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Pollution-Free Approaches of Research Works on Forest Products Field *1

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公害를 줄이기 위한 林產學 硏究의 方向 *1

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ABSTRACT

임산공업으로부터 발생되는 폐기물은 오염원으로서 그 위험도가 그다지 크지 않으나, 많은 공장들이 주거지와 인접해 있기 때문에 심한 오염원을 제공하는 것으로 인식되고 있다. 오늘날의 임산공업은 공장설립시 가장 중요하게 고려하는 사항으로서 환경에 미치는 충격을 최소로 하는 방향이며, 기본적으로는 무공해 측면에서 공장의 설계 및 작업이 이루어지고 있다.

본 논문에서는 임산공업으로부터 발생되는 오염원의 종류와 각각의 오염원들이 환경에 미치는 효과를 개관하였으며, 이들 오염원으로부터 환경을 지키려는 최근의 기술개발 및 연구 현황을 검토하였다.

환경오염을 줄이는 방법은 막대한 경비가 소요되기 때문에 원자재의 사용량을 줄이거나, 에너지 이용효율 등을 높이는 방향에서 노력하고 있지만 폐기물처리를 위한 효과적인 대안은 없다. 그러나 정부 및 산업체가 환경을 보전한다는 차원에서 어느정도의 처리수준이 적절한지에 관한 검토를 계속하고 있다. 그리고 폐기물의 회수 및 재이용이 환경을 보전하는데 큰 역할을 한다는데 정부, 지역사회, 산업체 및 개인간에도 그 인식이 커가고 있다.

1. INTRODUCTION

The progress of mankind from the primitive state to the present has always been closely associated with dependence on wood. It is to demonstrate that the higher the level of economic development, the greater is the dependence of men on wood. Also, wood is the only major raw material with a wide range of industrial uses, which is renewable, and hence capable of meeting the needs of a nation in perpetuity. Although wood resources is evaluating as a clean and environmentally benign energy, wood industry has some little and sometimes serious pollution problems.

Especially water pollution from the forest products industry is significant throughout many area of the world. It may not be dramatic, nor often catastrophic, such as high volume, high strength waste from pulp and paper industry. But, it may create severe degradation of water quality on a local basis due to the fact that so many sawmills and plywood mills are located on riverside and sea-

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shore.

The principal activities or sources of wastes from the forest products industries which may degrade water quality are logging practices which result in soil erosion or deposits of tree limbs and brush in stream beds ; long pond overflow, or other storage practices which permit organic materials to be leached from logs ; the effluent from hydraulic barker system ; plywood plant wastes primarily from glue machine clean up ; and, effluents from hardboard and fiberboard plants.

Lots of research works have been done for new and improved methods of treatment of wastes from the forest and logging activities, the wood products industry, and the pulp and paper industry. Research is conducted through in-house studies of new systems or methods of treatment and through an extensive extramural program concerned with grants and contracts with universities, foundations, and industries to study, develop, and demonstrate new methods of treatment.

The following discussion will touch briefly on the origins of various pollutants from forest products industry and our recent improvement and development to reduce those pollution problems.

2. THE WOOD STORAGE AND TREATMENT AND THE ENVIRONMENT

Numerous sawmills, plywood mills, and pulp and paper mills, which are all a part of the leading forest products industry require large inventories of logs to provide a continuous supply throughout the year. These logs are rafted and commonly found in rivers, lakes, sloughs, and manmade ponds, both for easy transportation and to prevent end checking.

Log handling and storage in water dislodges barks and permits organic materials to leach from the logs. Pine barks deposits exerted an oxygen demand of 0.4 to 2.0 g/m/day compared to 0.2 g/m/day in a control area with no bark. The wood sugar and other organics leached from the the logs exhibited BOD's in an average range of 40~60 mg/1, which is similar in strength to a weak domestic sewage and did exhibit some slight toxidity to salmon and trout fry.

The plywood industry (Boydston, 1971) uses three basic types of glue ; the protein glue for interior grade plywood ; the phenolic formaldehyde used for hardwood paneling. Each type presents different waste disposal problems and combinations of these may compound the problems. Plywood plants all produce wastes of high strength. Wastes from phenolic glues are toxic to aquatic organisms and cannot be treated by biological systems.

In treatment of glue wastewater, biological treatment is an effective method for treating protein or urea glue wastes but was not found feasible for wastes containing phenolic glues. Neutralization could be a feasible treatment process but provision must be made to handle the large amounts of sludge produces. The most feasible treatment system for phenolic glues was found to be a wastewater reuse program, thus eliminating the need for waste discharge. Plant flows are reduced by recycling to 40% of the original volume and the treatment plant was designed to reduce waste strength by over 85%. All plants should install and properly maintain adequate sized settling tanks for the removal of suspended solids. Coarse screens should precede the settling device.

