generation and Analysis

The fundamental questions are: how to generate and evaluate scenarios? For the generative process, two methods are presented. Intuitive scenarios deal with a less detailed level. Experts are presented with a conceptual model, and use a verbal scale to provide their impression of the relationships between the concepts. After that, a neural net–type algorithm generates numeric–verbal scenarios from different starting
points. In genetic scenarios, a scenario is viewed as a being, whose characteristics are completely defined by its inheritance. Its chromosome is thus an encoding of the input variables for the scenario. Different scenarios can now be produced using the methods of genetics; as through raising generations of scenarios, where issue is produced through combinations of genetic material. In this study, the focus is restricted to the analysis of one generation, and laying the foundation for actual genetic optimization.

In genetic scenarios, some basis for evaluation is needed. For this evaluation, the concepts of the environmentally friendly product and sustainable development are used. These must somehow be clothed in numbers. The starting point is investigating the environmental impact of products. This is done by choosing criteria from the areas of energy, raw materials and water discharges, and by storing expert opinions through the use of a simple weights–and–limits method. After that, a group of paper and pulp products are ranked on the basis of these expert opinions. A step in the direction of sustainable development is taken by including economic criteria in this definition of environmentally friendly behavior, and evaluating genetic scenarios on this basis. Replacing the coefficient method with expert systems and neural nets is a separate continuation project.

The Plot

Woven into the main plot are calculations, comparisons and different expert opinions. These deal with e.g. closed–cycle bleaching as an alternative to TCF pulps, the low degree of environmental friendliness shown by CTMP, the not necessarily favorable interaction between economy and public opinion, and, finally, fluctuations in public opinion needed to achieve certain goals. Thus, the study can be characterized as a study, richly illustrated with real–world examples, about the dangers of subjective opinions and suboptimal solutions in the making of technology choices for the pulp industry.

Results

The Environmentally Friendly Product

In the initial symposium for the SYTYKE research program, the wish was expressed that the question of environmentally friendly products should be addressed. Here, a simple mathematical method has been used. In some studies of the same basic question, experts have been asked to directly assign merit points to products. This was considered misleading, and instead, four Jaakko Pöyry experts were asked to give weights and limits for raw material use, energy aspects and water discharges. All in all, the criteria chosen were:

<table>
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<tr>
<th>Fibre raw material</th>
<th>Energy</th>
<th>Water discharges</th>
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<tbody>
<tr>
<td>The amount of recycled fibre (%)</td>
<td>Purchased power (MWh/ADt)</td>
<td>Suspended solids (kg/ADt)</td>
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<td></td>
<td>Total power (MWh/ADt)</td>
<td>COD (kg/ADt)</td>
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<td></td>
<td></td>
<td>BOD (kg/ADt)</td>
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<td>AOX (kg/ADt)</td>
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<td></td>
<td></td>
<td>P (kg/ADt)</td>
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<tr>
<td></td>
<td></td>
<td>N (kg/ADt)</td>
</tr>
</tbody>
</table>

The product assortment was chosen so as to cover a large enough part of the market, and address some key issues, e.g.

- TCF vs. closed–cycle bleaching
- recycled fibre vs. chemical pulp
- bleached vs. unbleached chemical pulp
The products and the criteria values, calculated using the "Jaakko Pöyry Mill Impact" program, are to be found in tables 1 and 2. The abbreviations used in the tables and pictures are the following:

UWF uncoated woodfree copying paper (chemical pulp)
UWFWas uncoated woodfree copying paper (recycled fiber)
UWFChe peroxide–bleached UWF
UWFClo UWF, closed bleaching cycles
NEWS newsprint (recycled fiber)
LWC coated mechanical paper
LWCChe peroxide–bleached LWC
LWCCclo LWC, closed bleaching cycles
TMP (CSF 100)
CTMP
BSKP bleached softwood kraft pulp
UBHKP unbleached hardwood kraft pulp
BHKP bleached hardwood kraft pulp
RECYCLED recycled fiber
BSKPChclo peroxide–bleached BSKP
BSKPClo BSKP, closed bleaching cycles
BHKPChe peroxide–bleached BHKP
BHKPClo BHKP, closed bleaching cycles

The Clo–alternatives are based on a method being developed and tested by Jaakko Pöyry Oy.

