EPA-R2-73-184
APRIL 1973

Environmental Protection Technology Series

State-of-the-Art Review of Pulp and Paper Waste Treatment

Office of Research and Monitoring
U.S. Environmental Protection Agency
Washington, D.C. 20460

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April 1973

STATE-OF-THE-ART REVIEW

OF

PULP AND PAPER WASTE TREATMENT

By

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Contract No. 68-01-0012
Projects 12040 GLV
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OFFICE OF RESEARCH AND MONITORING
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Price $2.85 domestic postpaid or $2.50 GPO Bookstore

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ABSTRACT

This report sets forth the state of the art in the treatment of pulp and paper mill wastewater as it stands in 1971. In order to lay a background for the sections on treatment, a review of both the general economic position of the industry as a whole and the major production processes is included. Such a background is needed since a considerable degree of loss control is practiced within the processes and water recycling is an almost universal practice in this industry.

Included also is a review of the water quality problems which the applied treatment processes are designed to rectify. Performance data for treatment processes and systems are presented together with a review of the applicability of common analytical methods to the measurement of waste characteristics and treatment effectiveness. The techniques used to monitor waste flowages for control purposes and as means of recording treatment efficiency are included.

Finally, the remaining problems relative to control and treatment of pulp and paper mill spent process waters are pointed out. Research and development needs directed toward solving these problems are defined in the light of such programs which are currently underway.

This report was submitted in fulfillment of Contract No. 68-01-0012 under the partial sponsorship of the U. S. Environmental Protection Agency. Questions concerning this report should be directed to Dr. Harry Gehm, WAPORA, Inc., 6900 Wisconsin Ave. NW, Washington D. C., 20015.

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SECTION I

RECOMMENDATIONS AND CONCLUSIONS

A review of the body of this report combined with the author's intimate contact with mill personnel leads to the following recommendations and conclusions on the immediate situation of the pulp and paper industry in maintaining and improving the quality of receiving waters with the aid of the available technology.

Receiving Waters

Satisfactory methods are available for handling the problems accessory to waste treatment and discharge, such as the removal of trash and the control of foam from pulp and paper mill effluents. While biological treatment can generally reduce the taste- and odor-producing capacity of pulping wastes in receiving waters, this area is receiving additonal attention by industry research groups. Since these tastes can be absorbed by the skin of fish it is desirable to eliminate the substances which create them. However, these substances rarely cause a problem in downstream water supplies that cannot be controlled by available potable water treatment techniques. When chemicals, such as hydrocarbons, used for foam control, are responsible, the problem can be solved by changing the foam control agent to one having a low taste and odor level and which is not absorbed by aquatic organisms.

As pointed out by Gellman and Blosser of the National Council for Air and Stream Improvement, Inc. (NCASI), the bulk of the industry's effort in pollution control has been directed toward the protection of fishing resources, and water quality standards are to a large degree keyed to the successful propagation, migration, growth, and harvesting of fish. Because of control activities, the industry's wastes have played no significant role in the annually-compiled fish kill statistics. Also, control measures have largely eliminated slime growths on commercially important fishing streams, and instances of the restoration of fisheries through cooperative programs of fish ladder reconstruction, river stocking, and effluent treatment have evidenced cooperative use of surface waters for both manufacturing and fishing. Research on the all important matter of aquatic productivity is well underway and is supported by both the federal government and the industry. Extension of such studies could shorten to some degree the time in which answers to the relationships between effluent quality and productivity are better established.

Analyses

The matter of bacterial quality of waters receiving pulp and paper mill effluent is a very complex matter as pointed out in the body of this report. It is not possible to judge potable quality of such waters by even the confirmed _E. coli_ index, and existing disinfection methods are not satisfactory for pulp mill effluents and attempts to use them could give rise to tastes and odors. It appears that complete segregation and treatment of sanitary wastewaters from process sewers represents the best method of protecting receiving waters from contamination by pathogenic organisms.

In any program involving effluent standards, the importance of the method of analysis to be employed for judging effluent quality parameters arises. It has been pointed out frequently, by both the pulp and paper industry and state regulatory agencies, that some of the techniques set forth in "Standard Methods for the Analysis of Water and Waste Waters," which are commonly used for effluent analysis, are unsuitable for use in analyzing pulp and paper mill wastes. This applies particularly to the determination of solids. In order to overcome these difficulties, various organizations involved in effluent control have developed special techniques which they believe provide more precise measurements than "Standard Methods" for general use or for application to particular wastes. It is strongly recommended that a survey be made of the methods employed throughout the country for determining the various classes of solids present in pulp and paper mill wastes. A critical examination could lead either to a selection of specific existing methods or recommendations on the development of superior techniques through a research program involving intensive industry participation.

Clarification

Satisfactory methods are available for removing the bulk of the suspended solids from most pulp and paper mill effluents. However, some wastes, such as those from the production of filled and coated papers and from waste paper reclamation, contain finely dispersed pigments and debris which in very low concentration impart opalescence to receiving waters. Present treatment methods are not adequate to handle this problem. Even where applied, chemical coagulation fails to cope with it since this process cannot produce the practically 100 percent reduction in suspended matter required to remove the opalescence. A similar haze in the effluent can remain after biological treatment. In other cases coagulants do not function well at all or require excessive dosage.

Fine suspended matter of both organic and inorganic nature remains in dispersion and affects the light absorption capacity of the water adversely even at very low total suspended solids levels. The effect these effluents have on receiving streams is strictly one of aesthetics and depends upon the initial appearance of the receiving stream, light, and bottom conditions as well as general surroundings such as vegetation along banks. The ordinary methods for measurement of turbidity and color do not yield results which can be considered a reliable index of appearance.

From the above observations it appears that there is a need for finding means for clarifying some pulp and paper mill effluent to an extremely high degree without excessive capital or operating cost. Techniques applied to date, such as diatonite filtration and rapid sand filtration, failed for one reason or another and the polyelectrolyte coagulants have not provided an answer to this problem.

Color

Another problem associated with aesthetics is that of color of pulping and bleaching effluents. While the industry and EPA are carrying on an extensive program on the removal of color, little is being done to clarify the interpretation of progressive stream standards which take cognizance of the natural color of particular receiving waters. Color consists largely of non-degradable substances but represents only a part of this class of materials present in pulping and bleaching wastes. A clarification of the significance of such substances in relation to water uses is urgently needed so that future water quality standards and treatment needs can be established intelligently.

This also has bearing on water reclamation for mill reuse so that waste treatment costs can be optimized. Greater knowledge of the water quality requirements for the various processes of pulp and paper manufacturing, particularly for bleaching, is needed for proper assessment of approaches to reclamation.

BOD Reduction

This industry has developed and applied biological treatment to a high degree and methods for its application are well advanced. There appears to be no problem in obtaining BOD reductions of 85 percent during the critical seasons by these methods. Higher degrees of removal have been observed periodically but are not well documented. It appears that special measures may need to be taken to retain the fine biological floc lost to the effluent if BOD reduction values on the order of 95 percent are to be obtained consistently, as may be desirable in some circumstances. These losses are due to bulking problems in the activated sludge process and dispersed growth in the case of aerated stabilization basins.

Treatment and Disposal of Residues

The primary problem in treating liquid wastes from the pulp and paper industry is the processing and ultimate disposal of residues resulting from treatment processes. At present these are largely sludges of various types. These will be joined more and more by raffinates and brines as higher degrees of waste treatment and water reclamation are practiced in the future. Frequently, the choice of treatment methods to be employed at a particular installation is predicated upon the feasibility of handling the residues of treatment and, in some instances, the obtainable degree of purification is predicated upon the existence of adequate means for sludge handling. Even where successful and acceptable methods for handling these residues are available, the cost of doing so runs as high as 50 percent of the entire cost of treatment.

One of the major problems in residue handling is that of the failure of some sludges to thicken to a degree that they can be dewatered to the extent necessary for further processing and ultimate disposal. Examples of sludges which do not thicken mechanically to a practical degree are biolgical sludges resulting from activated sludge treatment of the wastes, water treatment plant sludges, groundwood pulping fines, lignin residues, and slurries obtained on clarification of some white paper mill effluents. Some of these will not thicken mechanically to more than 2 percent solids. Lacking a free draining sludge to blend with these, thus rendering them dewaterable by common techniques, there is no adequate or economically feasible method for disposing of them. Stabilization methods, such as digestion, heat treatment, or direct to land disposal, have been proven inadequate or are obviously too costly to warrant consideration.

Also included in this category are sludges from some paper recycle operations. These sludges are true hydrogels and the problem of removal of water of imbibition from these colloidal systems has been the subject of considerable study by Zettlemoyer and many others. It appears obvious, however, that unless means are found for releasing a substantial portion of the water of imbibition from such hydrogels, at a cost compatible with those required for treatment of the particular waste under consideration, a major problem will continue to exist. An adequate solution to the hydrogel problem presumes that the energy requirement involved, whether it be applied in the form of heat or chemicals, be within reasonable bounds and not give rise to serious secondary problems.

The need for more intensive basic surface chemistry studies in this area cannot be overemphasized, since until the thermodynamics of the problem are better defined it is unlikely that any appreciable progress will be made toward its solution. Edisonian research and revival of long dormant techniques incorporating refinements in machinery and conditioning agents have not shown signs of achieving a solution, and the research efforts presently being expended in this area are deemed highly inadequate.

A second class of residue which presents major difficulties are those which are dewaterable by commonly applied methods but which produce cakes high in ash content which cannot be incinerated. These can be calcined, but the costs and problems accessory to this process are prohibitive. NCASI is funding a research and development program directed toward developing improved disposal methods for these sludges, particularly land reclamation.

A third type of treatment residues which will undoubtedly become a major future problem are those consisting mainly of dissolved salts and organics. These result from demineralizing water, ash from incineration of spent process liquors (such as pulping wastes), and from water softening and effluent treatment in the reclamation of spent process waters. If the elimination of discharge of materials to surface waters is ever to be achieved, better means for disposing of these residues is mandatory.

The magnitude of the problems set forth above are exemplified in the recycling of waste paper. This frequently results in sewer losses approximating 50 percent of the bale weight of the waste reclaimed and the suspended solids losses from large integrated pulp and paper mills frequently approach 60 tons of dry solids daily. With the increasing interest in recycling of waste materials, the urgency of the problem becomes very evident.

While there has been, and presently is, considerable research and developm effort by EPA, its predecessor agencies, and industry directed toward the solution of these problems, it appears that it is inadequate considering the proportions of their increasing magnitude and the interdependence of water quality improvement on residue handling and disposal. Further, there has not been a coordinated effort involving the several facets of the residue problem. Thus it appears of major importance that all current studies be tabulated and examined as to their adequacy of approach to the overall problem so that the desirability of specific areas of research, both basic and applied, can be established. This could be followed by a designation of a major research area by EPA and of specific projects to fill in the gaps in the present fragmented program. Coordination with interested industry and qualified contractors would assist in determining the best means of cooperative program implementation.

SECTION II

INTRODUCTION

The Environmental Protection Agency retained WAPORA, Inc. late in 1970 to prepare a state-of-the-art document dealing with the treatment of liquid effluents produced from the manufacture of pulp, paper, and related products such as building boards and felts of wood origin. This project was designated as contract number 68-01-0012.

Because of the large number of processes and products involved, together with the fact that day-to-day process variations frequently occur at any single mill, no attempt has been made to cover all products separately. Rather than attempt this insurmountable task, products have been classified into recognized groups, and ranges of effluent characteristics set forth for these.

Since the response to unit treatment processes of the spent process waters from the manufacture of these classes of product is similar, a section covering general treatment methods and their performance is included in addition to the information presented on the response of specific wastes to treatment as indicated by field performance data. Since sludge handling and disposal are accessory to treatment, a section on these practices is included. Similarly, as some paper and paperboard mills employ public sewage systems to dispose of their process wastewaters, this matter is also discussed and the exclusiveness of this practice pointed out.

Cooperation of the industry and its associations in supplying information and critical review of sections of this report was obtained and was indispensable to the project. Data were also made available by state pollution control regulatory agencies as well as the EPA.

A special attempt was made to annotate the report and a very extensive bibliography is included. While this is by no means complete, it does include for the most part the most pertinent references on each subject. Some of these in themselves are summary reports and are thoroughly referenced and others are critical reviews of the literature.

It is believed that this report will prove helpful to the industry in selecting waste treatment systems which will enable it to meet water quality standards. It will also point out to regulatory agencies what can be accomplished by waste treatment and control as well as the limitations of various types of treatment. In the recommendations and conclusions the authors have stated what they believe to be the areas of research and development most needed to improve water quality through effluent treatment. Recommendations on problems accessory to treatment such as sludge handling and disposal are included.

SECTION III

PRODUCTIVITY AND ECONOMICS OF THE INDUSTRY

Growth trends in the paper and allied products industry as projected by the Economics Department of the American Paper Institute (API), the U.S. Forest Service, and the Bureau of Domestic Commerce (BDC) are set forth below. It is to be noted, however, that the Forest Service forecasts were made in 1967 and those of the BDC in 1970. These are the latest available to the contractor, although revisions are in progress in both agencies for 1972 publication.

The trends projected by API Economics Department were obtained from the various papers presented to industry groups and to the Food and Agriculture Organization (FAO) of the United Nations during 1971 (1). They are, however, subject to interpretation and qualification as discussed in References (2,3,4).

Because of the current economic cloudiness surrounding the growth rate of all U.S. industry, and particularly the pulp and paper segment of it, the contractor will not attempt to pass judgment on the present reliability of these projections.

They are, of course, pertinent to a state-of-the-art review of the industry's waste treatment as an indicator of the quantity and kinds of wastes to be treated and water requirements in the coming decade and beyond. Their usefulness is limited, however, by the fact that they do not, as is the case in any such forecasts, reflect future process changes and improved treatment practices. Nor do they take into account future legislative requirements.

Paper and Paperboard

Another factor to be noted in the following tables is that the BDC projections of growth are expressed in value of shipments (5), the Forest Service in apparent consumption which includes imports (6), and the API in the U.S. production alone.

U. S. FOREST SERVICE (6)
Apparent Consumption
Million Tons

	Paper	Board	Total
1970	32.0	28.3	60.3
1975	37.7	34.4	72.1
1980	44.4	41.5	85.9
1985	51.7	49.8	101.5

BUREAU OF DOMESTIC COMMERCE (5)

(000 short tons)

Industry	1970[1]	Percent Increase 1969-70	1971[1]	Percent Increase 1970-71	1975[1]	Percent Increase 1970-75[2]	1980[1]	Percent Increase 1970-80[2]
Paper Mills.................								
Paperboard	9,400	1	9,800	4	12,000	5	15,500	5.1
Building paper and board....								
Sanitary paper products.....	1,562	6	1,687	8	2,294.4	8	3,349.9	7.9
Quantity shipped (000 short tons)..........	3,298	2	3,513	7	4,189	6.5	5,220	6.5

[1]Estimated by BDC. [2]Compound annual rate of growth.

ECONOMICS DEPARTMENT, AMERICAN PAPER INSTITUTE (2)

Production

1,000 Short Tons

	Paper	Paperboard	Other Grades	Total
1970	23,220	24,940	4,297	52,457
1975	29,704	31,873	5,634	67,211
1980	36,035	38,590	6,745	81,370
1985	43,260	46,300	8,115	97,675
1990	52,700	55,700	9,850	118,250

(See Appendix 1 for production figures from 1947; this table also shows data on exports and imports.)

The following 1975 and 1980 projections of growth in the production of various paper grades were prepared by the API for the FAO (1). The categories used therein do not coincide precisely with federal usage. Therefore, in the table on Page 18 (2) showing forecasts for the various paper grades in 1985, the categories used are somewhat different.

		Production	
	1969	1975	1980
TOTAL PAPER AND PAPERBOARD, Total:	51,180	64,027	77,490
Newsprint	3,163	3,620	3,780
Other printing and writing paper (includes bristols; excludes thin and file folder)	10,562	13,678	17,030
Other paper and paperboard, total:	37,455	46,729	56,680
Household and sanitary paper plus special thin	3,931	5,259	6,615
Fluting paper and paperboard	4,244	5,544	7,020
Kraft paper and paperboard, total:	14,232	18,785	23,455
Kraft liner	10,986	14,762	18,620
Other kraft paper and paperboard	3,246	4,023	4,835
Folding boxboard and foodboard	5,908	6,726	7,570
Other paper and paperboard, not elsewhere specified, total:	9,140	10,415	12,020
Paper, n.c.s.	4,259	4,878	5,560
Paperboard, n.c.s.	4,747	5,387	6,290
Wet Machine Board	134	150	170

	PRODUCTION	
	1969	1985F
	-----(million tons)-----	
Newsprint	3.3	5
Other Printing and Writing Papers	11.2	22
Packaging and Industrial Converting	5.5	9
Tissue Papers	3.5	7
TOTAL PAPER	23.5	43
Unbleached Kraft Paperboard	11.6	18
Bleached Packaging and Industrial Converting Paperboard	3.5	5-1/2
Semi-Chemical Paperboard	3.6	5-1/2
Combination Paperboard	7.3	17
TOTAL PAPERBOARD	26.0	46
Construction and Other Grades	4.5	8
TOTAL PAPER AND BOARD	54.0	98

Following are the Forest Service projections of demand for paper and board by grade through 1985:

	1970	1975	1980	1985
	(Millions of tons)			
Newsprint	9.7	11.0	12.5	14.3
Groundwood paper	1.2	1.3	1.4	1.5
Book paper (total)	6.3	7.8	9.5	11.4
Coated	3.8	5.0	6.3	7.8
Uncoated	2.5	2.8	3.2	3.6
Fine Paper	3.1	3.7	4.6	5.6
Coarse and Industrial Paper	6.3	7.4	8.6	9.8
Sanitary and Tissue Paper	3.7	4.7	5.9	7.1
Construction Paper	1.7	1.8	1.9	2.0
Container Board	14.6	18.2	22.4	27.4
Bending Board (total)	7.1	8.4	9.9	11.6
Special Food Board	3.0	3.7	4.6	5.6
Folding Box Board	4.1	4.7	5.3	6.0
Building Board (total)	3.2	3.9	4.7	5.6
Insulating Board	1.4	1.6	1.8	2.0
Hardboard	1.8	2.3	2.9	3.6
Other Board	3.4	3.9	4.5	5.2

(A table showing apparent consumption of paper and board by grade from 1920-1966 prepared by the Forest Service is presented in Appendix 2.)