Pollution (Thompson and Dust, 1971) of water during wood preserving operations with oily preservatives occurred principally during steam conditioning of wood and resulted from the entrainment of residual oil from the previous charge with condensate from steam operation. Barometric condensed cooling water containing condensed hydrocarbons, vacuum water, storm water from contaminated areas, and wash water from cleaning operations were the other major sources of polluted water. Drips from freshly treated charges and spillage from around cylinder doors were the main sources of contamination in salt-type treatments (Table 1).

Since these wastes contain heavy metal salts harmful to microorganisms, even in low concentrations, it is necessary the removal of those salts by primary precipitation prior to subjecting the wastewater to secondary treatments involving biological processes.

Table 1. Compositions of preserving effluents

Constituent	Concentration mg / 1
C O D	11,500 – 19,600
B O D	2,800 – 5,000
Total Solids (T.S)	6,340
Volatile T S	5,730
Phenols	17 – 85
pH	5.2
S S	1,420
Volatile S S	1,100
COD of raw Waste filtrate	7,080
Total N, total as nitrogen	89
N, ammonia as nitrogen	32
N, organics as nitrogen	57
Total P	〈 5.0

Flocculation and sedimentation are frequently employed as primary treatment for above wastewater. Jones and Frank (1971) reported that the phenol concentration in creosote wastewater was not reduced significantly by flocculation treatments which reduced the COD by 80 percent. Phenol is infinitely soluble in warm water and readily biodegradable, whereas pentachlorophenol is soluble only to the extent of about 17 mg / 1. Most of pentachlorophenol in wastewater was associated with entrained oils and were precipitated with oils during flocculation procedures.

Effluents from wood preserving plants usually had high turbidity readings caused by the presence of colloidal material, such as emulsifying oils, fiber fragments, and silt. Turbidity is not believed to be a serious problem in this type of waste because primary treatments involving chemical flocculation were ordinarily sufficient to reduce values to acceptable levels. Significant color improvement was obtained by clarification and percolation teatments through biologically-active soil. The odor of the effluents was not generally considered to be objectionable.

3. THE WOOD MACHINING AND THE ENVIROMENT

3.1 Noise and Vibration

It is common knowlege that noisy machinery has been for generations a characteristic of the wood processing industry. As researchers have proved, noise level increased as we added horsepower, accelerated cutter-head speeds, increased mechanization, and in general steped up the production tempo.

Noise is defined as unwanted sound or sound that is capable of degrading or damaging some human quality. Noise can have many adverse effects including damage to hearing, disruption of normal activity, and general annoyance. In industrial situations, noise can also cause worker fatigue and irritability and difficulty in communications and on-the-job training. These can all lead to a loss of productivity and decrease efficiency.

Table 2. Permissible noise exposures as contained in the Walsh-Healey Act.

Duration / day hr.	Sound level dBA
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

The mostly widely publicized noise standard is the Walsh-Healey Public Contracts Act (Lamb, 1971) which went into effect in May 1969. The permissible noise exposure levels and durations as specified in the Act are listed in Table 2. This regulation states that noise levels above 90 dBA are considered excessive and therefore, the duration of worker exposure must be limited. Christmen et al. (1956) summarized noise levels in various woodworking operations as in Table 3. Comparing the sound pressure levels of woodworking equiment with the standards of the Walsh-Healey Act immediately shows the seriousness of our problem.

Table 3. Overall average sound pressure levels for various woodworking machines.

Machine	Ave. Sound level dBA
Planer	108
Moulder	104
Shaper	100
Saws	100
Router	99
Jointer	98
Sander	97
Paint sprayer	91

Cudworth (1960) pointed two factors contributing to high sound levels in saws ; siren noise and resonant vibration. the siren effect results from teeth chopping the air, which is common with large teeth or deep gullets. Resonance vibrations are due to asymmetry in the saw disk or collar, and machinery problem. The noise of cross cut saw is 11.8 dBA higher and the rip noise is 2 dBA higher than conventional saws(Deaner, 1951 ; 1971). Depth of cut or feed rate does not significantly affect noise level (Kuleskov and Grirkov, 1966), but rpm, cutter-head and feed rolls are the principal source of noise(Schmutzler, 1967).

What can be done to reduce the noise at its source or screen it from the worker? There are several factors which should be considered when initiating a noise abatement program. It is necessary to first define the existing noise level and the primary sources of noise. In general, noise reduction will usually involve controlling noise at its source, its pathways, or controlling its reception by the worker. For air-borne noises consideration may be given to enclosure systems or sound absorptive material. For structural-borne noise, vibration isolator or damping material may be of help. Hearing protective devices do provide some protection.

Slotted platen lip was an advantage, especially in planing softwood, because in this operation the cutter-head is the major source of noise. the siren effect in saws could be eliminated by using a saw with a larger number of teeth and smaller gullets, by technique of slotting saws. The resonance noise could be reduced by better saw maintenance in hammering and setting, improved collars, and dampening tape. Several approaches to noise control were done such as modified room materials, machine dampening, enclosures, and personal ear protectors.