Table 1. Comparison of paper grades, calculated values for the criteria

<table>
<thead>
<tr>
<th></th>
<th>Recycled fiber (%)</th>
<th>Purch. power (MWh/ADt)</th>
<th>Power total (MWh/ADt)</th>
<th>SUSP (kg/ADt)</th>
<th>COD (kg/ADt)</th>
<th>BOD (kg/ADt)</th>
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<th>P (kg/ADt)</th>
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Table 2. Comparison of pulp grades, calculated values for the criteria

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<th>Power total (MWh/ADt)</th>
<th>SUSP (kg/ADt)</th>
<th>COD (kg/ADt)</th>
<th>BOD (kg/ADt)</th>
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<th>P (kg/ADt)</th>
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<td>4,5</td>
<td>18,0</td>
<td>5,5</td>
<td>0,0</td>
<td>0,022</td>
</tr>
<tr>
<td>BHKPCloclo</td>
<td>0</td>
<td>0,090</td>
<td>0,765</td>
<td>2,4</td>
<td>4,9</td>
<td>1,8</td>
<td>0,0</td>
<td>0,007</td>
</tr>
</tbody>
</table>

The rankings

The variations in pulp and paper grade rankings for different experts are illustrated by pictures 1 and 2. In them, the worst product receives the ranking 8, the best the ranking 1.

Considering the geographical concentration of the expert sample (four consultants from one company), a great variance in results is observable. Yet, the following points can be made:
- CTMP is unequivocally the most critical product, combining the downsides of mechanical and chemical pulp,
- recycled fiber is not a guaranteed victor in the competition (relatively high discharge levels, purchased power),
- even bleached kraft pulp, especially using closed cycle technology, is extremely competitive, particularly as to discharges,
- every definition of an environmentally friendly product is subjective.
Picture 1. Ranking of paper grades

<table>
<thead>
<tr>
<th>NEWS</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>UWF</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>UWFWas</td>
<td>7</td>
<td>7</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>LWC</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>UWFChe</td>
<td>7</td>
<td>5.5</td>
<td>6.5</td>
<td>1.5</td>
</tr>
<tr>
<td>UWFClo</td>
<td>7</td>
<td>5.5</td>
<td>6.5</td>
<td>1.5</td>
</tr>
<tr>
<td>LWCChe</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>LWCClo</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Picture 2. Ranking of pulp grades

<table>
<thead>
<tr>
<th>RECYCLED</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTMP</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>TMP</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>BSKP</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>BSKPClo</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>BHKP</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>BHKPClo</td>
<td>3.5</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>UBSKP</td>
<td>3.5</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Intuitive Scenarios

In a truly wide-angle analysis of the causes and effects of pulp production, incorporating a foray into the territory of social ramifications, the following factors among others can be distinguished (see picture 3):

- **THE STRENGTH OF PUBLIC OPINION.** Public opinion implies first and foremost the set of value judgments and emotions concerning the forest industry apparent in the media, and the view thereof that the expert has.
- **THE RATIONALITY OF PUBLIC OPINION.** In this case, rationality implies not losing oneself in the details: a capability of seeing the big picture without uncontrollable unacknowledged reflexes.
- **THE GREENNESS OF THE PRODUCT SORTIMENT.** The product sortiment is the "greener", the more it conforms to the current view of an environmentally friendly product.
- **THE STRINGENCY OF LEGISLATION AND DISCHARGE LIMITS.** That is: the constraints on the mill activities. In the background, a strong factor is the expert's evaluation of what can be achieved, and how the expert sees damage that has been and will be caused.
- **THE ENVIRONMENTAL CONSCIOUSNESS OF THE COMPANIES.** The degree to which the companies in their activities consider effects on the environment.
- **COMPANY PROFITABILITY.** A purely economic criterion.
- **THE STATE OF THE NATION'S ECONOMY.** A somewhat vague criterion, of which every one, however, has a clear opinion.
- **THE LEVEL OF EMPLOYMENT.** Obvious.
- **THE DISCHARGE SITUATION.** An expert's opinion of the discharge level can besides a view of the magnitude of the discharges incorporate a view of their effect, and e.g. an image of increasing strictness in evaluation as time goes by.