The by-grade forecasts indicate that the largest growth in paper grades may be expected in coated, writing, and tissue papers. Since the board categories vary between the two forecasts, a comparison would be inexact.

Wood Pulp

Projections for total wood pulp are as follows:

	1,000 Short Tons	
	API (Production)	Forest Service (Demand)
1970	43,201	46,400
1975	51,630	57,500
1980	59,463	71,300
1985	67,000	86,400
1990	75,000	

In its report to the FAO the API presented the following breakdown on pulp production by type:

1,000 Short Tons

	Production		
	Actual	Estimated	
	1969	1975	1980
TOTAL PULP	40,301	50,627	58,366
Wood pulp for making paper and paperboard, totals	37,706	47,401	54,449
Mechanical	4,241	5,470	6,942
Semi-chemical (including chemi-mechanical)	3,376	4,181	4,815
Chemical totals	30,089	37,750	42,692
Unbleached sulphite	390	395	389
Bleached sulphite	1,948	1,981	1,958
Unbleached sulphate R	15,571	18,565	20,165
Bleached and semibleached sulphate	11,991	16,809	20,180
Other fibre pulp for making paper and paperboard, total:	894	1,072	1,296
Dissolving pulp (wood and other fiber raw materials)	1,701	2,154	2,621

The Forest Service projections of demand for wood pulp by type are as follows:

	(Million Tons)			
	1970	1975	1980	1990
Dissolving and Special Alpha*	1.5	1.7	2.0	2.2
Sulfite	3.3	3.5	3.7	3.8
Sulfate	30.1	38.0	47.8	59.0
Soda	.2	.2	.2	.2
Groundwood	4.8	5.7	6.7	7.7
Semichemical	4.7	6.4	8.6	10.9
Defibrated, exploded, and screenings	1.8	2.0	2.3	2.6

*Includes a number of highly purified types of wood pulp obtained from the sulfite and sulfate pulping processes.

(Historical data of the Forest Service on pulp consumption may be found in Appendix 3. Production data by grade as compiled by the U.S. Bureau of Census are published by the API in "The Statistics of Paper" (7).

Although the numbers in the above are somewhat divergent, the author feels certain trends are evident. The use of groundwood pulp is expected to expand on a rather steady incline, as is NSSC pulping. Kraft pulping will continue a steady growth pattern but not at as rapid a pace as in the past ten years. Sulfite pulping in its present form, as discussed in other sections of this report, will probably hold steady at the 1972 production level.

Secondary Fiber Pulping

Since World War II the percentage of waste paper in terms in total raw material used in papermaking has remained rather steady at about ten million tons a year (8). The total reported for 1969 indicated that approximately 20 percent of our paper consumption was recycled during that year, continuing the trend of decline. However, a recent study by the Institute of Paper Chemistry indicates that the 1969 amount was actually 22.3 percent of total fiber furnish, and that of 1970 was 22.5 percent (9). Current API reports are very similar (2). Therefore, the downward trend has apparently been reverse.

The most economical use for recycled fiber is, of course, board production which has consumed 70 percent of the waste paper processed. The balance is used about equally for pulp substitute grades and deinking mills.

There are numerous factors, however, wnich have made it uneconomic for integrated mills to produce more pulp from waste paper or for non-integrated paper mills to buy more deinked pulp. The following are among the more significant (10,11,12,2):

(1) The quality of waste paper has been deteriorating and labor costs for sorting are prohibitive. Pre-sorting at the point of origin is seen as an economic necessity to stimulate increased use.

(2) Waste paper collection is more erratic than pulp production and prices fluctuate more.

(3) Improved management of company-owned forests has increased tree crops and mechanical harvesting and wood-handling equipment are reducing costs.

(4) Chemical pulping yields have been improved.

(5) The use of waste paper can result in costly effluent treatment and sludge disposal requirements. The deinking of some waste papers results in sewer losses of as high as 50 percent of the bale weight of the waste, producing an effluent high in suspended solids, turbidity, and BOD. The sludge produced on treatment is generally almost half ash, due to filler and coating materials washed from the old papers, and connot be incinerated by the usual equipment. Treatment and sludge disposal costs can readily destroy any financial advantage obtained by reclaiming fiber and also limit mill locations which can consider this practice. This is because land disposal is the most common, satisfactory, and economical method available for disposing of the sludge produced on effluent treatment, hence, the availability and proximity of sufficient suitable land can be a decisive factor. Land cost, is, of course, an added consideration.

A number of mills, including combination board mills, which have been utilizing a very high proportion of waste paper have been closed because of low margins of profit and uneconomic operating levels. The combination board mills were, however, primarily smaller and older mills which could not withstand the impact of the slowdown in demand. Nevertheless, and even though no immediate shortage of pulp wood is predicted, there are pressures building which will undoubtedly engender increased recycling. As the population and pounds per capita consumption increase, and the cutting rate of timber exceeds the growth rate (now predicted at just beyond 1980), the use of waste paper will become more economically attractive. Normal inflationary trends can be expected to increase the price of pulpwood as well as the necessity for harvesting remote areas and increasing competition from other wood-using industries (10).

Additionally, recycling has come into focus as a partial solution to the problems of solid waste disposal. Paper and paperboard account for nearly half of all municipal solid waste, although only about 12 percent of the total (2). This has led the U. S. Government and various state and local governments to revise procurement specifications for paper purchases to require varying percentages of recycled paper. The Resources Recovery Act of 1970 and the recommendations of the National Commission on Materials Policy are likely to further intensify the pressures toward recycling paper which will require the industry to develop the technology to utilize increased quantities efficiently, particularly for printing and writing papers.

In 1969, 1.9 million tons of waste paper were used in the production of 23.5 million tons of paper, 8.4 million tons in the production of approximately 26 million tons of paperboard, and 1.23 million tons in the production of 4.5 million tons of construction and wet machine board (2).

Projecting the ratios of waste paper use to production for each sector, the API has computed the waste paper demand in 1985 as illustrated in Table 1.

Estimated waste paper requirements through 1990 are as follows (2):

	1,000 tons
1975	13,670
1980	19,520
1985	27,930
1990	39,000

The National Academy of Science has projected 35 percent recycled paper by 1985 (13).

Not the least of the imponderables which will determine the rate of increase in reusing paper is the character of public demand. Up until the recent surge of environmental concern, industrial and other buyers preferred virgin fiber products. If, however, the current ecological motivation continues, it will increase the pressure on the industry to develop not only the technology for more efficient use of waste paper, but improved technology to control the attendant increase in water contaminants.

Table 1

WASTE PAPER REQUIREMENTS

	1969	1985F
	---(million	tons)---
Paper Production	23.5	43.3
Waste Paper Used	1.86	5.2
Waste Paper % Production	7.8%	12.0%
Paperboard Production	26.0	46.3
Waste Paper Used	8.69	19.5
Waste Paper % Production	33.4%	42.0%
Construction and Wet Machine Board Production	4.5	8.1
Waste Paper Used	1.22	3.25
Waste Paper % Production	27.1%	40.0%
Total Paper and Paperboard Production	54.0	97.7
Waste Paper Used	11.77	27.9
Waste Paper % Production	21.8%	28.5%
Waste Paper used for Molded Pulp and Miscellaneous	.206	
Waste Paper Exports	.408	

F - Forecast projection by API.

The General Services Administration has included wood residues in its definition of waste products, as well as the use of broke, trim, and other relatively clean mill waste. However, of the 35 percent total waste product content required in Federal Specifications for corrugated fiberboard, ten percent must be consumer-used waste paper. Percentages for minimum waste content of other paper grades are contained in a Fact Sheet issued by the General Services Administration in September 1971 (14).

Capacity

Presently a readjustment in production facilities is underway in the industry. Old, high production-cost mills, particularly those facing large expenditures for refurbishing and water pollution control, are being abandoned; 19 fine paper mills and 22 paperboard mills have closed down. Since 1962, 21 mills producing sulfite pulp have been permanently closed, as have 3 old kraft mills and 2 NSSC operations. The number of kraft mills has increased from 89 in 1964 to 121 in 1971. The number of such mills with a capacity of less than 100,000 tons of annual capacity has decreased from 19 in 1964 to 14 in 1971, however, those manufacturing between 100,000 and 200,000 tons have increased from 19 to 35 and those in the 200,000 to 300,000 range remained constant. Those whose capacity is in excess of 300,000 tons have increased since 1964 from 20 to 41 in number.

These data indicate that a considerable number of mills having difficult pollution problems have ceased to exist. The products they manufactured are now produced in large modern mills provided, in most cases, with modern waste treatment facilities. Tables showing growth trends in industry capacity through 1974 appear in Appendices 4 and 5 (18,19). Total capacity by geographic region is presented in Appendix 6 (333).

Per Capita Consumption

The United States continues its world leadership in per capita consumption of paper and paperboard although 1970 consumption declined slightly over 1969--from 576 pounds to 556 (363). This reflected factors influenced by the general downward trend in the economy, such as the drop in newspaper advertising space.

Sweden and Canada, the second and third ranking leaders in per capita consumption, continued their upward trend but the increase from 1969 to 1970 was, in both cases, only a fraction of that experienced from 1968 to 1969--approximately one-fourth and one-sixth, respectively.

Table 2 illustrates the per capita consumption of the 20 world leaders in 1968, 1969, and 1970.

Appendix 7 presents statistics for the United States for most years from 1899 through 1970. It is interesting to note that each year in which per capita consumption declined from the previous year represented a

Table 2

PER CAPITA CONSUMPTION OF PAPER AND BOARD

	1968	lbs/yr		1969*	lbs/yr		1970	lbs/yr**
1.	United States	551	1.	United States	576	1.	United States	556
2.	Sweden	370	2.	Sweden	410	2.	Sweden	420
3.	Canada	368	3.	Canada	393	3.	Canada	397
4.	Switzerland	294	4.	Switzerland	317	4.	Switzerland	339
5.	Denmark	272	5.	Denmark	313	5.	Denmark	326
6.	United Kingdom	270	6.	Netherlands	298	6.	Netherlands	304
7.	Netherlands	265	7.	United Kingdom	282	7.	United Kingdom	284
8.	Australia	249	8.	Fed. Rep. of Germany	270	8.	Fed. Rep. of Germany	275
9.	Fed. Rep. of Germany	244	9.	Australia	260	9.	Japan	267
10.	Norway	238	10.	Norway	255	10.	Norway	264
11.	New Zealand	228	11.	New Zealand	246	11.	Finland	252
12.	Finland	214	12.	Japan	243	12.	New Zealand	252
13.	Japan	213	13.	Belgium	236	13.	Belgium - Luxemburg	248
14.	Belgium	206	14.	Finland	230	14.	France	208
15.	France	179	15.	France	203	15.	Austria	175
16.	Ireland	148	16.	Ireland	173	16.	Ireland	173
17.	Iceland	147	17.	Austria	161	17.	Hong Kong	165
18.	Austria	146	18.	Iceland	148	18.	Dem. Rep. of Germany	165
19.	Dem. Rep. of Germany	135	19.	Italy	144	19.	Panama	145
20.	Italy	128	20.	Dem. Rep. of Germany	143	20.	Costa Rica	144

* Does not include British Honduras (250) and Panama (145).

** Rounded

SOURCE: Pulp & Paper

period of economic uncertainly, ranging from the depression year of 1934, to what might be termed a slack economy, to actual repression in later years. These years are indicated by asterisks in Appendix 7.

Employment

The paper and allied products industry is a large employer. Total employment (excluding the building paper industry) reached a record high of 716,000 in 1969, a gain of 114,000 from 1960. However, the total dropped to 710,000 in 1970 (7).

Although wages have been rising in line with the general increase in wage rates, labor costs as a percentage of sales have remained relatively stable due to technological improvements which have reduced the man-hours required per unit of output. According to the Bureau of Domestic Commerce, between 1963 and 1970 average output increased 25 percent from 235 to 293 tons of paper and board per production worker. In 1968, each ton of output required 7.7 man-hours, a decrease of 18 percent from the requirement of 9.4 man-hours per ton in 1963 (5,15).

The BDC reports payroll costs for 1970 at a level equivalent to 21 percent of the value of shipments in its profile of paper, paperboard, and building paper and building board mills (5). For 1969, the API reported an average of 20.2 percent for 21 non-integrated paper companies and 24.3 percent for 32 integrated companies (16).

The 1970 average hourly earnings for the paper and allied products industry was reported at $3.44 by the Bureau of Labor Statistics--$3.80 for paper and pulp employees, $3.86 in the paperboard industry, $3.12 converted paper and paperboard products, and $3.18 in paperboard containers and boxes (17).

Profits

Profits of the paper and allied products industry are marginal, partly because of the very high capital investment required. Profits after taxes in this industry, in relation to net worth, have been consistently below the ratio for all manufacturing industries and in recent years the ratio of profits to sales has also been somewhat lower.

At this writing the profit situation is still feeling the effects of lower demand in 1970, and increased costs. According to the Paper Trade Journal, industry sales for the first half of 1971 are up 2.9 percent and net profit down 26.9 percent, before extraordinary items, from the first six months of 1970.

Comparing the years 1969 and 1970 in terms of sales and profits, of the 40 companies responsible for the bulk of the tonnage in this country, 28 showed an increase in sales and 11 a decrease (324). Profits increased for only 6 operations and declined for 34. The extent of the decline in profits was in most cases appreciable despite, in many instances, an increase in sales. Three companies which had a profitable year in 1969 suffered a substantial loss in 1970 and companies which had a small loss in 1969 suffered triple that loss in 1970. Only five companies showed an increase in profits in 1970 over 1969. Of the 20 companies having increased sales and lower profits in 1970, seven declined less than ten percent, five between 10 and 20 percent, six between 20 and 30 percent and two in excess of 30 percent.

Table 3 presents a comparison of 1969 sales and profits with those of 1970 for 30 of the largest United States paper producers as published by "Paper Processing."

Profit and loss data for the paper and allied products industry for the years 1947 through 1970 appear in Appendix 8.

Table 3

SALES VS. PROFITS OF MAJOR U.S. PAPER MANUFACTURERS

(Thousands of dollars)

Company	1970 Sales	1969 Sales	1970 Profits	1969 Profits
International Paper Company	$1,840,832	$1,777,251	$82,477	$115,614
Boise Cascade Corporation	1,716,860	1,738,690	36,560	81,210
U.S. Plywood-Champion Papers, Inc.	1,355,944	1,492,590	37,809	68,265
Weyerhaeuser Company	1,233,423	1,199,046	124,207	131,362
Georgia-Pacific Corporation	1,194,430	1,160,160	79,220	91,760
Mead Corporation	1,038,000	1,031,000	19,900	35,900
Crown Zellerbach Corporation	955,288	919,282	41,905	53,963
Kimberly-Clark Corporation	868,742	834,714	38,315	49,930
St. Regis Paper Company	857,431	867,827	35,764	41,196
Scott Paper Company	755,700	731,500	49,100	60,000
Diamond International Corporation	505,046	498,094	34,606	35,671
Union Camp Corporation	462,200	449,537	30,777	30,383
Westvaco Corporation	420,344	419,598	17,130	21,864
Great Northern-Nekoosa Corporation	355,291	344,139	16,480	20,252
Hammermill Paper Company	352,413	353,272	9,364	14,076
Potlatch Forests, Inc.	319,270	340,435	10,980	14,541
Hoerner-Waldorf Corporation	250,372	237,202	13,845	12,176
Brown Company	216,828	195,675	1,381	1,693
Inland Container Corporation	197,196	191,716	7,031	9,504
Fibreboard Corporation	169,722	181,820	1,154	9,301
Southwest Forest Industries, Inc.	162,786	139,302	4,768	6,475
Federal Paperboard Company, Inc.	133,000	132,659	3,893	4,181
Consolidated Papers, Inc.	131,988	127,746	3,349	5,251
Longview Fibre Company	127,345	129,573	11,195	13,244
Sonoco Products Company	125,907	125,180	6,331	6,719

SECTION IV.

WATER QUALITY PROBLEMS OF THE INDUSTRY

The pulp and paper industry employs an estimated 1800 billion gallons of water annually (20) and since losses from evaporation, etc., amount generally to less than ten percent, most of this finds its way into surface waters. Both process water and water for accessory uses such as cooling and power generation are included in this figure. Over 60 percent of the total is process water (21) which comes into contact with the raw materials and product and retains a small percentage of them. Examples are its use for washing and debarking wood, grinding, defibrinating, and cook-raw materials as well as a furnish carrier in pulp bleaching and in the papermaking system. The quantity used in a particular mill varies considerably with the products manufactured as well as the specific equipment used and its arrangement. Quality requirements also vary widely depending upon the quality of the product. For example, coarse papers such as wrapping and board products can use water of much lower quality than that needed for fine papers (22,23) in which cleanliness and brightness are basic requirements.

Water reuse has long been practiced in the industry (24) for several reasons. One is to reduce water costs and a second is to reduce fiber and filler losses which, up to a point, decline with the degree of recirculation (25). Others are the conservation of heat and chemical additives such as sizings. Haynes (26) estimated that by 1966 process water was recycled 2.5 times in the southern kraft industry, which is responsible for a very large percentage of the total pulp and paper tonnage in the country.

Spent process waters resulting from raw material handling, pulp and paper manufacture, and chemical recovery are classified as organic wastes since most of them are high in this type of compound which can be present both in suspension and solution (27). Dissolved organics consist of such substances as lignins, tannins, sugars, and cellulose degradation products leached or cooked from wood or other raw materials. They can also consist of adhesives and sizing materials such as starches and resinates added in the papermaking process. Suspended organic matter can consist of bark, bark and fly ash and wood fines, fiber, fiber debris, and suspended papermaking additives.