3. 2 Solid Wastes Disposal (Incineration)

Landfills were once the answer to the solid waste issue, but not anymore. Landfill capacity has decreased. People don't want existing landfills to be expanded or new landfills to be created. Also, with more strict landfill regulations and a decreasing number of acceptable sites, the cost for landfilling has increased abruptly and is certain to continue.

From the 1700s through the early 1900s, wood was combusted to produce ash for chemical extraction. The ash was mainly used to produce potash for fertilizer, but some also went into soap and glass manufacture and into potassium cyanide used in the recovery of gold from tailings and low grade ores(Bradley, 1915). According to two-time oil shocks, energy from biomass has been increased. Most of biomass energy comes from saw mills, paper mills, and electrical generating plants that burn large quantities of wood residues to produce steam and electricity. The ash residue is becoming a significant disposal problem as environmental regulations become more stringent and landfill sites become less available and more expensive.

Several ash disposal and utilization methods were evaluated in the late 1980s as environmental concerns increased. In America, apperoximately 15% ash is landfilled, 80% is land applied, and 5% is disposed of in some other way, mainly as a sewage sludge composting agent(Greene, 1988). In Europe, ash is used as a feedstock for cement production, a soil amendment on forest lands, and roadbase material. Also ash was used to neutralize acidic wastes due to the high alka linity and the absorbent nature. Gray et al. (1988) evaluated the treatment of landfill leachate with wood-coal ash. About 33% of the BOD and COD and 88% of the total suspended solids were removed. In addition, the ash removed 80~100% of the heavy metals. This study suggested that ash could be used to cover landfills or added to landfill leachates to reduce metal and organic content of leachate. Ash has been used effectively as a bulking and odor agent in composting of municipal sewage sludge in aerated static piles (Logsdon, 1989 ; Hart, 1986).

Wood ash is a valuable liming agent and soil amendment that enhances agricultural and forest soils and replace macro-and microelements removed during plant growth and harvesting (Etiegni, 1990 : Magdoff, 1984 ; Gray 1987). Typical reactions of wood ash were shown in Table 4. Land application of ash appears to be a safe, cost-effective disposal method, assuming transportation distances are relatively short. But, application rate should be limited to a level that maintains the soil pH within acceptable ranges for plant growth.

Table 4. Typical reactions of wood ash components

Wood + O_2	→	Charcoal + CaO + K_2O + M_xO_y + CO_2 + H_2O
CaO + H_2O	→	Ca(OH)
$Ca(OH)_2$ + CO_2	→	$CaCO_3$ + H_2O
$CaCO_3$ + H_2O + CO_2	→	$Ca(HCO_3)_2$
K_2O + H_2O	→	2 KOH
2 KOH + CO_2	→	K_2CO_3 + H_2O

Many regulatory agencies have difficulty in classifying wood ash. Under the Resource Conservation and Recovery Act in America, ash is not characterized as a hazardous waste because there are no pH cirteria for a solid. But, the State of Washington classifies wood ash as a dnagerous waste when its pH exceeds 12.5. This classification necessitated special handling and disposal procedures which have caused major problems for several ash generating facilities. As in Table 5, heavy-metal concentrations in ash do not appear to be a significant problem because the extractable metal concentrations of wood ash did not exceed the limits of the Environment Protection Toxicity Test (EPA, 1986) for classification as a hazardous waste. As a conclusion, the recycling of ash back to agricultural lands can help improve soil productivity and also conserve valuable landfill space. Land application appears to be a safe and economic method for disposing of and utilizing wood ash.

Table 5. A comparison of heavy metal in wood ash, limestone and soil

Metal	Concentration, ppm			
	Standards (U.S.)	Wood ash	Ground limestone	Average soil
Cd	10	3.5	0.04	0.06
Cr	1,000	26.1	11	100
Cu	1,000	123	–	20
Pb	700	28	9	10
Ni	200	75.5	–	40
Zn	2,000	521.6	–	50

* Source : A.G. Campbell, Tappi 73(9) ; 141~146(1990)

4. THE BOARD MANUFACTURING AND THE ENVIRONMENT

4.1 Emissions of Formaldehyde

For many years the wood industry has used condensation polymers of formaldehyde as woodworking adhesives. Among these adhesives are urea formaldehyde, melamine formaldehyde, phenol formaldehyde, and resorcinol formaldehyde. These adhesives to give a greater or lesser extent give off free formaldehyde during their use in the producing plant and during storage or use of the resulting glued wood products(USDA, 1969). In the early days of the wood industry, plants were small and the problem was not as great as it is today. This simply means that in today's plants there is much larger quanity of glue and glue surface available to evolve formaldehyde odor.

Experience in our own wood industry indicated that the workers sometimes bothered by the formaldehyde odor concentration in the layup area. During a period of increasing instances of accidents involving smashed fingers or hurt toes and legs, many employees indicated on their accident report that they felt the formaldehyde odor in some way had been a contributing cause of the injury (Freeman and Grendon, 1971). Thus, it became critical concerns to find out what odor level could be tolerated (Table 6).