The method here called "intuitive scenarios" is in fact the FCM-method (fuzzy cognitive map), related to neural networks. In it, experts define dependencies between concepts, whereafter impulses input to the model can lead to equilibrium states and cycles to be interpreted appropriately.

The impulse

THE STRENGTH OF PUBLIC OPINION increases slightly.
THE RATIONALITY OF PUBLIC OPINION diminishes slightly.
COMPANY PROFITABILITY diminishes considerably.
THE STATE OF THE NATION'S ECONOMY worsens considerably.
THE LEVEL OF EMPLOYMENT down considerably.

gives the result described in table 3: simultaneously a view of things to come in the near future. The experts used were four Jaakko Pöyry consultants of different backgrounds.
Picture 3. Example model, example dependencies.

Table 3. Analysis of equilibrium state for one situation

<table>
<thead>
<tr>
<th>Experts</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public opinion</td>
<td>Weakened considerably; simultaneously a moderate diminishing of rationality.</td>
<td>Strengthened slightly.</td>
<td>Strengthened moderately, a slight diminishing of rationality.</td>
<td>Weakened slightly; rationality slightly diminished.</td>
</tr>
<tr>
<td>Company level</td>
<td>Greenness of products, environmental consciousness and profitability diminished considerably.</td>
<td>Profitability weakened considerably.</td>
<td>Greenness of products increased moderately, a slight increase in environmental consciousness, profitability weakened considerably.</td>
<td>Product greenness diminished moderately, environmental consciousness and profitability diminished considerably.</td>
</tr>
<tr>
<td>Discharges</td>
<td>Situation worsened slightly.</td>
<td>No change.</td>
<td>Situation worsened considerably.</td>
<td>Situation worsened moderately.</td>
</tr>
</tbody>
</table>
An analysis of cycles of opinion and economy accentuates the importance of interaction between these components. In the example in the report (which is not presented here), opinion and economy even seem to shy away from proximity and chase each other from one extreme position to another. This example is, hopefully, unrealistic. What is obvious is, that ith complicated interaction, small differences in premises lead to big differences in conclusions. This is the curse inherent in many essential, large-scale problems.

Scenario Simulation

In scenario simulation, a greater amount of detail is present compared to the intuitive scenarios in the previous section: a precise technical simulation with databases (water discharges, productions, mill-specific descriptions and furnishes for 19 chemical pulp mills in Finland, a knowledge base about the means to achieve water discharge reductions), a viewpoint where the forest industry is viewed as a being fighting for its survival and a simple definition of sustainable development for scenario evaluation. The end result can be called a genetic simulation that produces scenarios for the pulp industry in Finland. The core of a scenario is the chromosome – the seed that triggers the events that constitute the scenario. The chromosome chosen is described by table 4. 166 variables depicting the scenario are divided into areas (genes).

An essential part of the model is its view of opinion dynamics. This describes how external pressures, public opinion in matters related to water discharges, the dependence of legislation on public opinion, mill-specific discharge limits and the mills’ environmental strategies interact. Three values for external pressure have been chosen: the present (AOX+recycled fiber), an increased focus on recycled fiber and, finally, heightened energy conservation pressure. Public opinion in matters related to water discharges defines the current focal point(s). Legislation dependent on public opinion tightens the mill-specific levels selectively, and the mills’ environmental strategies are either active (pre-emptive) or passive (reactive).