The organic fraction contains both biodegradable and refractory substances. Examples of the former are wood sugars and cellulose degradation products such as fatty and hydroxy acids, alcohols, and ketones. The latter is exemplified by the lignins, most of which, as they appear in pulping wastes, are not biodegradable as demonstrated by Lawrance (28) and others.

Pulp and paper mill effluents are notoriously low in phosphorus and nitrogen, most containing insufficient concentration of these elements to support the optimum rate of biological oxidation. For this reason nutrient supplements have to be added when the wastes are treated by methods involving microbial activity.

Inorganic materials are also present in both suspension and solution. The suspended materials consist of silt washed from logs, chemical recovery residues such as grits and dregs, process water treatment sludges, and paper filler and coating materials such as clay, talc, and calcium carbonate. Dissolved inorganics consist of sizing chemicals and salts from chemical recovery system wash water and from bleaching operations.

Receiving Water Problems Caused by Pulp and Paper Mill Wastes

Suspended organic matter can have several effects on receiving bodies of water. The settleable variety, such as bark and wood fines, as well as all coarser fibers, are inclined to settle to the bottom where they decompose. When such deposits blanket the bottom they interfere with the normal development and livelihood of benthal-dwelling organisms upon which fish feed (29). If the dissolved oxygen is depleted altogether, anaerobic decomposition of the residual organic matter takes place. This can create gases such as hydrogen sulfide and methane which give rise to offensive odors and unsightly gas-floated islands of fibrous sludge. Anaerobic decomposition is also accompanied by a blackening of the water and solubles formed by the process, such as fatty acids and alcohols, can exert a considerable oxygen demand on the overlying water as pointed out by several investigators (30,31,32). This situation can also retard the self-purification process in surface waters to a marked degree.

Biodegradable dissolved and dispersed organics also deplete dissolved oxygen in water (33) and may create anaerobic conditions.

Biological imbalance in streams resulting in slime infestations has resulted from the discharge of oxidizable pulping solubles (34). A critical review of the literature on the subject by Harrison (35) was presented in 1957 and was followed by extensive studies of the problem by Amberg (36), Cauley (37), and others (38,39). This phenomenon can be caused by wood sugars and cellulose degradation products such as fatty acids which stimulate the growth of Sphaerotilus natans and similar organisms. Growth can occur on suspended wood particles such as groundwood rejects or grow freely or attached to rocks, tree branches, or logs floating in the stream. They also grow upon or are collected by fishing nets. The resulting clogging shortens fishing time and poses a difficult cleaning operation which in time shortens net life. They can also clog water inlet screens rapidly and cannot be cleaned from the screens effectively by usual methods.

These slimes absorb nutrients from the water and the extent of their proliferation appears to be determined by the quantity of suitable nutrient passing a particular slime mass in a given period of time, rather than the concentration. Their growth has been controlled by intermittent discharge of wastewaters whereby periodic starvation causes a dying off of the organisms. Treatment to remove the nutrients has proven to be a more effective means for controlling this problem. Those slime problems arising from growth on suspended wood particles are being controlled simply by preventing their discharge. The practice of storing logs in water, which can involve the slime problem, is being solved by land storage.

Refractive organic matter contains, among other things, color bodies which can impart an undesirable appearance to surface waters. The cost of removing color at downstream water treatment plants can be raised by these materials as pointed out by Herbert (40). The nature of these substances in kraft bleaching effluents is described in Lunar and Dance (41,42). They consist mainly of carboxylic acids in the case of caustic extraction effluent, and chlorine containing unsaturated acidic fragments of lignins in the case of chlorination-stage wash water.

Inorganic materials in solution are rarely considered to contribute to water quality problems since the discharge of acids and alkalies is largely under control and the remainder consists largely of sulfates and chlorides of sodium and calcium from pulping and bleaching operations. Under the conditions of insufficient dilution, however, the addition of these salts can raise the total solids and chloride content of receiving waters above the levels stipulated by prevailing standards, or required for downstream uses such as irrigation or some industrial processes. The suspended inorganics consisting of silt, clays, talc, calcium carbonate, and titanium dioxide can cause turbidity and unsightly opalescence in receiving waters or can form bottom deposits which blanket benthal deposits or inhibit biological activity through preventing light penetration.

Van Horn (43) investigated the causes of tastes and odors imparted to receiving waters and their inhabitants by kraft pulping effluents. The responsible compounds were found to be sulfides and organic sulfur compounds, resin acids, and turpines. The sulfides as a rule are rapidly oxidized in surface waters while the latter are more persistent. Van Horn also demonstrated that the skin, rather than the flesh of fish, picked up odorous substances, a taste panel being unable to detect any off taste in fish which had been skinned and cooked. Tokar and Owens (44) also studied this effect. Their findings showed that water containing 1.5 percent by volume of unbleached kraft effluent imparted a taste to salmon. Treatment of this waste altered this percentage to 2.9.

In most instances reported, fish taste downstream of kraft mills has been found to result from kerosene used in foam control. A change in foam control agent to a type that does not impart taste and odor to either water or fish has been found to correct this condition.

The taste and odor producing potential of chlorinated phenolic bodies present in pulping wastes are discussed by Dence (45). It was concluded that forming odiferous chlor-phenol compounds and their tendency to do so should be investigated.

Fiber Leaching

It has been demonstrated that oxygen uptake from physically stable cellulosic bottom deposits was proportional to their surface area. Depth influenced the demand only up to one foot, past which it proved an insignificant factor. Mixing and turbulence increase the oxygen demand of the deposit since these conditions cause soluble materials to be leached from the sludge mass.

Stagnant flow conditions produced oxygen demands of 0.2 grams of oxygen per square meter per day. The demand increased to 2.7 grams under eddying conditions and to 4.4 grams under slight scour. Covering of such deposits with silt caused radical decrease of the oxygen demand and fresh deposits are considerably more active than old ones.

The degree of leaching from bark, according to McKeown (46), in terms of BOD_5, COD, color, Kjeldahl nitrogen, and phosphorus, decreases with time of storage in bark piles. Aging in underwater deposits decreased the leaching potential faster than it decreases through storage in log piles. Concentrations of the leachings increase with contact time approaching limiting values, the time required to reach the limit depending upon the age of the bark and conditions of water contact. The total amount leached increases with the water volume involved.

With the exception of phosphorus, the degree of leaching was very much lower in salt water than in fresh water and leaching rates under stagnant conditions are lower than they are in water that is mixed. Sulfide production is higher in saline water, presumably because of its high sulfate content. The deoxygenation rate constant for fresh bark extract is similar to that of most raw pulping process wastewaters (0125 day^{-1}, base 10).

Bioassay experiments employing fresh hardwood and softwood barks from Northeastern species exhibit a TLm of 42 percent with chinook salmon as the test organism.

Aquatic Biology

Pulping effluents have long been associated with damage to aquatic and marine life as a result of fish kills downstream of mills and alleged damage to shellfish cultivation waters. Many publications have appeared in the literature dealing with specific situations which must be judged on an individual basis. However, a large amount of experimental work has been done on problem definition and control. These studies have provided solutions to some of the problems and are leading to the solution of others. This is reflected by the fact that pulp mill related fish kills are now rarities as indicated by the federal census of such occurrences over a period of eight years (276).

The reduction has resulted from the addition and improvement of spent liquor recovery systems, effluent control and treatment, and the prevention of spills of potentially toxic liquors and wastewaters. Recent investigations have been directed toward determining the more subtle effects which pulp and paper mill wastes might have on the reproduction and productivity of aquatic life. These areas are defined by Warren (126) in considerable detail.

Van Horn (277,278,279) has critically reviewed the literature on the effects of pulp and paper mills on aquatic biology. Many of the problems have resulted from oxygen depletion. The effect this factor has on various species of fish and fish eggs has been studied in detail by Warren, Duoderoff, Scott, and others and the findings were summarized by Fry (280) and Duoderoff (281).

Dissolved oxygen levels of the same order as is presently required by state-federal stream standards were recommended. These standards are believed by many investigators to be on the high side particularly for warm waters. The concentration allowing fish survival is considerably lower than that required for the eggs and fry of some species, and that needed to support their normal level of activity.

In any event, one cannot look for any final answer to the matter of dissolved oxygen requirements under all conditions. This appears to be interdependent on the concentration of other gases such as carbon dioxide as demonstrated by Warren (282).

Van Horn (283,284,269,285) and others (286,287,288,289,290) identified substances present in kraft pulping effluents that are toxic to aquatic life. While many compounds having toxic properties can be extracted from kraft effluents the common offenders appear to be sulfides, mercaptans, resin acids, and terpines. In the case of high kraft liquor losses, alkali can be a factor as well. However, the above-named materials are toxic at the part per million level and are probably the substances involved in any obscure aquatic problems that might arise.

Some of these substances such as the sulfur compounds are removed by short-period storage, probably as a result of oxidation (288).

Biological treatment and self-purification are very effective in destroying and removing the toxic components from kraft effluents as demonstrated by Warren (291), O'Neal (292), and others (239). High degree treatment can destroy it entirely as evidenced by the fact that treated effluent will frequently in itself support fish life, i.e., the presence and multiplication of fish in long-term storage oxidation basins handling both bleached and unbleached kraft pulping effluents. Field bioassay tests have also shown that effluents from aerated stabilization basims and activated sludge plants treating both bleached and unbleached kraft effluents exhibited no toxicity to common species of fish.

The fact that a large segment of the kraft pulping industry is already practicing or is committed to biological treatment indicates that the acute toxicity problem of this group is a problem of the past.

Servizi et al (294,295) and Das (296) investigated the toxicity of bleached kraft chlorination waste to young salmon. They believe that chlorinated catchecol compounds were responsible for the problem, but found that treatment is effective in destroying the toxicity of this wastewater.

Methods for the detection and quantitative measurement of minute concentrations of sulfide mercaptans and resin acids were published by Van Horn (277). The technique for determining resin acids was later improved by Carpenter (270).

The effluent from sulfite mills not practicing liquor recovery has been shown to be toxic to salmon (297,298). However, most of the problems relative to the discharge of spent sulfite liquor have been due to oxygen depletion. Since recovery or other disposition of spent sulfite liquor will be universal practice in this country within the next few years, concern is with the effect of the residual sulfite mill effluents rather than the spent liquor itself. These do not contain acutely toxic substances as does kraft pulping effluents but have a higher demand for dissolved oxygen. These can be readily destroyed by biological oxidation since they contain mainly fatty acids (299,300,152). The residual, consisting of lignosulfonates and other refractory organics, represents only a very small percentage of the original concentration present in the spent liquor.

Studies have been made on the effect of kraft mill effluents on the migration and spawning of alewives and striped bass. Van Horn (301) determined that bleached kraft effluent did not influence alewife runs in the lower Roanoke River. The same author reviewed with Brandt and Hassler (302) studies covering four years of investigation of the spawning habits of striped bass in the Roanoke River. Spawning was demonstrated to take place throughout the river and did not appear to be influenced adversely either along the river or in the estuary. Dimick (303) studied avoidance reactions of salmonoids to kraft effluents in laboratory streams. While demonstrating that such a reaction could take place, the value of such tests in evaluating conditions prevailing during actual fish runs appeared doubtful.

The question of aquatic productivity appears to be one of great moment and is discussed in detail by Warren (277). Should pulping effluents not affect productivity adversely there is little cause for concern for the aquatic environment because of their discharge. Warren and others (304) conducted extensive experiments on production and food relations of young chinook salmon in laboratory streams receiving untreated and treated kraft pulp mill effluent. Results obtained were inconclusive due to the difficulty in maintaining a balanced population of food organisms although no marked diminution in productivity was recorded in the streams receiving the wastewaters. Presently, a similar project is being carried on in artificial streams with the cooperation of the industry. This is a long-term study and should provide the desired information.

Warren and others (305) demonstrated that enrichment of an experimental stream with small quantities of sucrose caused a decided increase in trout productivity. This indicates the possibility that the productivity of some streams could be enhanced by the addition of low concentrations of wastes containing carbohydrates, such as pulping effluents.

Extensive research has been conducted to determine the effect of kraft and sulfite pulping effluents on bivalves, particularly oysters and their larvae, both in this country (306) and in Japan (307). Some of these studies have been concerned with the development of a test using oyster larvae to determine if an effluent is inimical to the organisms. Several tests have been developed to date but investigators disagree on details of the tests and their interpretations. Both kraft and sulfite pulping effluents exhibit toxicity to bivalves but the concentration at which this is the case is not clearly established since captive tests leave much to be desired and their validity is repeatedly questioned. Field tests in recent years yielded a clear relationship between pulp mill discharges and oyster bed productivity. As a result, the practice of discharging spent sulfite liquor to coastal waters is being rapidly eliminated and kraft mills do not appear to be at all involved in the situation.

The subject of the effects of wood fibers on aquatic life were investigated further in recent years by Smith and his associates. Kramer and Smith (308) studied the effect of aspen and conifer groundwood on walleye eggs and found no significant effect of fiber concentrations of 60 and 120 mg/l on survival. McLeod and Smith (309) found that fiber concentrations in the 100 to 800 mg/l range could decrease swimming endurance of walleyes when the dissolved oxygen concentration was low (2.5 mg/l). Increased fiber concentration leads to marked increase in gill-cleaning reflexes which appears to raise the energy requirement for maintenance. These phenomena were interpreted to indicate stress which could decrease survival and production of fish in natural habitats high in fiber content. Smith et al (215) determined that 150 mg/l fiber concentration raised the metabolic rate 18 percent and lowered the hematocrit count of walleyes. This increase could be inimical at high temperatures and low dissolved oxygen levels.

It should be noted that the fiber concentration levels employed in these studies are extremely high. They are equal to or above those which would be expected in the untreated effluent of a modern mill and very much higher than concentrations appearing in effluents receiving primary treatment.

Heavy Metals

Widespread publicity associating pulp mills with the discharge of mercury was not directed toward pulp and paper manufacture primarily, but rather to chlorine-caustic operations carried on at mill sites. It was feared that chemicals produced at the several mercury cell chlorine-caustic plants might find their way into pulp and paper effluents. However, any such conditions that once existed have been corrected and this is now a most unlikely possibility.

On the whole, heavy metals which might be present in pulping effluents originate from one or more of three sources, i.e., (1) chemicals used in pulp processing, (2) additives used in papermaking, or (3) products of equipment corrosion. Pulp processing chemicals, mainly sulfur, salt cake, limestone, sodium-hydrosulfite, chlorine and chlorine compounds, and caustic soda, are normally low in heavy metals and their use is such that those present would likely be precipitated in the process and be discharged with solid residues.

The only heavy metal that has been identified with pulp mill effluents is zinc since the hydrosulfite salt is used at a few mills for bleaching groundwood. The quantity used is sufficiently low so that zinc probably does not reach toxic levels in the waters receiving these wastes.

Few heavy metals or their salts are employed in papermaking other than as insolubles such as completely inert oxide pigments.

While corrosive chemicals are handled and some corrosion takes place in pulp and papermaking equipment, metal losses of an order that would cause appreciable concentrations of metals like nickel and chromium to appear in effluents is unlikely because of the high resistance to corrosion of the materials of construction now employed throughout the industry. It might be anticipated that metals such as iron might appear in low concentration due to corrosion from refiners, beaters, and similar equipment.

It can be concluded from the above observations that it is most unlikely that heavy metals of toxic nature reach critical levels in pulp and paper mill effluents and the absence of any history of difficulties arising from these bears this out. While little is known about their presence, detailed investigations in this area, at present, do not seem justifiable in the light of the identifiable and pressing problems needing attention with respect to these wastewaters.

Sewer Losses of Inorganic Chemicals

Although the chemicals used for pulping and bleaching are inorganic in nature, their ions leaving the processes are frequently associated to a substantial degree with organic molecules (45,41,42,223). For example, in the sulfite processes, the base cation forms a lignosulfonate salt, and in kraft soda pulping, the soda ion becomes associated with lignins, resin, and fatty acids to form their salts. In bleaching, a portion of the chlorine becomes attached to organics as does the caustic employed in the extraction stages.

However, all kraft and modern sulfite mills lose some of the inorganic reagents as used or formed in the process. They find their way into the mill effluent, either in their original state or in a modified form, and, as previously pointed out, can have undesirable effects on the use of surface water.

Sulfite mill effluents can contain sulfurous and sulfuric acids as well as the sulfate, or sulfite, bisulfite, or thiosulfate of the particular base employed. Sodium sulfate and some sodium carbonate as well as sodium chloride, calcium sulfate and carbonate appear in kraft mill effluents. Sodium and calcium chloride as well as hydrochloric acids appear in appreciable amounts in bleaching effluents and chemical preparation can account for some inorganic sewer losses.

In addition to the inorganic constitutents contributed to pulping and bleaching spent process waters, inorganics are also contributed by the wood. The ash content of common species of pulp wood ranges from 0.3 to 1.2 percent on the air-dried basis. Hence, a ton of wood will contribute from 6 to 24 pounds of inorganic matter to the pulping system. On a pulp yield basis of 50 percent, these figures double.

A water containing 100 mg/l of total inorganic solids will contribute 16 pounds to the system assuming a water usage of 20,000 gallons per ton of pulp. This contribution will increase in direct proportion to the salt concentration in the process water.

Insoluble inorganics are discharged from the alkaline pulping recovery processes in the form of dregs settled out from the green liquor and grits removed from the slaking operation (211). These materials are seldom discharged to the outfall and are generally lagooned. However, a small amount of them find their way into the mill sewer system. They consist mainly of silica, alumina, iron, magnesium, and calcium compounds of an insoluble nature together with traces of sodium carbonate, sulfide, sulfate, and calcium hydroxide.

There are also some minor intermittent sources of inorganics contained in liquor filter backwash, hypochlorite, and acid tower wash-up. These constitute very minor sources.

Sulfite, bisulfite, and neutral sulfite pulping effluents from mills practicing recovery employ magnesium, ammonia, or sodium as a base (204,205,175). It is anticipated that calcium base pulping will practically disappear in this country within the next few years since calcium base recovery systems are not economical here and present several technical difficulties not shared by the more soluble base systems. Because of this, attention is given herein to the inorganic constitutents of soluble base mills equipped with modern recovery systems.