Table 6. Emission classes of W. Germany regulation for HCHO release of PB

Emission class	HCHO equilibrium concentration, ppm
1	〈 0.1
2	〉0.1 − 1.0
3	〉1.0 − 2.3

The evolved formaldehyde vapors are a major or minor hazard depending on concentration. Sax(1951) reported that the vapors have a suffocating effect and irritate the mucous membrane. Burning of the eyes and nose, weeping, and irritation of the throat result. Complaints and claims by workers in the plant as well as by ultimate consumers of the board products rapidly led to "low odor" boards binder. Urea-formaldehyde binders which typically are made by using a lower molar ratio of formaldehyde to urea and also by incorporating some amine sequestering agents or free urea to absorb any free formaldehyde that is liberated.

4. 2 Adhesive Wash Water

In plywood plants considerable quantities of liquid wastes are produced from the block heating vats or chambers, the leakage of hydraulic oil, cleaning of veneer dryers, and cleaning of adhesive handling equipment as in Table 7 (Frank and Eck, 1969). The adhesive wash water (Haskell, 1971) is a particularly troublesome waste to dispose of because of its dark color, high alkalinity, heavy load of suspended solids. Wash water comes from wash down of adhesive mixers, storage tanks, transfer lines, and application equipment. The waste changes the color and clarity of the water. As dilution takes palce the suspended solids begin to settle. In a confined area the solids may cause suffocation of fish. Death of fish and other pond life may also be caused by the high alkalinity of the wastewater and by the phenolic substances. The solids settling to the bottom of the pond or stream may destroy bottom life of the type necessary for survival of most fish life. Sludge may also destroy spawning beds. The presence of phenolic bodies may show up in the odor and taste of drinking water (AFS, 1967).

Table 7. Chemical analysis of plywood glue wastes after settling

Analysis & Units	Plant #1	Plant #2	Plant #3
pH	11.6	9.4	10.8
COD, mg /1	1,814	1,917	1,621
TOC, mg /1	772	723	540
Total P, mg /1	15	9	12
Total N, mg /1	110	64	3
Phenols, μg /1	1,667	1,790	222
S S, mg /1	148	356	330
D S, mg /1	1,479	1,458	790
Total solids, mg /1	1,627	1,814	1,120
Total volatile SS, mg /1	125	338	322
Total volatile S, mg /1	1,122	1,267	919

*Source : J.R. Boydston, FPJ 21(9) : 58−63 (1971)

Some methods of disposal are discharge to a stream, lagooning, municipal sewage treratment, precipitation with acid, incineration, and reuse. Lagooning may be satisfactory depending on the location of the plywood plant and the size of the lagoon. The lagoon acts to dilute the liquid wastes so that suspended solids will fall to the bottom of the lagoon. Dilution also lowers the pH of the waste. The BOD and COD and phenolic bodies content are reduced. The overflow from the lagoon is usually drained to a stream. But the disadvantages of lagoons are the large installation costs and the need for large pieces of land. The best mothod is to use the wash water to replace fresh water in adhesive mixes. Good quality adhesives can be made with wash water substituted for fresh water in the mix.

5. THE PAPER INDUSTRY AND THE ENVIRONMENT

The pulp and paper industry's involvement with the environment begins with its use of wood as its primary source of fiber, continues through its use of large amounts of water in its processing of that fiber, and ends with the final disposal of the basic products-paper-in some way. Along with the water consumed, the industry affects the airwith by-products of the chemical reactions involved in the pulping, chemical recovery, and power generation portions of the process.

While the industry has made great strides in the past decades in waste and pollution control, the future will require no letup in improvements. The air and water pollution contributions from the paper industry worldwide have become a major source of environmental controversy between industry and communities. The environmental issues affecting the paper industry are :

- Wood procurement
- Water use land discoloration
- Chlorinated by-products in the waste stream
- Odor control
- Acid desposition and stack emissions
- Waste paper and recycling

5. 1 Wood Procurement

The pulp and paper industry is known to the public as a large consumer of wood. As long wood remains the most efficient source of fiber for papermaking, the paper industry will remain a part of this issue. The fiber raw material is a dominating cost element in pulp manufacture. It greatly influences product quality as well. Despite alarming forest devastation in certain regions, the forest-based industry should be able to secure its raw material supply, provided appropriate silviculture and forest regeneration programs are implemented in ciritical areas. An increasing proportion of the wood will be derived from plantations. Because species such as eucalyptus grow much faster than softwood, it is evident that a gradual shift towards the use of more plantation hardwood fibers will take place.

Long term relief may come from substituting nonwood fiber source such as kenaf and greater use of agricultural fiber such as bagasse, wheat straw, and others, but for now the harvesting of a tree will still cause resentement among a certain segment of the public.