A very small subset of the possible combinations of the parameters (theoretically $1.5 \times 10^{116}$, in practice a much smaller number) has been chosen for closer scrutiny here. As a scenario evaluator, an extension of the criteria for an environmentally friendly product towards sustainable development is used. The view is of the entire industry, the time period is 1995–2010 and an economic dimension is added. The four expert definitions used when ranking products are extended in this way; a purely economic and an AOX/recycling-viewpoint are added. When the scenario descriptions are coded as follows: E=energy, R=recycled fiber, P=present (AOX+recycled fiber), SD1=sustainable development definition 1, the results described in table 5 are achieved.
Table 4. The chromosome for the 19–mill–case divided into genes.

<table>
<thead>
<tr>
<th>Level</th>
<th>Gene</th>
<th>Index for the parameters in the chromosome</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro</td>
<td>Conjuncture</td>
<td>1–2</td>
<td>Conjunctures 1 and 2 (2 conjunctures in scenario; the shift from 1 to 2 at moment defined by shiftyear parameter 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Shiftyear</td>
</tr>
<tr>
<td></td>
<td>External pressure</td>
<td>4–5</td>
<td>External pressure 1 and 2 (analogous with conjuncture parameter)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>Shiftyear</td>
</tr>
<tr>
<td></td>
<td>Public opinion as to water discharges</td>
<td>7–9</td>
<td>Opinion climate 1–3 (analogous with conjuncture parameter)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10–11</td>
<td>Shiftyears 1 and 2</td>
</tr>
<tr>
<td></td>
<td>Dependency of legislation on public opinion</td>
<td>12–14</td>
<td></td>
</tr>
<tr>
<td>Micro</td>
<td>Environmental strategy of a mill</td>
<td>15–33</td>
<td>1 &quot;Reactively&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 &quot;Pre-emptively&quot;</td>
</tr>
<tr>
<td></td>
<td>Mill–specific limit for suspended solids</td>
<td>34–52</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Mill–specific limit for COD</td>
<td>53–71</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Mill–specific limit for BOD</td>
<td>72–90</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Mill–specific limit for AOX</td>
<td>91–109</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Mill–specific limit for P</td>
<td>110–128</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Mill–specific limit for N</td>
<td>129–147</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>Deadline for limits</td>
<td>148–166</td>
<td>1996–2010</td>
</tr>
</tbody>
</table>

Table 5. The scenario rankings

<table>
<thead>
<tr>
<th>Best scenario</th>
<th>Worst scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD1</td>
<td>EE</td>
</tr>
<tr>
<td>SD2</td>
<td>PE</td>
</tr>
<tr>
<td>SD3</td>
<td>PE</td>
</tr>
<tr>
<td>SD4</td>
<td>PE</td>
</tr>
<tr>
<td>SD5</td>
<td>PP</td>
</tr>
<tr>
<td>SD6</td>
<td>EE</td>
</tr>
</tbody>
</table>
Attention is drawn to the following subresults:

- RR, the intensive recycling pressure option, achieves consistently bad ratings. Production shifts to the continent are one of the explaining factors behind this phenomenon.
- EE (see picture 4), the pure energy conservation option, is top-ranked for definition SD6, which focused on recycled fiber and AOX.

"Holistic" is a word that is brandished more and more with sometimes less and less justification. Here, its use is motivated. One-sided examinations lead at their worst to situations where one suboptimal solution is followed by another; where all resources are spent plugging leaks which cause other leaks. The closed cycle solution is a holistic solution; tunnel vision guarantees inferior solutions.

![Graph showing water discharges for the EE-scenario](image)


**Outlook**

The "environmentally friendly product" is a subjective concept, essential problems are plagued by complicated interdependencies and feedback loops, technology solutions for the pulp industry often drift from one suboptimum to another. Ways to counter these problems are

- identification of the subjective components and recognition of their importance
- focusing on the problems in their full extent and glory

An increasing use of computers and mathematical methods changes from an extremely useful activity to an absolute prerequisite for comprehension.
VESI-JA YMPÄRISTÖHALLINNON JULKAISUJA - sarja A