Magnesium base sulfite and magnefite pulp mills discharge magnesium salts as the sulfite, sulfate, and hydroxide in low concentrations. A recovery of cooking chemicals in excess of 98 percent is not uncommon for these operations. Hence, an effluent containing less than 25#/AD ton of pulp of MgO can be anticipated. In fact, the latter should be lower because of the high solubility of the base.

It should be pointed out here that data regarding direct effluent analyses for inorganic ions are not abundant in the literature. One reason is that in the past these have not resulted in serious receiving water use probelms. Additionally, specialized analytical methods must be used to determine the quantity of the ions attached to organic matter and of those that are not. Such analyses are generally complex and have been limited to the research area by both the industry and government. The ash content of the total solids content of an effluent (as commonly measured) yields a result inclusive of both the free and combined inorganic ions present in the system. Hence, very little information is available regarding the concentration of inorganic compounds as such in pulp mill or bleach plant effluents.

The same is true of the effluents from paper mills, but for a different reason (288). A large percentage of many of the additives such as sizing chemicals and adhesives are incorporated in the paper and do not find their way into effluents. Little in the way of investigation of the soluble inorganics in paper mill effluents has been made; however, the losses of insoluble filler, coating materials, and pigments, some of which are not retained in the sheet, have been explored to a considerable degree. This has been particularly the case since special reagents are now commonly employed to increase their retention. Because of the extremely wide range of products manufactured and similar range of these materials used in the operations, the sewer losses of these cover a range estimated to be from 5 to 30 pounds per ton of product. These consist of calcium carbonate, clay, talc, titanium dioxide, and other materials of similar physical properties (345,346).

Reprocessing of paper and broke leads to the discharge of large quantities of inorganics in the effluent when these contain fillers or pigments or are coated (224,225). These processes are the major source of such materials in many white paper manufacturing operations and in the case of deinking produce effluents higher in these substances than any other paper manufacturing effluent.

As stated elsewhere in this report, wood is low in phosphorus and nitrogen and the discharge of most effluents from its pulping do not result in effluents which promote eutrophication. Exceptions can exist due to use of ammonia in pulping and phosphates as detergents, pigment dispersants, or for water treatment. Nutrients are added to some wastes in the form of ammonia and phosphoric acid at a low level (12). It is unlikely that sufficient of these nutrients appear in the effluent to be an important factor in promoting eutrophication because of their low initial level and the fact that they are adsorbed to a degree in the biomass of the treatment system (168).

SECTION V

GENERAL PROCESSES EMPLOYED FOR EFFLUENT MANAGEMENT AND TREATMENT

While some pulp and paper mill effluents are controlled individually or pretreated before joining the general stream, in most cases the entire combined effluent receives final treatment with the exception of uncontaminated cooling waters and at times some very weak wastes. Since the effluents from most modern mills are as relatively weak as sanitary sewage, they are treatable by similar methods. However, modification of such systems are generally necessary because of differences in waste characteristics. The following section describes the methods commonly employed and presents generally well-established performance data for unit processes of treatment and sludge handling.

Sewering

In most modern pulp mills sewer segregation is common to the extent that wastes low in suspended solids and those that are high in them are sewered separately (47). If bleaching is practiced, a separate acid proof sewer--generally of polyvinyl chloride or fiberglass construction--is provided to carry the chlorination effluent so that it can be neutralized before joining the common effluent stream. This is good practice because direct mixing of this bleaching wash water with that from alkaline extraction can cause a serious foaming problem. Bleaching waste is often low in suspended solids and BOD_5 and is sometimes by-passed around the clarification system.

Some mills are equipped with a waste holding basin to which the sewer carrying pulping wastes, tank overflows, and apron and floor drains can be diverted when liquor losses are high for one reason or another. The basin contents are then metered into the overall discharge at a suitable controlled rate when the effluent strength is normal. Some of these systems are equipped with conductivity recorders which activate diversion valves automatically when high losses are indicated, sending the flow to storage basins.

Where small volumes of strong wastes are involved, such as the exploded wood hardboard process, these are segregated for separate handling such as land disposal and incineration. In general, however, all dilute wastes from most mills are ultimately combined for external treatment.

Screening

In addition to the screening procedures commonly used in wood preparation, it is standard practice to screen total mill effluents through bar racks having one-half inch openings (48). It is well to protect following units from large objects such as logs, tools, etc., which get into sewers from time to time. This is done by placing a manually-cleaned bar rack with openings of two inches or more in the channel ahead of the fine screen. In large mills the finer screens are mechanically operated and screenings are taken to a dump or incinerated since they contain mainly combustible matter such as paper, bark, and wood chips or slivers. It is extremely important that the screening operation be efficiently carried out since the nature of the materials removed is such that they can cause serious trouble in succeeding treatment equipment.

Ordinarily grit chambers are not employed nor do they appear to be necessary since little coarse detritus matter normally finds its way into the process sewers. In the case of waste paper mills, such materials are removed in the process itself and dumped with the trash removed from hydropulpers.

In larger mills, flow-measuring flumes are frequently installed in the channels following the screening operation and small mills usually employ weirs for flow measurement (49). In some cases the flow of the final effluent is measured rather than the treatment plant influent.

Neutralization

In the case of effluents from acid sulfite pulping, acid sulfite liquor recovery systems, and the acid stages of bleaching, neutralization is required unless these are mixed with other wastes containing sufficient alkalinity to accomplish this. Neutralization is achieved, in practice, by either adding caustic soda, lime, or limestone in controlled dosage. This can also be accomplished by passing the waste through a limestone bed as discussed by Lott (50) who developed a mathematical model for the design of these devices.

Clarification

While sedimentation, flotation, and filtration are all used to remove fiber and other suspended matter from mill process waters internally (25), external clarification is almost universally achieved by sedimentation (51) but in some instances flotation is also effectively employed (25). Sedimentation is accomplished in mechanical clarifiers, alternating basins, or, in the case of very large storage oxidation installations, in the inlet section of the large impoundment areas used for this purpose.

The trend in the industry is strongly toward the mechanical clarifier (52). These have been found to be effective in removing over 95 percent of the settleable suspended solids from all the effluents produced if properly designed and installed. They are generally equipped with a skimmer and, for effluents containing entrained air, a de-aerating device. Clarifier design has been discussed by Knapp et al (53) and the application of mathematical models to such treatment by Morean (54) and Edde (55).

A NCASI survey (56) of practice at southern mills covers the performance of settling for treating these wastes. The literature is also replete with descriptions and performance data for the various specific types of wastes and individual installations, examples being those by Nemerow (57), Palladino (58), Fuller, Williams, and Moultar (59), and Linsey, Sullins, and Fluharty (60).

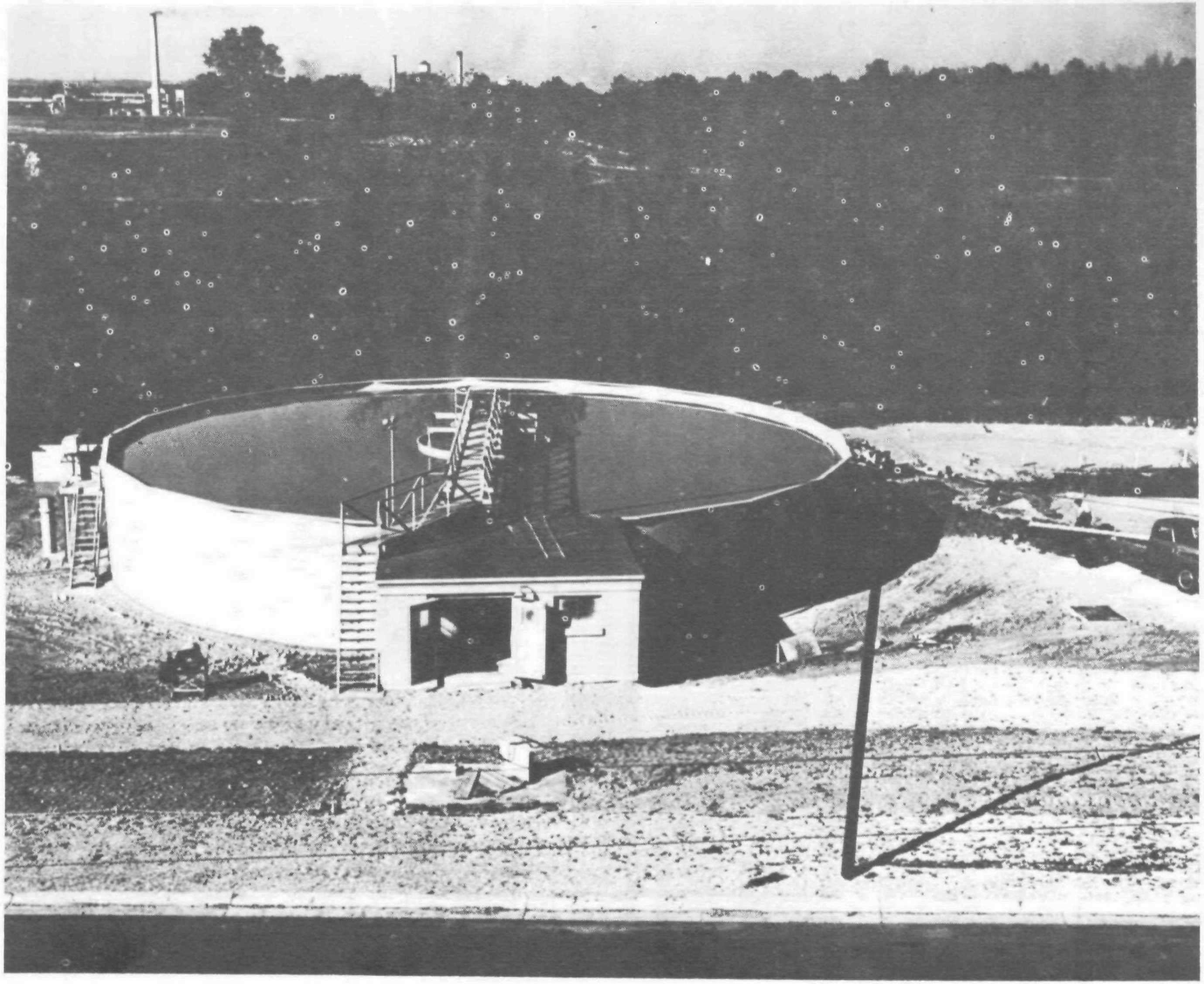
Presently more than 75 of the 118 kraft pulp mills in the U.S. are equipped with mechanical clarifiers and 21 with settling basins. The waste from 15 of the 38 acid sulfite mills and 25 of the 39 neutral sulfite mills are treated in clarifiers. While most waste paperboard mills discharge into public sewers, at least 30 of these are equipped with their own clarifiers as are five of the six large deinking operations; the remaining employ alternating settling basins. Most large groundwood operations are associated with kraft and sulfite pulping and newsprint manufacture and the effluent is combined for treatment with the effluent from all operations. The sewers are for the most part served by mechanical clarifiers.

A clear distinction must be made between total suspended solids and settleable solids. The total suspended solids are all the solids suspended in an effluent. In laboratory tests particularly, all of these are removed by filtration through a gooch crucible or fine filter paper, both of which are used to measure them. The settleable fraction of these is that which separates from the liquid on one hour's quiescent settling in a laboratory vessel. Hence, the true measure of performance of a settling device is the percentage of the settleable fraction that the device will remove, since it cannot be expected to separate those which will not settle under the most favorable conditions.

The performance of clarifiers in terms of removal of total suspended solids reduction is presented in Figure 1. These data were obtained from a detailed industry survey of practice and performance (53) and are representative of results obtained in actual installations. It will be noted that removals of total suspended solids averaged greater than 80 percent for all except deinking mill effluent which averaged just under 70 percent. This is due to the relatively large percentage of inorganic fines in the form of fillers and ink that are highly dispersed in the waste due to peptizing agents employed in the deinking process.

Depsite the high percentage reduction obtained on settling, wastes containing pigments and fillers are inclined to be quite turbid after the bulk of the suspended matter is settled out. Such material as titanium dioxide, carbon black, iron oxides, and other highly optically active materials are responsible for this. Decoating wastes behave in much the same manner with some inorganic materials remaining in dispersion due to the peptizing action of starches used in the coating process.

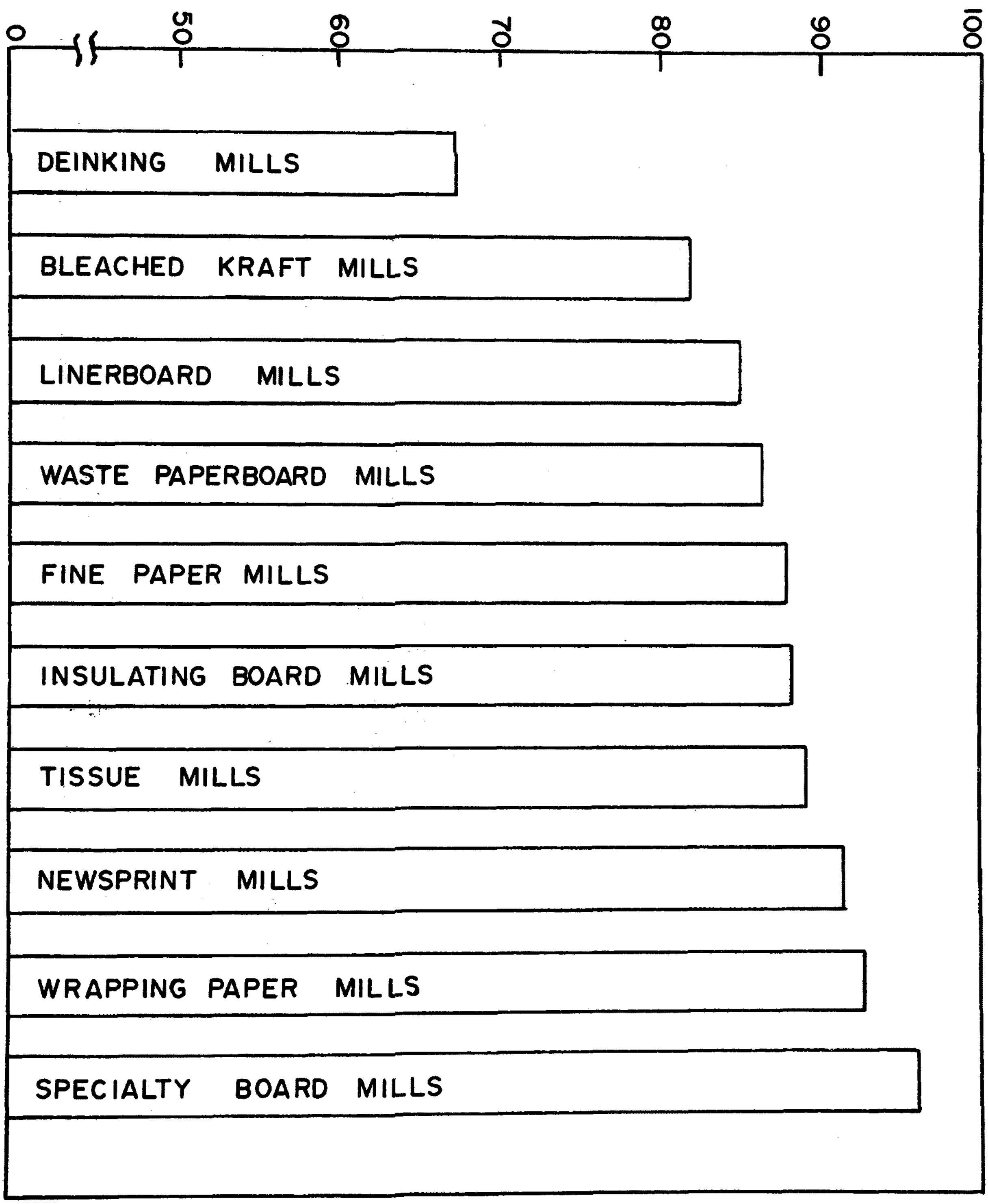
Since at least a portion of the settleable solids present in pulp and paper mill effluents is biodegradable, clarification results in some reduction in the BOD value. The magnitude of this reduction is high in the case of effluents containing mainly suspended organics and small quantities of dissolved organic matter. For example, some



Clarifier at Paper Mill

FIGURE 1

PERCENT TOTAL SUSPENDED SOLIDS
REDUCTION EFFECTED BY SETTLING



specialty board effluents contain little but fiber fines, hence their removal produces a BOD reduction exceeding 90 percent. Conversely, waste paperboard mill effluents contain a considerable quantity of organic materials dissolved from the old papers. Hence, even when clarified to crystal clarity, they can retain as much as a third of their originial BOD value. This is also true of effluents containing pulping and bleaching solubles.

Another factor involved is the fact that the oxygen uptake rate of fiber is slower than that of dissolved materials, since it must first be liquified by microbial decomposition before oxidation can take place. This effect is illustrated in Figure 2 which compares the BOD rate curves of dissolved materials with that of fiber. It will be noted that the oxygen demand of the solubles was largely satisfied in 5 days, while the fiber continued to consume oxygen over the 20-day period of incubation. Thus, the mere fact that the BOD is a five-day test stresses, in the results obtained with settling, the presence of dissolved oxygen-consuming materials and limits the demand figure assigned to the settleable organics.

Results obtained on tabulation of BOD data for a number of mills producing various products is presented in Figure 3. It is obvious from these results that effluents from tissue and fine paper mills, which were low in dissolved organic matter, showed high BOD reductions on settling. Pulp mill and waste paper operations yielded low BOD reductions since they contain appreciable organic matter in solution.

Treatment plant performance data from an integrated mill was treated statistically by Burns and Eckenfelder (61). Their statistical comparison of primary clarifier performance in terms of suspended solids and BOD reduction is presented in Figure 4.

A variation of ±5 percent occurred in suspended solids removal and about the same for BOD_5 reduction.

BOD Reduction

Biochemical oxygen demanding materials can be precipitated from most pulp and paper mill wastes by the use of coagulating chemicals. However, the percentage reduction obtained in this manner is small as compared to that obtainable by biological treatment. Hence, the latter method is the most widely practiced. It also affords a flexibility in the degree of BOD reduction obtained since systems can be tailored to receiving streams' requirements relative to dissolved oxygen resources and consumption rate.