5. 2 Water Pollution Problem

The highest water use is for drinking purposes. Pollution from domestic sewage will impair water portability due to bacterial infection. Substances of industrial origin may adversely affect the taste and odor of drinking water. Other problems such as foaming, radioactivity, or heavy metal ion contamination have been encountered in spectific situations.

In spite of its use of large volumes of water, the pulp and paper industry uses only 1% of all the industrial water consumption in the world (Kline, 1980). However, these numbers fail to mention that effluent from pulp and paper mills affects the quality of approximately 40 % of all the rivers in the world (EPA 1976). This impact on protable water makes the industry subject to a great deal of scrutiny by regulatory agencies and public bodies.

The pollutants in the effluent discharged from pulp and paper mill are pH, temperature, BOD, COD, suspended solids, toxicity, and color. The other pollutants and the amount of color in the mill's effluent vary depending on the type of pulping and bleaching processes used.

A Water Pollution Control Act was passed in 1956 in United States which required all states to adopt regulations requiring wastewater treatment for industries and municipalities. Primary treatment(wastewater or solids removal) was required of all new facilities, and secondary treatment (reduction of organic contaminations) was required of some mills. This was expanded in the 1960s and 1970s to require all mills to provide primary and secondary treatment. While the level of treatment required varies, generally 85~95% of organic contaminants removal is required for all pulp and paper mills. Approximately 99% of suspended solids removal is required.

Conventional wastewater treatment systems provide for the removal of suspended solids and biologically oxidizable material and for pH and temperature control. These systems usually combine primary physical-chemical treatment with secondary biological treatment and clarification (Table 8). The conventional biological treatment processes include activated sludge, aerated stabilization basins, oxidation ponds or lagoons, and trickling filters (Jank, 1976). These systems utilize a heterogeneous population of microorganisms to convert soluble organic matter to new cellular material and detoxify mill wastes.

Table 8. Normal waste removal efficiencies

Removal methods	Removal efficiencies, %			
	SS	BOD	COD	Color
Primary treatment				
Sedimentation basin	50−90	10−40	10−30	−
Gravity clarifier	60−90	10−40	10−30	0−10
Dissolved air flotation	70−95	20−50	10−40	−
Secondary treatment				
Oxidation pond	0−90	30−50	−	0−10
Trickling filter	−	30−70	20−50	0−15
Aerated lagoon	−	40−85	30−60	0−10
Activated sludge	−	75−95	30−70	10−30
Irrigation	−	60−95	−	−
Sedimentation basin	60−95	−	−	−
Secondary clarifier	70−98	−	−	−

The bacteria are the most important micororganisms in these processes, and are very efficient in reducing the BOD of the wastewater. However, bacteria do not have the enzyme systems necessary for rapid degradation of the colored compounds, lignin and its degradation products, in the effluents. As a result, the colored wastewater from bleach plants passes through conventional biological treatment systems relatively unchanged (Ganczarczyk, 1972). Treated effluents may still contain high amounts of color and low, but still serious, levels of chlorinated aromatics as shown in Fig. 1.

Color in wastewater arises from compounds which absorb light at wavelengths in the visible region of the light spectrum. Lignin and its degradation products are the principal source of color in pulping and bleaching effluent stream. The removal of color from pulp and

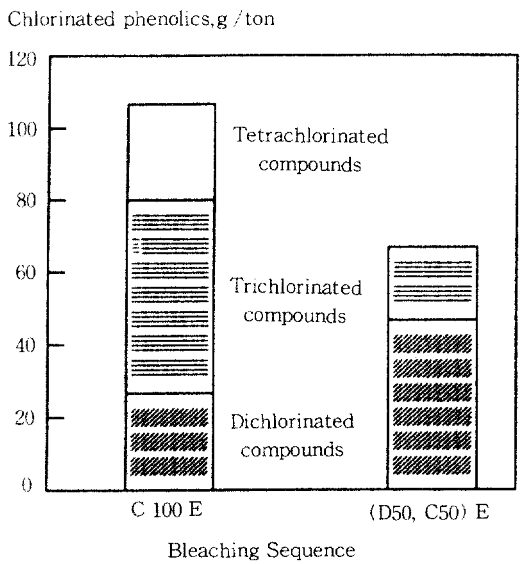

Fig. 1. Effect of ClO_2 on formation of chlorinated phenolic compounds during pulp bleaching

* Source : P. F. Earl & D. W. Reeve, Tappi 73 (1) : 179−183(1990)

paper mill effluents has been the subject of increasing concern and governmental regulation for several reasons (Rush and Shannon, 1976). The color imparts aesthetically objectionable feeling to the public, absorbs sunlight needed for underwater plant growth, and cuts off oxygen sources vital to aquatic community.

Some years ago, it was learned that white-rot fungi can attack and decolorize chlorinated lignin compounds in kraft mill effluents (Marton et al., 1969). An early attempt to exploit this discovery was made in Canada in 1974 in a study by the Nova Scotia Research Foundations cited by Paice and Jurasek in 1984.

A biological treatment system using a white-rot fungus *Phanerochaete chrysosporium* to decolorize bleach plant effluents has been proposed(Eaton et al., 1981 ; Prasad & Joyce, 1991) and developed by the U.S. Forest Products Laboratory and North Carolina State University as the FPL/NCSU "MyCoR(Mycelial Color Removal) process". These systems are usually 10 times less expensive than physicalchemical processes, and thus could offer an economic alternative for color removal (Kirk et al., 1975 ; 1978 ; Huynh, 1985 ; Chang et al., 1987). The MyCoR Process, in which fungus is grown on rotating discs, converts 70% of the organic chlorides to inorganic chlorides in 48 hr., while decolorizing the effluent and reducing both BOD and COD by about half. The MyCoR process has been licensed for commercial use(Fig. 2). In 1985, it was reported that the white-rot fungus *P. chrysosporium* can degrade PCBs, dioxins, and even DDT(Bumpus et al., 1985 ; Eaton, 1985).

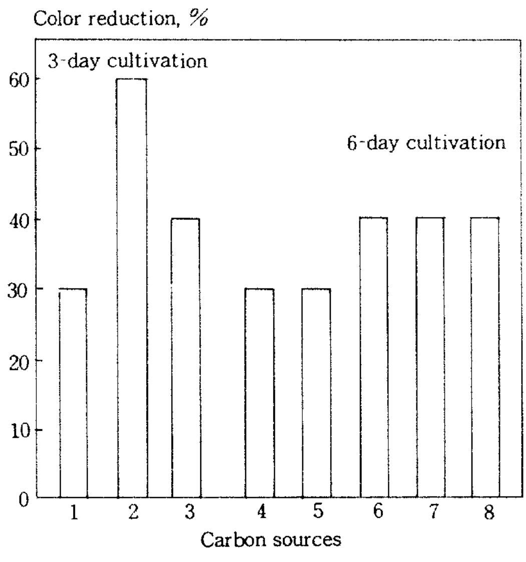

Fig. 2. Influence of different carbon sources on decolorization of K P bleaching effluent.
1. Control, 2. Glucose 0.05%,
3. Sucrose 0.05%, 4. Bark 0.3%
5. Powdered bark 0.4%, 6. Pulp 0.45%,
7. CMC 0.01% 8. Pith 0.2%
* Source : D. Y. Prasad & T. W. Joyce, Tappi 74(1) :165-169(1991)

Livernoche et al. (1981. 1983) and Royer et al. (1983) have experimented with another white-rot organism, *Coriolus versicolor* ; they also reported 80% color removal in three days treatment. The organism can be immobilized in beads of calcium alginate, and a cascade system of reactors containing fluidized beds of the immobilized organism has been tested successfully on a laboratory scale. Bacterial cultures too have been marketed for decolorizing kraft mill effluents. Examples are strains of *Pseudomonas aeruginosa,* which are capable of reducing kraft mill effluent color by 26-54% or more under aerobic conditions (Blair, 1984 ; 1985 ; Ghosal, 1985 ; Rojo, 1987). Recently, workers at Amgen, a biotechnology company located in Thousand Oaks, California, reported on a recombinant *Escherichia coli* that can efficiently degrade trichloroethylene after growth in the presence of toluene (Winter et al., 1989).

As far as dioxins concerned, small amounts of dioxin compounds such as polychlorinated dibenzo-*p*-dioxin (PCDD) and furans(PCDF) have been detected in pulp mill sludge and effluents (EPA, 1989 ; McBride et al., 1988 ; Clement et al., 1989 ; Swanson et al., 1987. 1988). Possible precusors for dioxins include the unchlorinated analogs, dibenzofuran (DBF), and dibenzo-*p*-dioxin (DBD), as well as low molecular weight lignin fragments generated during pulping, which include diaryl ethers, substituted phenols, and catechols. Additional washing and aqueous ethanol washing of brownstock pulps could reduced the level of PCDD/F by as much as 25% and 80%, respectively(Hise and Hintz, 1990). But, the majority of dioxins in the environment come from sources such as the burning of domestic trash, vehicle exhaust, and natural sources such as forest fires.

For promising solution those pollution problems, first and foremost is the use of Oxygen in the pulp bleaching stage as a replacement for chlorine. Other process alternatives inlcude chlorine dioxide substitution, controlling residence time, extended delignification in pulping, and modified washing.

Table 9. COD and total color loading for conventional 5-stage belaching and biobleaching.

L/I		Bleaching sequence	
		CEDED (Conventional)	FCED (Bio bleaching)
COD kg/t of pulp	C	10.08	5.03
	E_1	17.64	8.86
	$D_1E_2D_2$	3.07	1.78
	Total	31.42	15.94
Total Color		38.25	8.23

* Source : K. Sakai et al., Tappi 74(11) : 123-127 (1991)

The strong interest in developing cost-effective technologies based on biological systems (Tab. 9) is bound to have an impact on our problem of removing colors and chlorinated organics from pulp mill effluents.