All pulp and paper mill wastes can be oxidized biologically. Some need to be diluted and/or neutralized and most, being low in nitrogen and phosphorus, require addition of these nutrients when higher rate processes are applied. Their amenability to such treatment is evidenced in the references presented in the annual reviews of the literature published

FIGURE 2

BOD RATES OF SUSPENDED
AND DISSOLVED ORGANIC MATTER

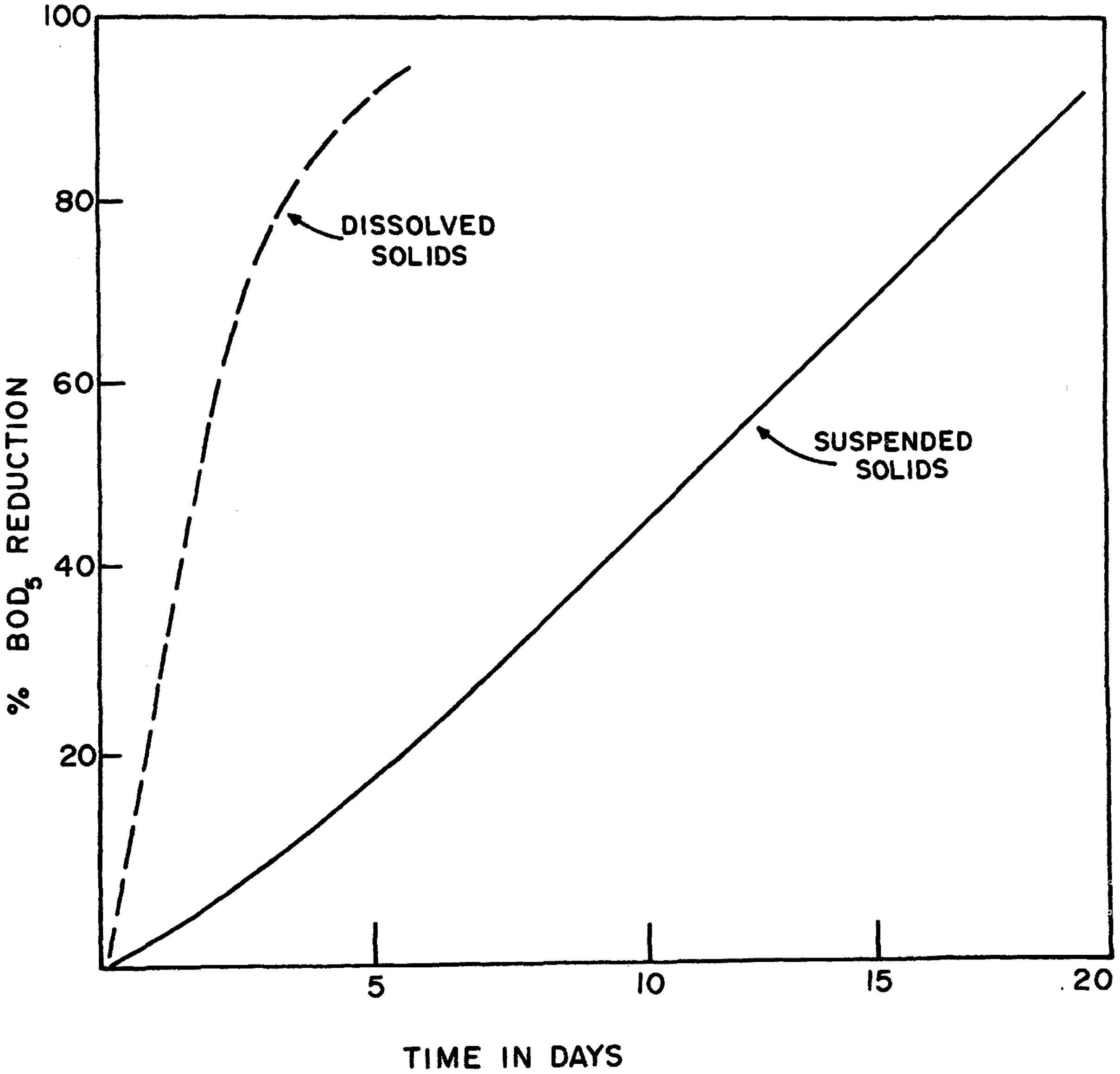


FIGURE 3

BOD$_5$ REDUCTION EFFECTED BY SETTLING

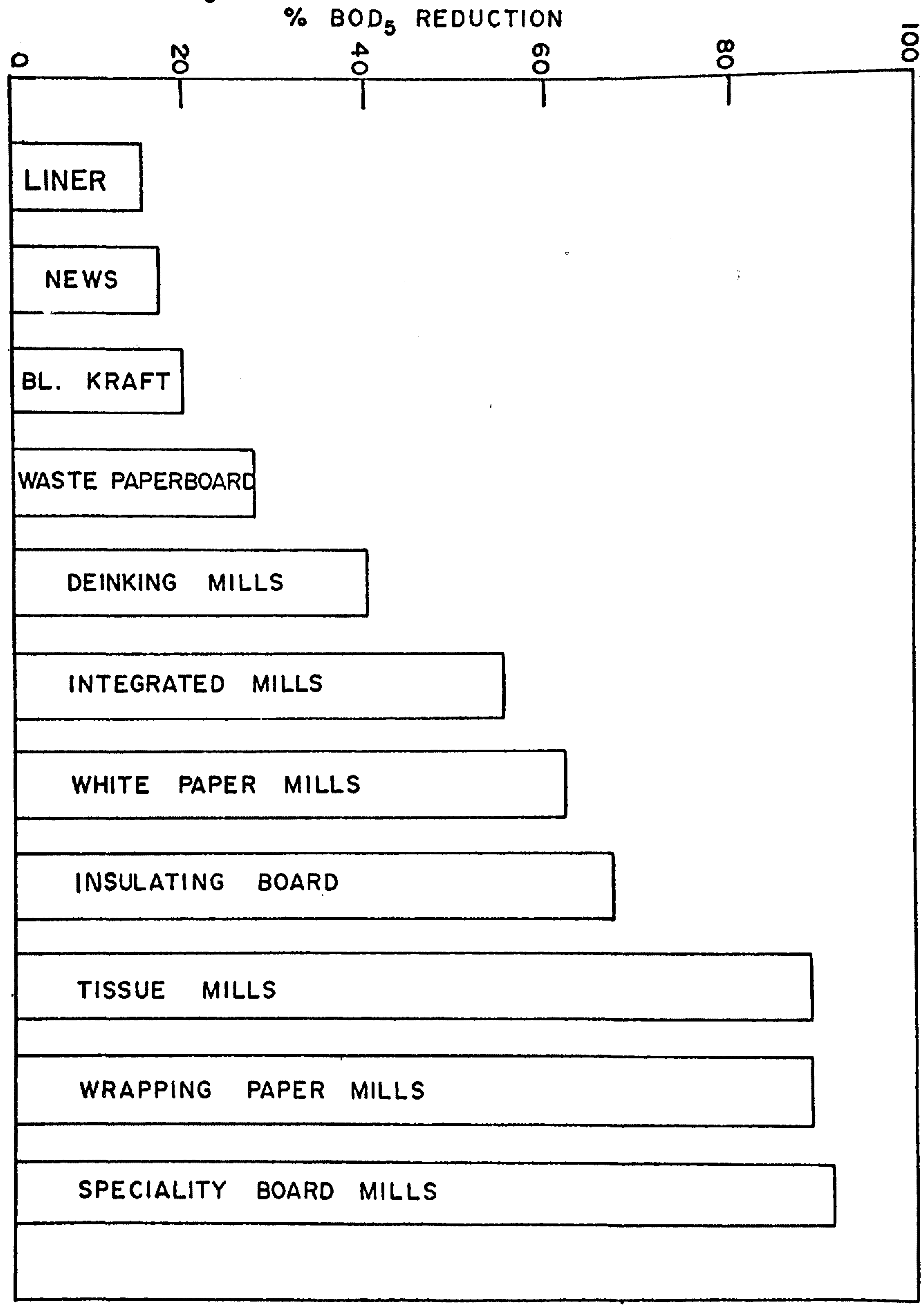
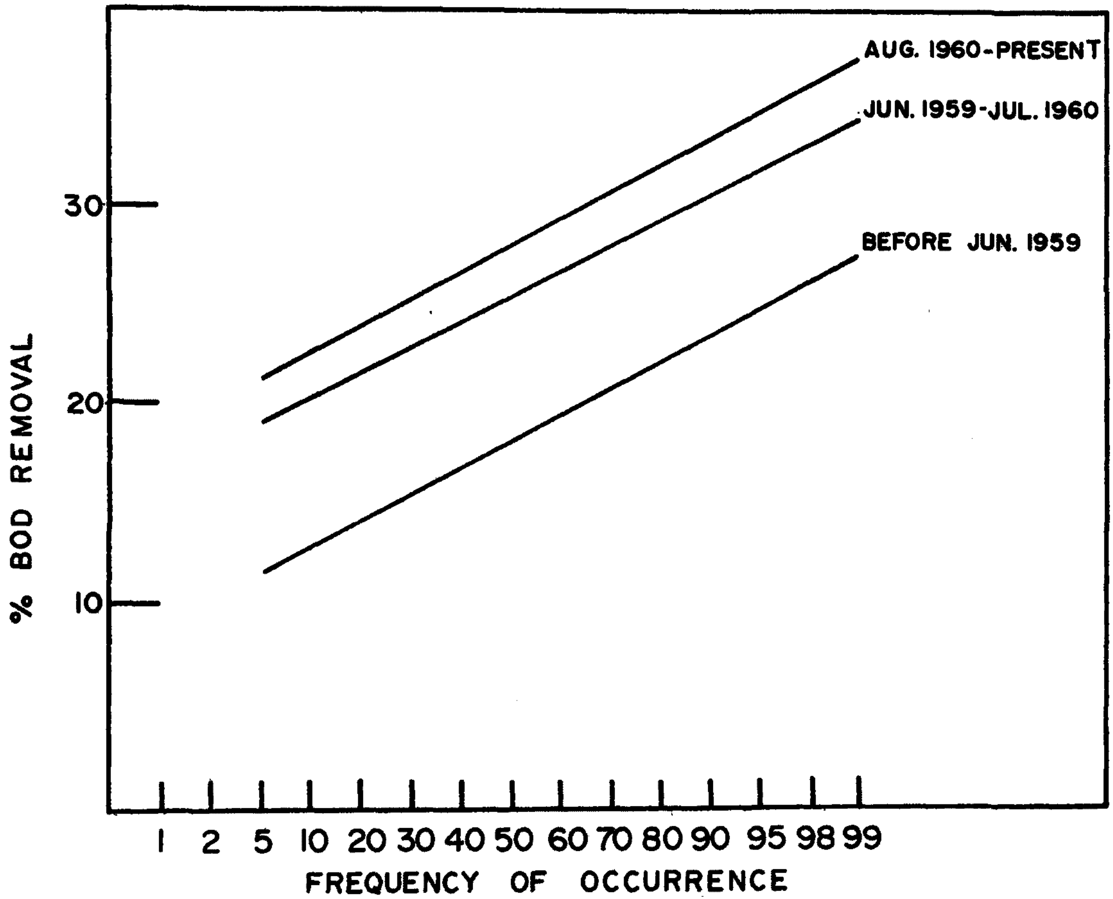


FIGURE 4

STATISTICAL COMPARISON OF PRIMARY TREATMENT PERFORMANCE - BOD REMOVAL



by the WPCF, in the bibliography of biological treatment of pulp and paper mill effluents, and in a manual on the subject published by the NCASI (62,63).

Through the years, all forms of biological treatment have been explored extensively. Of these, three have become established and widely applied These are storage oxidation, aerated stabilization, and activated sludge. There are also modifications such as contact stabilization and extended aeration. Very intensive investigation of trickling filters has not led to their adoption except for special purposes. There is only one large unit in operation and it is a pre-treatment device. These filters have the ability to remove a fraction of the BOD_5 from a large volume of waste, but if a high percentage reduction is required filter size becomes disproportionately large, and therefore, costly (64). Small plastic media filters are sometimes used in pre-cooling towers and as such remove some BOD as pointed out by Burns and Eckenfelder (65, 66). They have also been applied to in-mill cooling and treatment of kraft mill condensates on an experimental basis by Estridge (67). In this capacity they act not only as biological treatment units, but stripping devices as well since the constituents of the condensates responsible for the BOD are volatile organics such as methanol. The use of log and chip piles as biological filters has been a subject of investigation (68,69) although adoption of this technique is most unlikely since it disrupts the raw material flow of the mill.

Storage Oxidation:

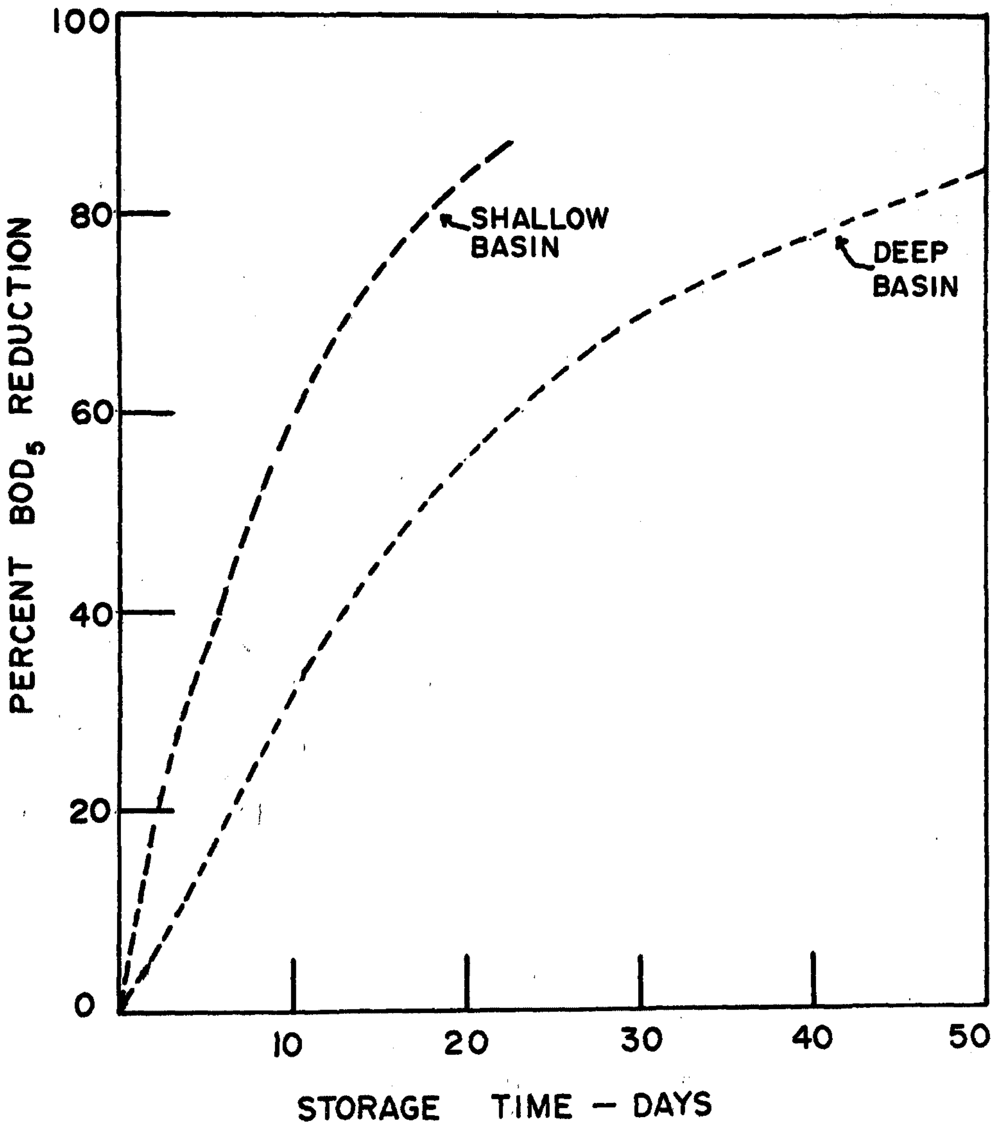
Storage oxidation was the first type of biological treatment adopted in the industry. This was first used by, and is still most prevalent in the southern kraft industry, where a number of mills were able to procure large areas of land having suitable topography remote from dwellings for this purpose. The high ambient temperatures of the south allow maximum oxidation rates to be realized throughout the entire dry season in most cases. Berger (70) summarized results obtained at a number of these mills. Heustis (71,72), Bodenheimer (73), Webster (74), and Chapman (75) report on results obtained with both deep and shallow storage oxidation basins. BOD loadings for which these basins are designed are from 50 to 60 pounds per acre of surface area per day. Reductions obtained in relation to time are presented in Figure 5.

It is imperative that settleable solids be effectively removed ahead of such basins since if deposited therein they will liquify on decomposition adding more BOD than was contained in the wastewater itself. Under these conditions the effluent can deteriorate to a point where its BOD is higher than the influent. Nutrients do not accelerate the slow oxidation occurring under these conditions so are not employed. Retention time ranges from 20 to over 300 days producing BOD reductions from about 50 to in excess of 95 percent.

This method of treatment enjoys the advantage of being capable of handling accidental discharges of strong waste without upset and performs well on a continuous basis since no mechanical devices are

FIGURE 5

EFFECT OF STORAGE TIME
ON BOD REDUCTION



involved which can get out of order. Twenty-one large kraft mills in the U.S. employ this type of treatment, as pointed out by Gehm and Gove (76), as does one large deinking mill described by Ross (77). A number of very small mills also use these basins although use of this method is limited to weak wastes because of odor problems. Porges (78), in a survey of the application of storage oxidation in industry, lists most of these installations, and their design is discussed by Hermann and Gloyna (79), Blosser (63), and Edde (80).

In some cases these basins are also used for discharge regulation when mills are located below peak load hydro-power stations, in semi-arid regions, or where stream flows reach extremely low levels.