Table 10. Water use

Year	Water use (gal/ton)
1959	36,000
1971	28,000
1975	26,700
1985	19,100
1988	17,500
1990	15,000

Industry waste minimization is necessary to conseve disposal options and provide waterwater plant flexibility. Also public recycling and reuse are necessary to conserve natural resources and reduce waste disposal needs. For example, in 1959 chemical pulping and papermaking averaged 36,000 gallons of water to produce a ton of pulp. In 1971 this had been reduced to 28,000 gallons, and in 1990 the average is less than 15,000 gallons/ton as shown in Table 10 (Berger, 1990).

An NCASI (National Council for Air and Stream Improvement's) survey(Miner and Unwin, 1991) shows that the U.S. Paper industry has significantly reduced water use and wastewater loads since 1975 as shown in Table 11.

Technology in white water treatment has made it possible to begin serious discussion of a truly "closed" mill in which intake water would be limited to boiler needs and evaporation, and effluent would be nonexistent or, if there is effluent at all, would be at the same quality at the intake water. In Kuwait, on the Persian Gulf, a recycled mill using only standard equipment operates in a desert community that must import its water. Its daily water consumption is less than 1 % of a typical North American or European mill. While

Table 11. Reduction of wastewater by recycling

	Wasteloads reductions %	Wastewater quantities reductions %
Wood Preparation		
Water reuse	80-90	70
Long log	95	85
Pulping Process		
Water reuse	30	30
Liquor recovery	60-90	60-90
Pulp Screening		
Water reuse	20-60	20-60
Washing & Thickening		
Use of vacuum filters	20-60	20-60
Ms countercurrent V.F.	60-90	60-90
Bleaching		
Water reuse	30-80	...
Paper Machine		
Fiber recovery & white-water reuse	20-70	60-80

this may not represent a universal solution, it does indicated the degree of improvement possible without technology breakthroughs. Legislation on effluent in several U.S. States and in western Europe will force an number of urban mills to reach this level of water comsumption and treatment before the turn of the century.

5. 3 Air Pollution Problem

The major types and sources of air pollutants of prime interest to the pulp and paper industry are summarized in Table 12. The most severe air pollution problems are usually associated with kraft pulp mills.

Kraft mill odor is principally due to four reduced sulfur gases(i. e., hydrogen sulfide, methyl mercaptan, dimethylsulfide, and dimethyl disulfide), referred to collectively as "total reduced sulfur" or "TRS emissions". Some characteristics of these gases are given in Table 13.

Table 12. Major air pollutants

Type	Source
Fine particulates	Principally soda fume from the recovery furnace
Coarse particulates	Most notably "fly ash" from hog fuel and coal-fired burner
Sulfur oxides	Sulfite mill
Nitrogen oxides	All combustion processes
Reduced sulfur gases	Mainly from kraft pulping and recovery opreations
Volatile organic compounds	Noncondensible gases from digester relief and spent liquor evaporation

Table 13. Characteristics of kraft mill reduced sulfur gases

Compound	Type of odor	Odor threshold
Hydrogen sulfide	Rotten egg	1 ppb
Methyl mercaptan	Rotten cabbage	1 ppb
Dimethyl sulfide	Vegetable sulfide	10 ppb
Dimethyl disulfide	Vegetable sulfide	10 ppb

Air pollution abatement efforts in the pulp and paper industry are concerned with the control of gaseous and particulate emissions. In particular, odor control is perhaps the most significant task facing the industry. Although the odorous materials(principally reduced sulfur gases) are not dangerous in airborne concentrations, community resentment tends to focus on the obvious and prevailing odor. All types of airborne emissions may be partly controlled by operating strategies or by modifications to the production process. However, some type of external treatment of discharging gas volumes is also required in most pollution control applications. The major strategies for odor reduction are black liquor oxidation, control of sulfur concentration in the recovery cycle, "proper operation" of the recovery furnace, and collection-incineration of noncondensible gases from cooking and evaporation operations.

Table 14. Air pollution control equipment

Pollutants	Control equipment
Gases and Vapors	Catalytic combustion
	Thermal incineration
	Adsorption
	Wet scrubbing
Particulates	Mechanical collection
	Fabric filtration
	Dry scrubbing(Dry granular filtration)
	Electrostatic precipitation
	Wet scrubbing
	Hybrid designs

Elimination of odors is not as straightforward as the elimination of particulates and /or odorless gases. Odors are difficult to measure and a tolerable or acceptable level is not easily defined. The task if to reduce the amount of odorant at the point of emission by whatever methods are abailable, and then disperse the emitted material to the maximum extent so that it is far less concentrated by the time it reaches any point where there are people to smell it.

In 1970, tall chimneys were used as pollution control devices to disperse contaminants and reduce the concentration at ground level to a permissible value. While specific limits are now applied principally to the discharge concentration, a high stack still plays an importand role with respect to odor control.

Strictly speaking, there are three types of air pollutants : particulates, gases(odors), and liquid droplets(e.g., mists and aerosols). However, liquid droplets are easy to remove not normally considered as a pollution problem. The main types of equipment available for the removal of particulates and gases are listed in Table 14. The proper choice of equipment is determined by careful assessment of performance requirements, process and safety considerations, and economic factors. It can be noted that the scrubber is the only class of equipment suitable for simultaneous removal of both particulates and gases.

Table 15. Odorous emissions control technology capability in the kraft process

	lbs reduced S /ton of pulp	
	No control	Control
Recovery furnace	9	0.1
Contact evaporator	10	0.1−0.15
Lime kiln	1−2	0.1−0.2
Digesters & evaporators	2−7	0
Brownstock washing system	0.8	0
Blow system	0.1	0
Smelt tanks	0.1	0.01

• Source : H. F. Berger, Tappi 73(8) : 82−83(1990)

Table 15 summarizes data from NCASI reports(Berger, 1990) and clearly shows that the kraft industry has made tremendous progress in reducing odorous emissions. Kraft mills in every state are currently required to utilize the best available control technology for total reduced sulfur(TRS) as well as for particulate emissions.

Most effective remedy for reducing emissions is to burn the noncondensible gases in an incinerator(or lime kiln) and to use a limestone and water scrubber for the sulfide compounds. While these improve the situation, the real solution will come from completely controlling gaseous emissions from the pulping process.

5. 4. Wastepaper and Recycling

Paper is nominally recyclable which has led many to demand that the paper industry use more secondary fiber. Recycling paper can concentrate inks and other nonfiber components into amounts which consitute hazardous waste, and recycled paper without those chemicals removed is unacceptable for most uses.

The two real roadblocks to increased use of secondary fiber are the contamination of the paper and the lack of products that allow secondary fiber to be used in their manufacture. Contamination of most waste paper prior to collection makes it difficult or impossible to reuse, and cost-effective recycling of grades other than newsprint and old corrugated clippings is almost never done.

Wastepaper recycling in the industrialized countries is expected to rise above the 50% level currently. In addition, economic incentives and advances in paper technology may stimulate wastepaper collections in developing countries so their rates become economically signicant for their import-export flow. With increased public environmental awareness, more wastepaper should be recovered from households in the coming decades. The amount of wastepaper recovered is almost the same as the amount used. As a result, only as much is collected as is needed.

The watsepaper recovery problem increasingly will be seen to include the cost of household refuse disposal and the reduction of disposal costs, which will result from an increase in waste paper recovery. A breakthrough in the technology for the use of used fibers could result in a lower cost to use many wastepapers mixed other waste. This would, in turn, reduce the cost of additional wastepaper recycling and give impetus to increased collections.

Improved deinking methods, including the treatment of inks with hydrogen peroxide and other chemicals, is one thechnology which will help in recycling. Better contaminants removal equipment and methods will help in recycling corrugated containers. Changing the limits for secondary fiber in linerboard, setting quality standards for food packaging board based on contaminants level and not on fiber source also would help increase recycling. Other improvements, especially at the collection and storage facilities, can increase the amount of fiber which will be available for recycling.

Research in the areas of recyclable inks, better repulping and papermaking processes, recycled fiber characteristics, and recycled paper and board properties is perhaps our greatest need to meet the recycling challenge.

6. CONCLUSION

An important consideration of modern Forest Products mill design and operation is to minimize losses from the process and to treat mill effluents so that their impact on the environment is minimal and essentially non-pollution. The driving force of pollution abatement programs within industry is generally capital-omtensive and entails significant operating costs. The incremental cost attributed to pollution abatement is now accepted as a cost of operation and is usually passed along to the customer in the form of higher priced products.

Wastes from the forest products industry are not normally of large volume or strength as some of the more drastic pollution sources, but location of sawmils, board mills and pulp and paper mills on small river and seashore near from the residence can result in significant pollution problems. The ever-increasing competition for water will also require higher degrees of treatment by the industry if water quality degradation is to be aboided.

While abatement programs are expensive, the typical mill enjoys concomitant benefits of reduced raw material usage and better overall energy utilization. There can be little argument against sensible waste management. However, debate is ongoing between Industry and Government as to what level of discharge is required for adequate compliance with the spirit of environmental protection. The present state-of-the-art is such that the characteristics of these wastes are well known and economical methods of treatment are now available for the prevention of pollution by the forest products industry.

Concerning recycling wastes, the age of recovery will continue to lower and eliminate traditional barriers among suppliers, customers, their customers, and end consumers as team efforts bring the talent together to handle the logistics of gathering, handling, separating, and marketing by-products of solid wastes. At the same time national, state, and local governments and municipalities are compelling industry to accelerate recycling as part of a national resource recovery initiative and reduction of waste disposal.

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