Activated Sludge Treatment:

As a result of experimental work started in 1950 (81), the activated sludge process was adapted to treating pulp and paper mill wastes. Early experiments were followed by pilot plant investigation by Palladino (82), Gehm (83), Bishop (84), and Kniskern (85). Trials on modifications of the process were later carried on by Weston and Rice (86) and its adaptation to other specific wastes by Nylander and Rennerfelt (87), Shnidler (88), Sullins (89), and Waldmeyer (90).

Design and operation of the first large plant to be built were described by Moore and Kass (91) and its operation by Pearman and Burns (92). This plant, treating waste from a bleached kraft and linerboard mill, was followed by others treating kraft pulp mill newsprint and fine paper wastewaters as well as waste paperboard effluent in this country, and similar wastes in Europe (93,94,95).

This process operates successfully at over ten mills in this country. It has been found capable of removing in excess of 80 percent of the BOD_5 from effluents to which nutrients have been added. Because of the nature and temperature of these wastes, high oxidation rates are possible so that loadings in excess of 100 pounds of BOD per 1000 cubic feet per day of aeration capacity are obtainable, allowing the use of relatively small aeration tanks. Mechanical surface aerators are most commonly employed although diffused air has been used at two plants. The major difficulty relative to their operation is the dewatering and disposal of the waste activated sludge. This material is extremely slimy and must be mixed with more free materials to be successfully dewatered; primary sludge, bark, and fly ash being examples of these. In one instance it has been disposed of on plowed land. Experimental work employing centrifugal thickening and heat treatment is now underway in the hope of finding a solution to this problem.

Three mills employ modifications of the activated sludge process, one using contact stabilization (96) and two extended aeration plants (96, 97), and one treating strong wastes from a magnesium base bleach sulfite pulp mill.

Design and operation of a number of these plants are described in NCASI Technical Bulletin #220 (97) and #214 (80), and others by Coughlan (98), Billings and Narum (99), and Butler (100).

Aerated Stabilization Basins:

The long period of time required to produce a relatively high degree of BOD reduction on storage is due to the low rate of natural reaeration. This time can be reduced substantially by induced aeration as pointed out by Amberg (101), Eckenfelder (102), and a number of others (103, 104,105,106,107). In order for the potential of this method of treatment to be fully realized, it is necessary to add nutrients since most pulp and paper effluents are deficient in these elements. These additions are usually made in the form of ammonia and phosphoric acid. The longer the retention period of the waste undergoing biological oxidation, the lower the nutrient requirement. In some instances no addition is required since the small quantity contributed by sanitary sewage, boiler blow down, and detergents suffices. The effect of nutrients on the oxidation rate of pulp and paper wastes is discussed by Nowacki (108,109) and Tracy (110) in detail.

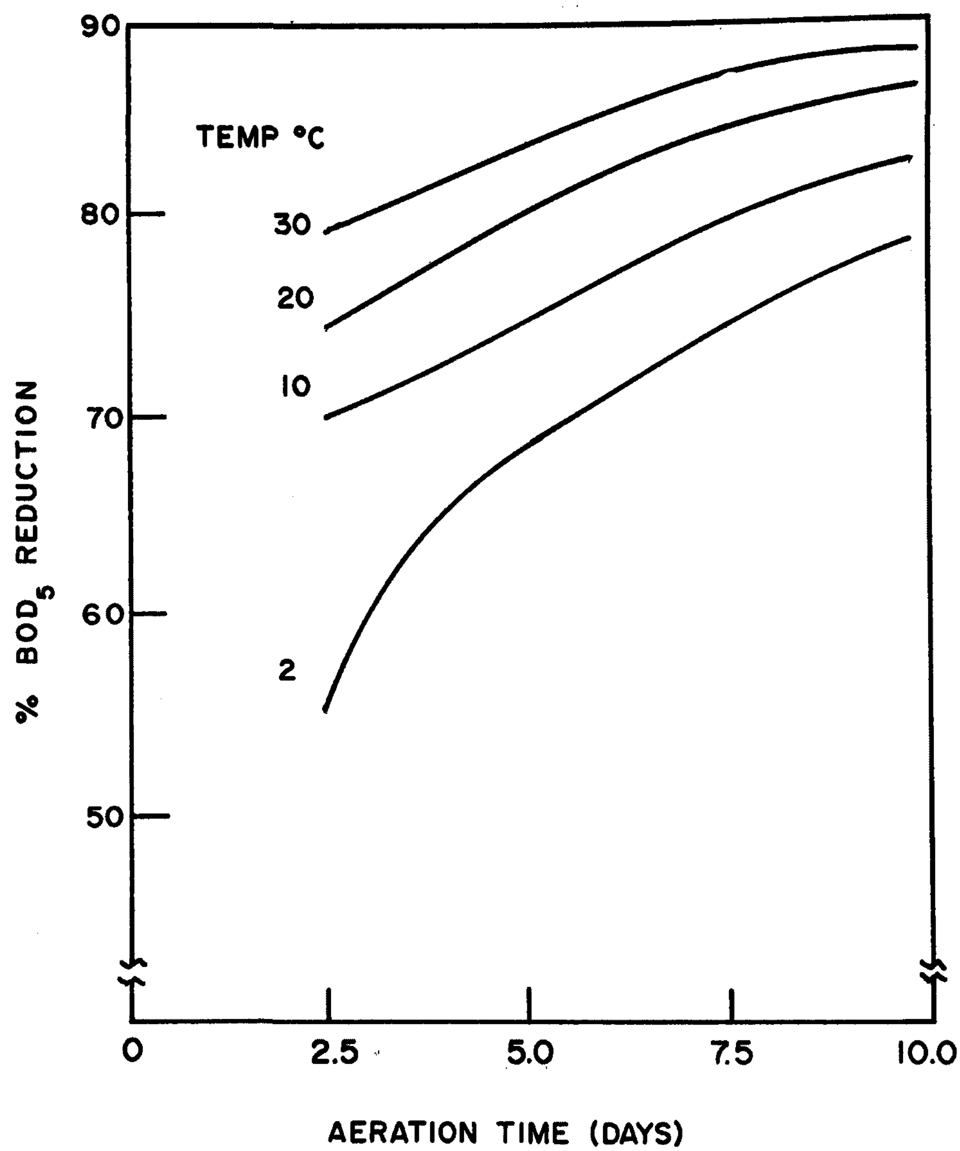
Aeration is generally induced by mechanical surface aerators which are capable of dissolving on the order of 50 pounds of oxygen per horsepower day (111,112,113). Diffused air can be employed but is less efficient. Recently a downflow bubble aerator has been developed for use in deep basins (114).

Eckenfelder (115) and Edde (116) discuss the design of these basins including configuration, power requirement, and aerator placement,. These basins are generally designed for from five to ten days retention time since this provides a sufficient period to produce a BOD_5 reduction on the order of more than 80 percent and allows stabilization of the biomass by means of autogenous respiration as well as dispersion of most of the resulting debris. Some sludge accumulates in the bottom of these basins but is relatively inert and readily removed periodically. If BOD_5 removal in excess of 90 percent is required, the retention period is about ten days. At some mills a settling basin follows the aeration unit in order to improve effluent clarity. Gellman (117,118) and Gehm and Gellman (119) discussed the performance of aerated basins treating various types of pulping and papermaking wastes finding them all responsive to this treatment.

Vamvakias et al (120) investigated the effect of temperature on the efficiency of the process under carefully controlled laboratory conditions as did Weston and Rice (86). They found that while efficiency decreased with the temperature, this effect was not as severe as anticipated and that good BOD_5 reductions were obtained in five days at 2°C. The adverse effect of low temperature is minimized with increased retention time as shown in Figure 6. Bailey (96) reporting on basin performance at sub-freezing ambient temperatures indicated that operation under these conditions was satisfactory.

FIGURE 6

EFFECT OF TEMPERATURE ON BOD REDUCTION
IN AERATED STABILIZATION BASINS



However, the effect of temperature for aerated stabilization basins is not too well established. Initial temperature of the waste, basin configuration, and depth all affect the operating temperature during cold weather. Some winter decline in efficiency can be anticipated for basins of this type.

Operation of a number of these basins at large kraft mills is reported in the literature, i.e., papers by Bailey (121), White (122), and Ebersole (123). Canadian operations are reviewed by Voege and Stanley (124). Some 30 installations of this kind have been made at pulp and paper mills in the U.S. They provide a high degree of BOD reduction without very extensive land use and at capital and operating costs lower than those for highly accelerated oxidation processes. The advantage of this method is that it does not produce a slimy waste sludge, difficult to dewater and dispose of. Effluents produced at reasonably high BOD reductions are not conducive to slime production in receiving waters.

Burns and Eckenfelder (125) prepared statistical analyses of activated sludge plant performance and Weston and Rice (86) did likewise for aerated stabilization basins. Typical data from the activated sludge study is shown in Figure 7. Overall performance in terms of BOD reduction was found to range from about 70 to 85 percent with 80 percent reduction being achieved 80 percent of the time.

Biological Treatment Summary:

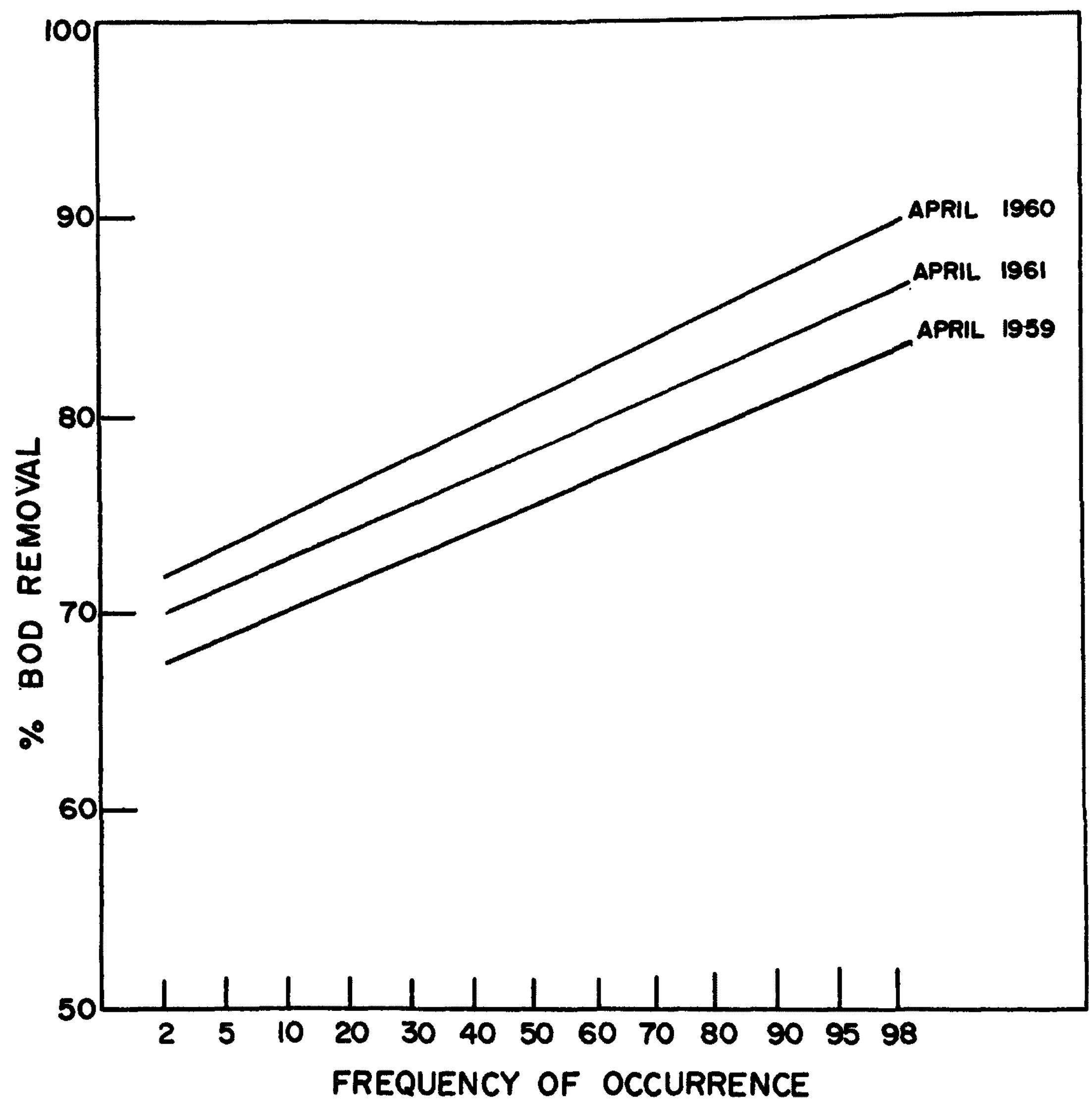
It can be concluded that biological treatment in its several forms is now extensively employed in the pulp and paper industry for reducing the BOD of spent process waters. When properly preconditioned all of the weak wastes of the industry are responsive to such treatment, with the degree of reduction depending upon the extensiveness of the facilities provided. The selection of the specific method at a particular mill frequently depends upon land availability since the methods requiring a considerable area are the least expensive and often the most reliable. Within limits, the level of BOD reduction can be adjusted by design and operation to meet local requirements. Natural performance limits have been established by statistical analysis of the performance of such plants over long periods of time by Burns and Eckenfelder (125) and Weston and Rice (86).

Added benefits obtainable from biological treatment are the destruction of toxicity to aquatic life (126), reduction in foaming tendencies (127), and reduction of turbidity-producing inorganic coating additives. High degree treatment also eliminates the tendency of pulping effluents to stimulate slime production in receiving waters (128).

The shortcomings of biological treatment are its failure to remove color to a high degree and the production by high rate processes of a waste sludge of an extremely slimy nature (129). Color bodies are not oxidized (28) and at best only a fraction of them absorbed into the biomass. The use of these processes will be limited until better solutions than those presently available are found to solve the sludge disposal problem.

FIGURE 7

STATISTICAL COMPARISON OF SECONDARY TREATMENT EFFICIENCY-BOD REMOVAL



Irrigation and Land Disposal

Irrigation:

Although extensive field studies of the disposal of mill effluents by irrigation have been made by large kraft producers (130,131,132,133), actual use of this technique has been made only by small paper mills. This is because of the limited amount of effluent that can be applied per acre in relation to the volume of mill discharge. It had been hoped that irrigation of southern woodlands would lead to an increase in wood yield that would justify the extensive irrigation systems required. Experiments left considerable doubt that the increased yields realized could justify the cost (133,134), hence, no large-scale project of this kind was developed. However, rice, vegetables, peanuts, and fodder crops were all successfully grown at high yields using kraft mill effluents as irrigation water.

A number of small mills employ irrigation as both a means of secondary treatment and as a seasonal supplement to secondary treatment. There are descriptions of some of these applications in the literature (135, 136,137,138,139,140). Wastes from fine paper, tissue, corrugated board, waste paperboard, and hardboard production are all treated in this fashion, mainly by small mills located on streams having very low seasonal flow.

Extensive investigations conducted by NCASI and reported in several technical bulletions (141,142,143) and by Gellman (144) have established the parameters and good practice requirements for this form of treatment. Percolation through the soil is extremely effective and, during dry weather, color bodies present in pulping wastes are inclined to leach out when the soil is washed with rain water. From 10 to 20 thousand gallons per acre per day of weak wastewaters can be successfully disposed of in this manner. With stronger wastes the BOD or organic solids determine the allowable application rate. Blosser and Caron (138) recommend that BOD loadings be held to less than 200 pounds per acre per day. Parsons (137) reports that total solids application of as high as 500 pounds per acre per day have been applied in irrigating with fiberboard wastewater having a solids content of two percent.

While spray disposal started as a summer dry weather procedure, it has been used at some locations recently the year round with a measure of success (140).

Land Disposal:

Soil percolation is employed for the disposal of spent acid and neutral sulfite liquors at small mills. Experience with this method of disposal has been reported by Billings (145), Guerri (146), and Wisniewski et al (147). One mill recently reported on disposing of 200,000 gallons of NSSC liquor containing ten per cent solids from a 250 ton dry mill. An average of one-sixteenth inch per day is applied, three-eighths to seven-sixteenths inch being sprayed on in a day and a six-day resting period allowed. The liquor solids are absorbed and decomposed in the soil and do not reach adjacent surface water or wells. This method is applicable only at small mills having especially suitable land which is not in the proximity of dwellings.

Foam Control

Effluent foaming in receiving waters is a problem experienced by pulp mills since alkaline liquors have a strong propensity to impart this quality to water. Other waste constituents can do likewise but these are the most common offenders in both treatment plants and receiving streams. Some paper mill wastes can also cause this effect due to residual amounts of additives present in the white water discharged, as can coating-kitchen wash waters.

There is relatively little literature on the measurement of foaming capacity or its control in pulp and paper effluents despite the fact that control methods are well established, widely used, and quite effective. Carpenter (127) developed a method for comparing foaming potential based upon methods employed in the detergent industry which appears to be the only technique presently available to measure this factor in pulp and paper effluents.

Foaming problems are common within mills themselves and these difficulties are frequently the cause of the problem in effluents, foam or black liquor being carried directly into sewers. In-mill sewering arrangements can give rise to foaming. This can be avoided by correction of the sewer system to prevent direct admixture of alkaline and acid wastewaters within them and correcting arrangements and pumping systems which give rise to air entrapment, a major cause of foaming in itself. Maximum control of black liquor losses is mandatory if foaming is to be kept at a reasonable level both during effluent treatment and in discharge.

Since some biological treatment processes depend upon aeration of the waste, foam is bound to develop. Under normal conditions with most wastes this can be maintained at a minimum level by in-plant control or by the use of surface sprays installed in treatment basins. In most instances with good mill loss control, foam levels will stabilize in treatment units and not become unmanageable. Biological treatment is effective in itself in reducing foaming tendencies.

SECTION VI

ADVANCED WASTE TREATMENT

With some qualifications, satisfactory methods are available both for clarifying pulp and paper mill effluents and reducing their content of biologically oxidizable matter responsible for deoxygenization and slime growth in receiving waters. Such treatment appears to be effective in destroying potentially aquatically toxic components present in kraft mill effluents but also those materials adversely affecting fish productivity.

The remaining difficulties in clarification are the removal, to the extremely high degree desirable, of pigments used in papermaking--such as titanium dioxide and carbon black which are exceptionally optically active. Through light reflectance and absorption they can, in infinitesimal concentration, affect the appearance of surface waters to an undesirable degree.

The major problem attendant to the reduction of biologically active substances is disposition of the zoogleal matter formed as a result of its decomposition. Separation of this from final effluents and its dewatering and disposal are the subject of considerable research and development which, if pursued, should provide answers to this problem in the not too distant future.

A third problem is the disposal of sludges high in ash content which are not responsive to incineration. The industry has been investigating advanced land disposal methods for sludge and is seeking assistance from the Office of Solid Wastes Management Programs in extending these investigations.

The major remaining problem involves the biologically refractive fraction of pulping wastes largely responsible for color. An examination of the literature and number of private communications established the values for color discharged from various pulping processes shown in Table 4. Wood species, age, and processing variables all affect these values but the ranges shown reflect the usual situation.

The individual process distribution of color from the kraft process in a linerboard mill is shown in Table 5.

This is subject to great variation from mill to mill and from time to time since it depends upon both equipment capacity and momentary functioning efficiency of each unit process.

Research and development work on color reduction started over 30 years ago in the United States. These studies were stimulated by complaints of discoloration of small streams by mills located on them rather than by specific governmental regulation. Today, as federal and state standards are being set which contain color limitations, the industry is fortunate in having an appreciable background in this area, and has been able to respond with large-scale process demonstrations which can be expected to lead to workable systems of practical economy.

Table 4

VALUES FOR COLOR DISCHARGED FROM VARIOUS PULPING PROCESSES

Effluent	Pounds of Color Units per Ton of Product
Kraft Pulping	50 to 300
Kraft Papermaking	3 to 8
Kraft Bleaching	200 to 300
NSSC Pulping (Recovery)	200 to 250
Sulfite Pulping (Recovery)	30 to 200
Sulfite Bleaching	50 to 300

Table 5

UNIT PROCESS FLOW AND COLOR DISTRIBUTION

IN INDIVIDUAL KRAFT PULPING EFFLUENTS

	Flow Thous. Gal/Ton	Color Units
Paper Mill	11.4	10
Pulp Mill	0.9	520
Evaporators	0.1	3760
Recovery	0.2	20
Caustic House	.8	20

Research and development studies carried on by NCASI, individual pulp and paper companies, and universities supported in part by Federal grants, included the following:

1. Improved methods for the measurement of color in effluents and receiving waters.

2. The physical and chemical characteristics of color bodies contained in pulping and bleaching effluents.

3. Effect of biological oxidation on color.

4. Possible application of the foam separation process to color removal.

5. Adsorption of color by activated carbon, resins, various minerals, and by the soil, together with adsorbent recovery for reuse.

6. Application of membrane processes for color removal.

7. The effectiveness of bleaching process changes on effluent color.

8. The effectiveness of chemical reagents for reducing the color of water together with their recovery for reuse.

Data obtained from a review of these studies are set forth briefly below, together with some conclusions which can be drawn:

The measurement of color is affected by the pH of the wastes. Hence, for comparative purposes, and to better reflect the effect on receiving waters in terms of color, measurement is made near neutrality (pH 7.6). The optimum wavelength for spectrophotometer measurement appears to be 465 mμm for all the common pulping and bleaching effluents (159, 160).

Color bodies present in these wastes pass, to a large degree, through submicron filters, hence are probably molecular in nature rather than colloidal sols. Bennett et al (161) have shown conclusively that the solids contained in spent caustic extract consist of comparatively low molecular weight chlorine-substituted acidic material displaying little phenolic character and that their precipitation by lime and other reagents is a chemical reaction rather than physical in nature.

Even extended biological oxidation both in treatment systems and in surface water has relatively little effect on waste color, particularly that originating from bleaching. Activated sludge treatment can remove up to one-third of the color from kraft pulping effluents. It is not as effective when bleachery wastes are present. This observed reduction is probably due to adsorption of some of the color by the sludge matrix. A darkening has been observed on storage oxidation which is probably caused by iron tannate formed by reaction of tannins with soil ingredients.

Attempts to remove appreciable percentages of the color from pulping and bleaching wastes by the foam separation process failed to achieve results (162). A separation could be obtained on addition of a relatively large dosage of a surfactant but economics ruled out its use. Recently, experiments along the same line have been conducted in France (163) yielding similar results.

The most effective adsorbent for color bodies has been found to be activated carbon (164, 165). Most other adsorbents were found to be of little practical value. Present research deals with the manufacture of a low cost and effective carbon that can be used once and burned, as well as development of satisfactory thermal and chemical carbon recovery processes. Regeneration is presently a basic requirement for the efficient application of carbon adsorption (311).

On percolation of color bodies through the soil, they are adsorbed to a high degree by most soils during the dry season and leach out during wet periods when rain water passes through the soil at a relatively high rate (166).

A large paper company which has considerable research and development capability in recovery processes has received a large federal grant to help finance a process for manufacturing low cost carbon from black liquor and applying it to effluent reclamation. Some preliminary results have been reported by Timpe et al (167) on the adsorption properties of such materials for which high loadings were observed. One resin manufacturer reports the development of a new group of synthetic adsorbents that will be laboratory tested for pulping and bleaching wastes shortly (168).

An extensive research and development program on the use of reverse osmosis for concentrating the dissolved solids present in weak sulfite wastes and reclaiming process water was conducted jointly by the former Pulp Manufacturer's Research League and the Environmental Protection Agency (EPA) (169). After extensive laboratory work with the process, a portable reverse osmosis pilot plant was assembled and operated at several mills of different types including acid sulfite and NSSC plants. In additon to concentrating solids for introduction into recovery or incineration systems and reclaiming water, the separation of acetic acid and sugars having unique properties was attempted. While the reports covering these investigations have not as yet been published, it has been pointed out by the participants (312) that flux rates obtained were undesirably low and the membrane life fell short of that required for commercial practicability. These observations were confirmed by other investigators (313). Very extensive effort is being expended by membrane manufacturers and others supplying hardware for these systems and it is anticipated that these shortcomings will be overcome to some degree in the not too distant future.

As an outgrowth of these studies, a Wisconsin paper company, which manufactures NSSC pulp and corrugating medium, has agreed to join in a project with EPA-OWP to conduct comparative pilot plant tests of various proprietary reverse osmosis systems for concentrating weak pulping wastes to a degree that they can be introduced into the existing fluidized bed burner handling the spent liquor. If results obtained with the most efficient unit tested appear favorable, plans call for the installation of a demonstration unit at the mill. The company is attracted to the process because it removes both BOD and color and could possibly lead to a closed system.

While there is considerable interest in oxygen bleaching and the Rapson process for improving the discharge from bleacheries, neither of these processes have as yet been operated in the United States (233).

However, five mills are now employing a change in bleaching sequence to reduce effluent color. By employing a C-H-H-D sequence, caustic extraction is eliminated, resulting in a color reduction of about 90 percent. The cost of this procedure is between 50 cents and a dollar per ton of pulp bleached. Its use is limited to production of book and similar papers because of the resultant low pulp strength.

Biological treatment removes, at best, only about one-third of the color from bleaching effluents and is more effective for unbleached mills.

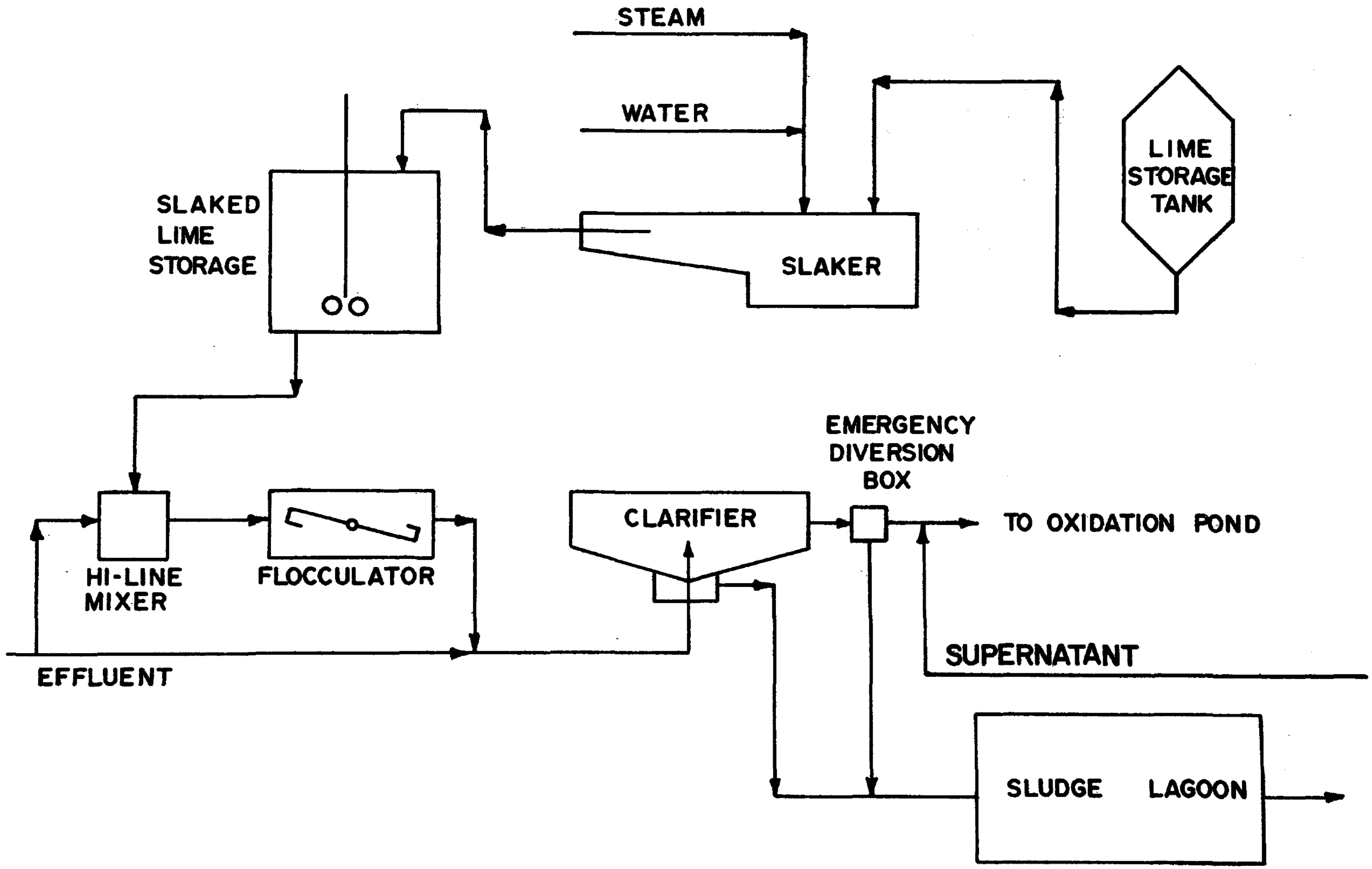
Sanks (171) experimented with ion exchange resins for reducing color as has Walker (168). This work is still in the early stages and has been plagued by irregularity of results.

Chemical precipitation processes have been a major subject of interest for 30 years and many reagents and combinations thereof were tried for removing color bodies. Of those tested, interest remains in lime and, to a much lesser degree, in alum. Extended research by the NCASI in collaboration with mills and university investigators has demonstrated the general effectiveness of this process in a comparatively large number of mill situations and opens up the possibility of its incorporation into the kraft recovery system. Today, five large full-scale operations of this kind are underway either employing the basic procedure of effluent control or determining its feasibility.

The first large-scale installation was made at a new 400 ton per day linerboard mill located at the upper end of a "dead" estuary where a high degree of suspended solids, BOD, and color removal is required. The process employed has been described in detail by Davis (72) and a flow sheet of it is presented in Figure 8. The waste treatment facilities were a joint venture of the company and EPA.

This system employs between 30 and 40 tons per day of calcium oxide which is produced from limestone in the mill's recovery system kiln which was sized to handle this load in addition to the normal requirement of the causticizing system. It is the minimum dosage required for

FIGURE 8 INTERSTATE CONTAINER CORPORATION COLOR REMOVAL PROCESS



maximum color reduction since the hydrous sludge produced by the precipitated color bodies and suspended matter in the mill waste is disposed of in lagoons. The average raw waste color value of 750 units is reduced to between 50 and 100 units and is accompanied by a BOD_5 reduction ranging from 25 to 35 percent. Further treatment is provided by storage oxidation. Experiments are now being conducted at this mill on recarbonation of the effluent from lime treatment using kiln off-gas as the source of carbon dioxide.

The second installation to be put into operation is the NCASI "massive lime" process as described by Berger and Gehm (173). It is integrated with the recovery system of the bleached kraft mill where it is installed as illustrated in Figure 9. It is designed to handle a portion of the caustic extract of sufficient size so that operating and recovery problems which might arise from its use can be identified. This installation has been in operation for too short a period to permit a report and is also an industry-EPA undertaking.

A third joint project of this type is under construction by a combined kraft and semi-chemical pulp mill, the flow diagram for which is shown in Figure 10. The process employs a minimum lime dosage to obtain good precipitation of color bodies and uses the lime mud from causticizing as a filter-aid to permit its handling on the mud filter. Operation of this unit is anticipated in the near future, treating a mixture of unbleached kraft and NSSC pulping effluents.

A similar process has been employed by one company to treat a mixture of caustic extract and hydraulic barker waste at one mill and caustic extract alone at another site, both of which are full-scale operations. The process appears at present operable although some problems have appeared in dewatering the organic-laden mud.

Berger (174) suggests still another process which is diagrammed in Figure 11. In this the lime mud, which contains some free $Ca(OH)_2$, is added to the colored effluent together with supplementary hydrate. Precipitates obtained are dewatered on a filter together and the cake is returned to the kiln. This process is still in the laboratory stage and may not prove to have any advantage over the other system employing lime mud.

Both acid and neutral sulfite pulping effluents respond to lime treatment as reported by Sutemeister (175) and by Vilbrant (176). Their work dealt with strong spent liquors, the former being directed toward separation of liquor sulfonates for by-product manufacture.

Detailed performance data of an advanced waste treatment system embracing color reduction at a linerboard mill is reported by Davis (177). A simplified flow diagram of the system is presented in Figure 12. The data showed that effluent color values of from 50 to 180 units were obtained when treating a feed ranging from 460 to 2120 units. Beyond a certain level no further color reduction resulted from an increase in the lime dosage

FIGURE 9 MASSIVE LIME PROCESS FOR COLOR REMOVAL

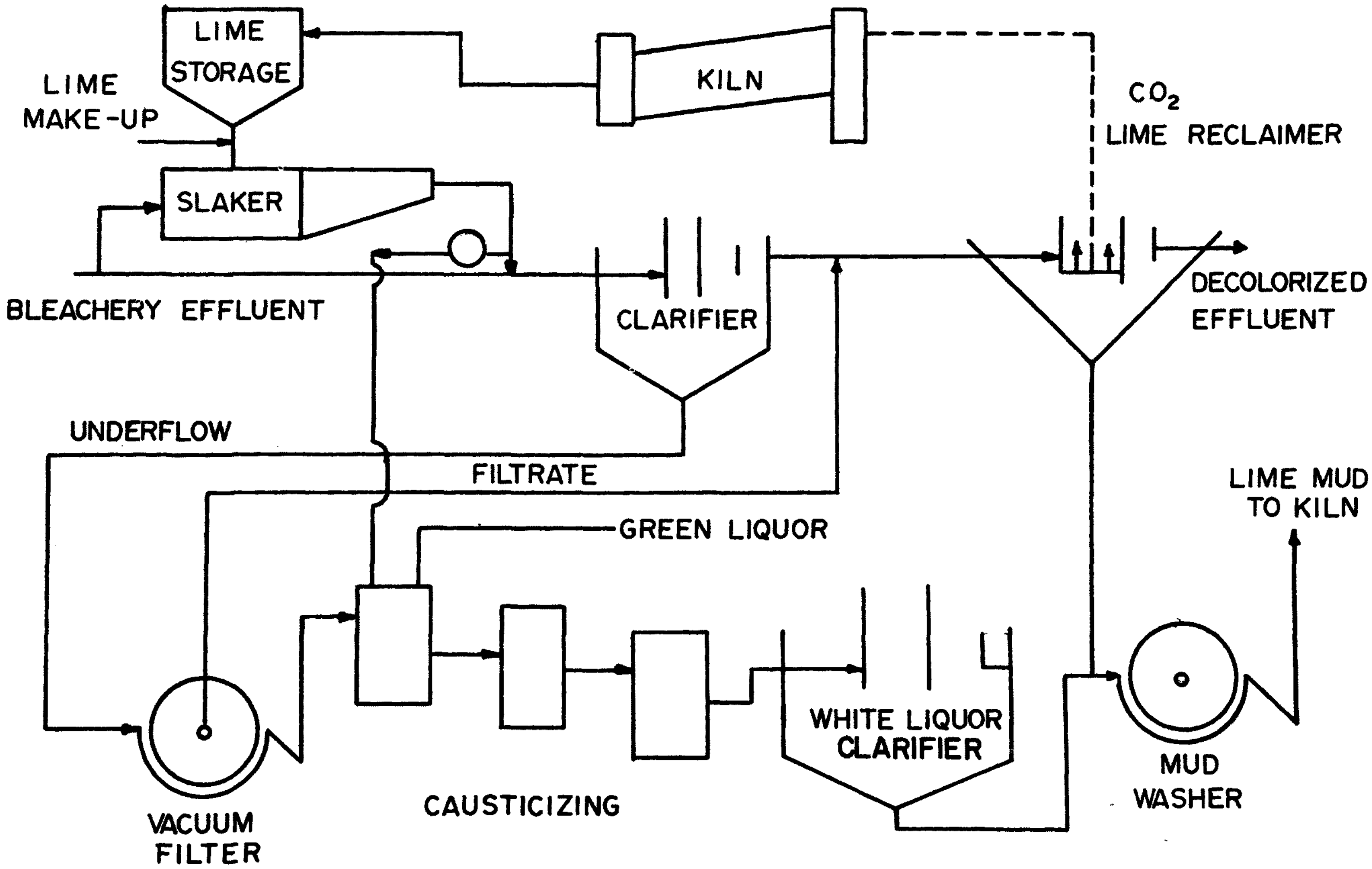


FIGURE 10 CONTINENTAL CAN CO. INC., COLOR REMOVAL PROCESS

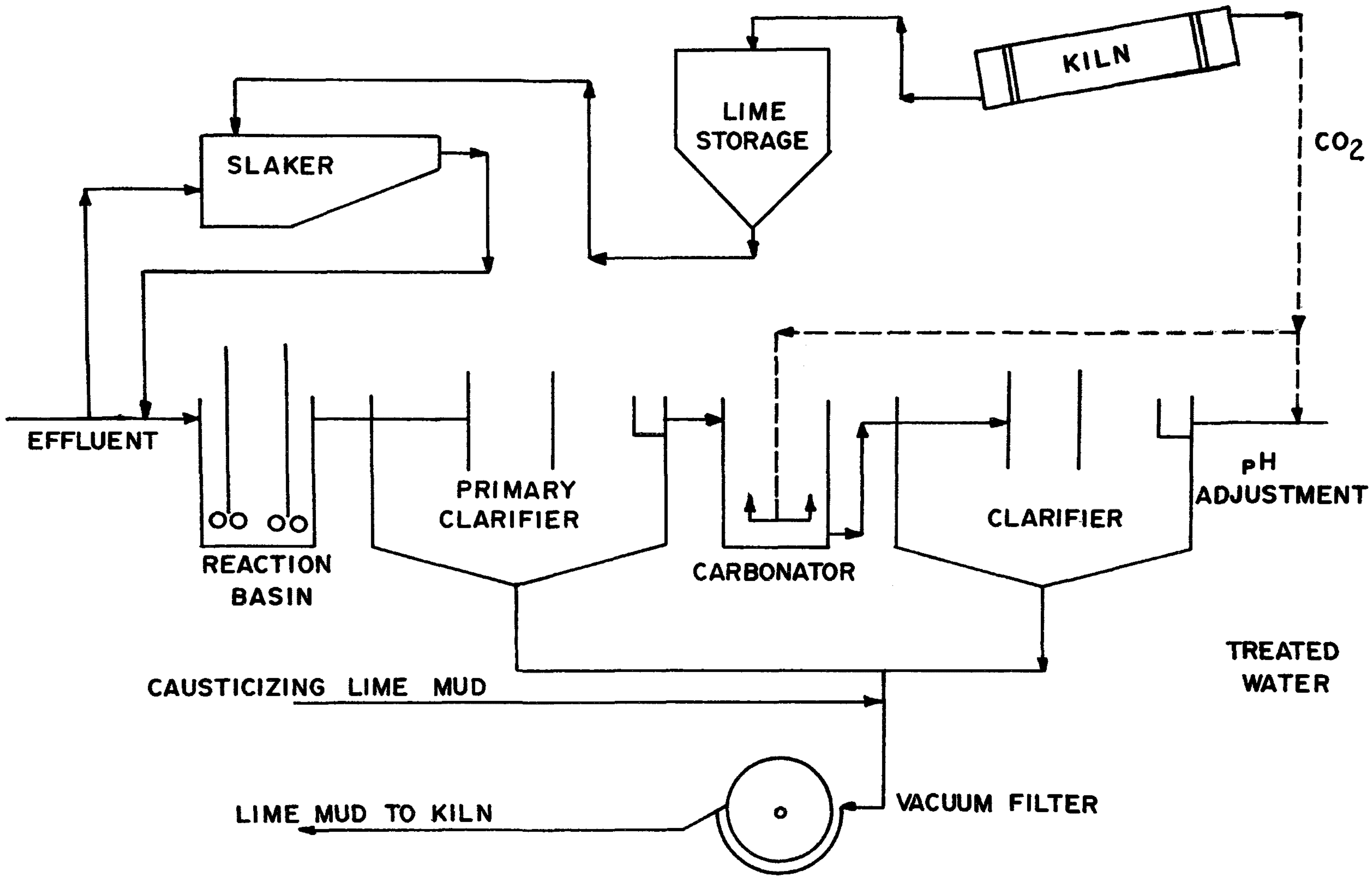


FIGURE 11 LIME MUD PROCESS FOR COLOR REMOVAL

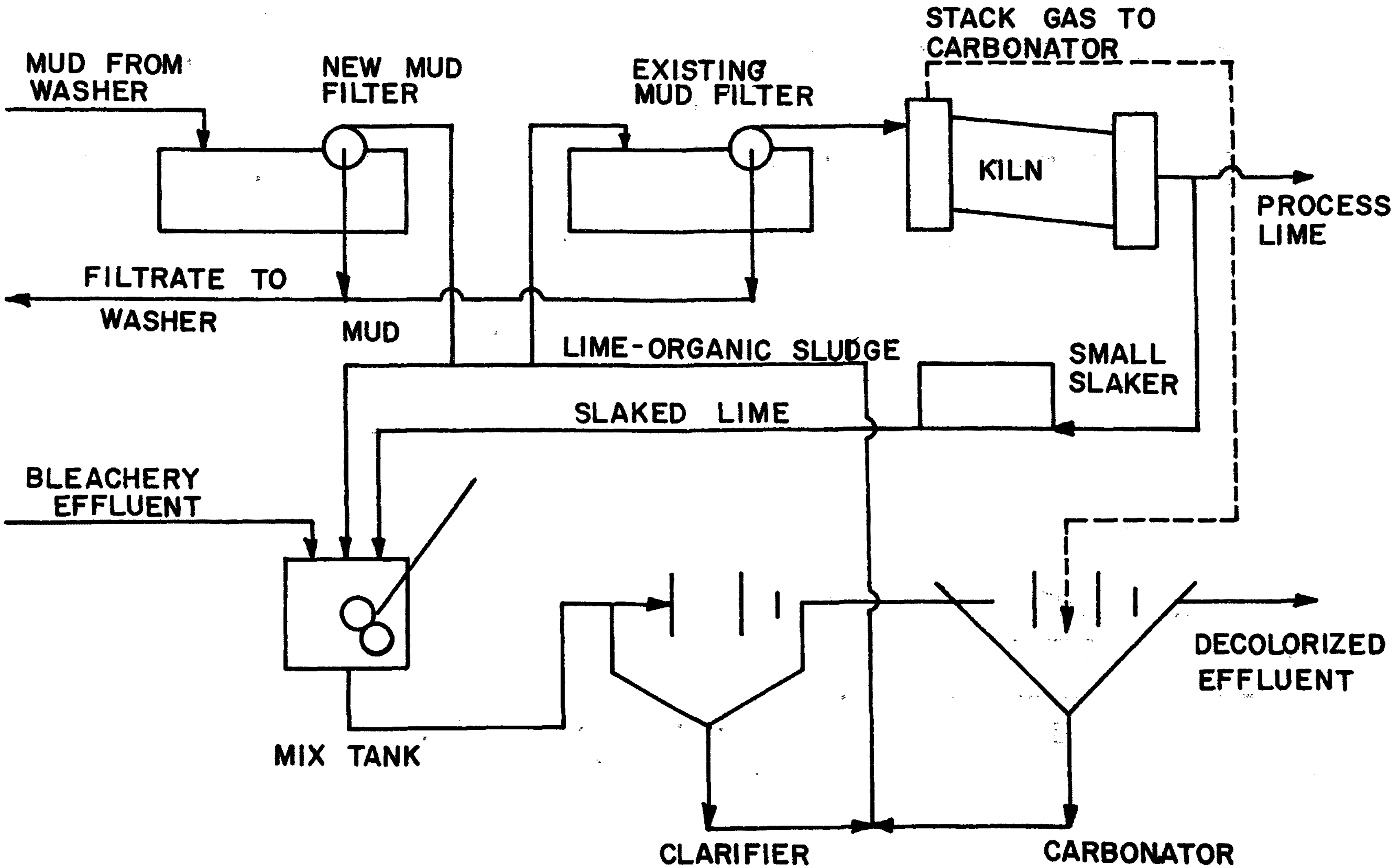
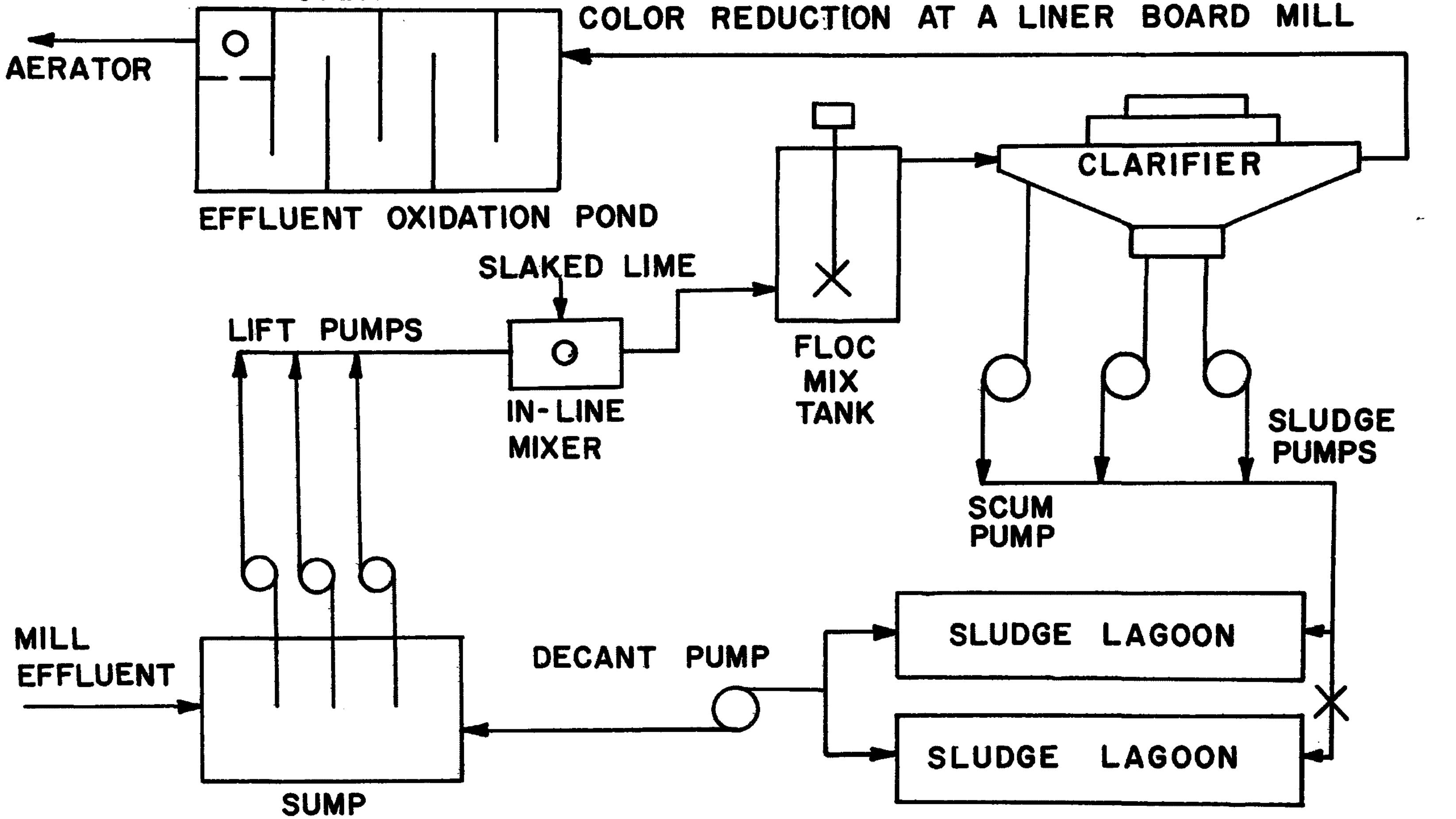


FIGURE 12

ADVANCED WASTE TREATMENT SYSTEM EMBRACING COLOR REDUCTION AT A LINER BOARD MILL



at any feed color values, indicating that a constant fraction of non-precipitable color is present in this waste. This is demonstrated by Figure 13 which was reproduced from Davis' paper.

Average BOD and COD reductions have amounted to 34 and 46 percent, respectively. The lower values observed were 190 mg/l for BOD and 400 mg/l for COD. These values in relation to residual color are shown in Figure 14 reproduced from the same paper.

Subsequent treatment of the effluent is by sto age oxidation which represents no problem in the large basins provided, the effluent containing between one and two pounds of BOD_5 per ton of product. However, about one-sixth of the capacity is consumed in neutralization of the caustic effluent through reaction with atmospheric carbon dioxide before biological oxidation can commence.

Continuing studies have been directed toward neutralization and lime recovery by reaction with lime kiln off-gas before discharge to the basin. Such treatment might also serve to minimize the leaching of color from the basin bottom which now occurs and reduces the effectiveness of color reduction treatment markedly. The organic content of the soil in the swampy area in which these basins are constructed is responsible for this condition.

The final effluent from the basin is raised to near dissolved oxygen saturation in a small basin containing a mechanical aerator.

This experience has indicated that color reduction costs for lime precipitation are very high for the simplest type of full chemical pulping and papermaking operation with the most efficient recovery system available, the major cost being for lime. As pointed out by Davis, the percent increases in color reduction above the 1000 ppm $Ca(OH)_2$ level costs $38 per million gallons of waste treated or about 50 cents per ton of product. Thus it is obvious that a process involving lime recovery is needed to make the lime precipitation process acceptable to widespread application.

It can be concluded from this review that substantial work is being carried on in the United States in the area of color reduction from pulping and bleaching wastes. These studies have a further impact since in the process of removing color a very substantial portion of the total organic matter present in the wastes is also removed. This makes the processes attractive from the standpoint of water reclamation whether it is practiced in-mill or on downstream water.

The willingness of the federal government to contribute substantially to the industry effort in this area bears witness to the importance currrently attached to the problems at the regulatory level.

FIGURE 13

TREATED WASTE COLOR vs LIME CONCENTRATION

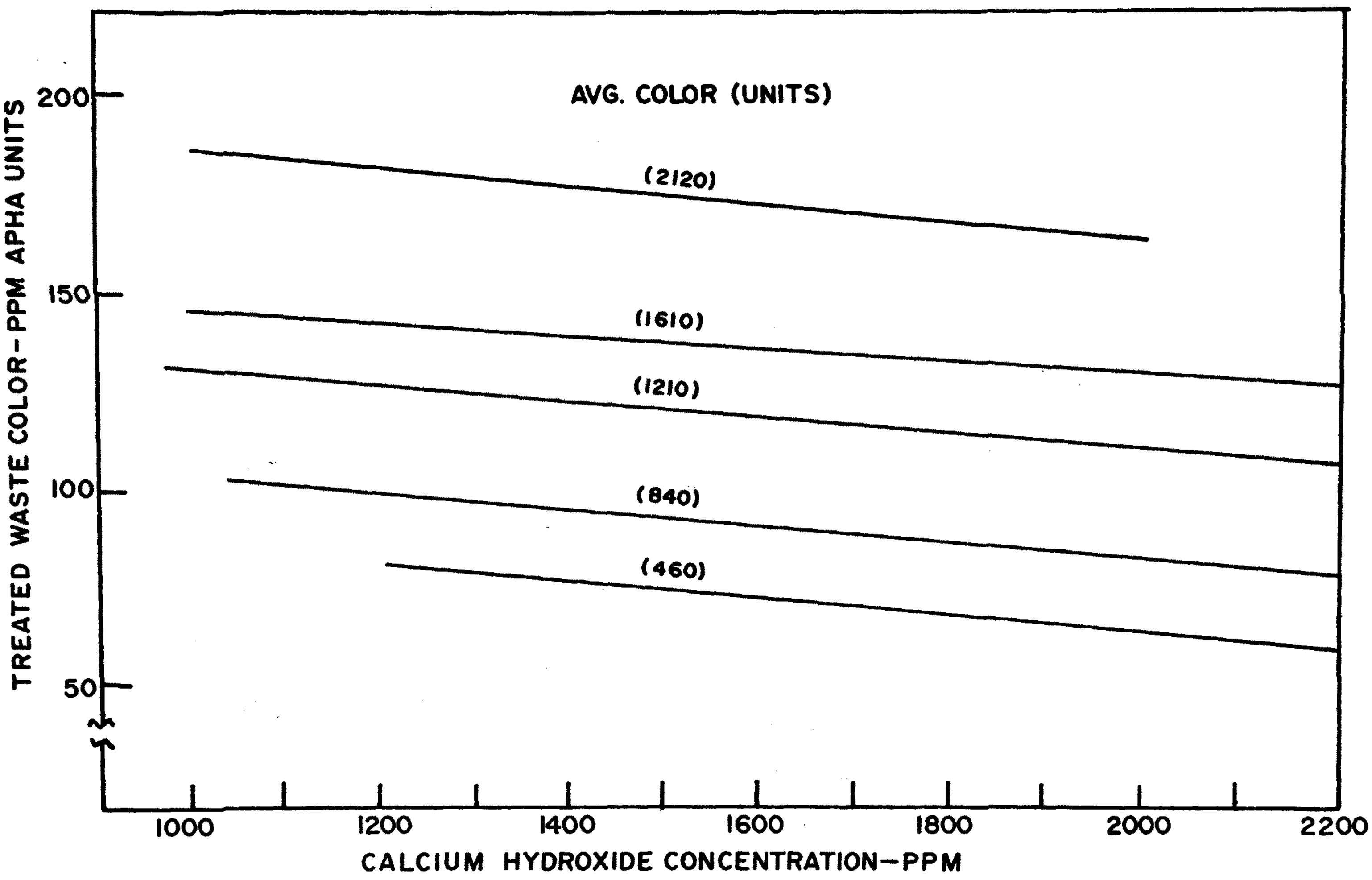
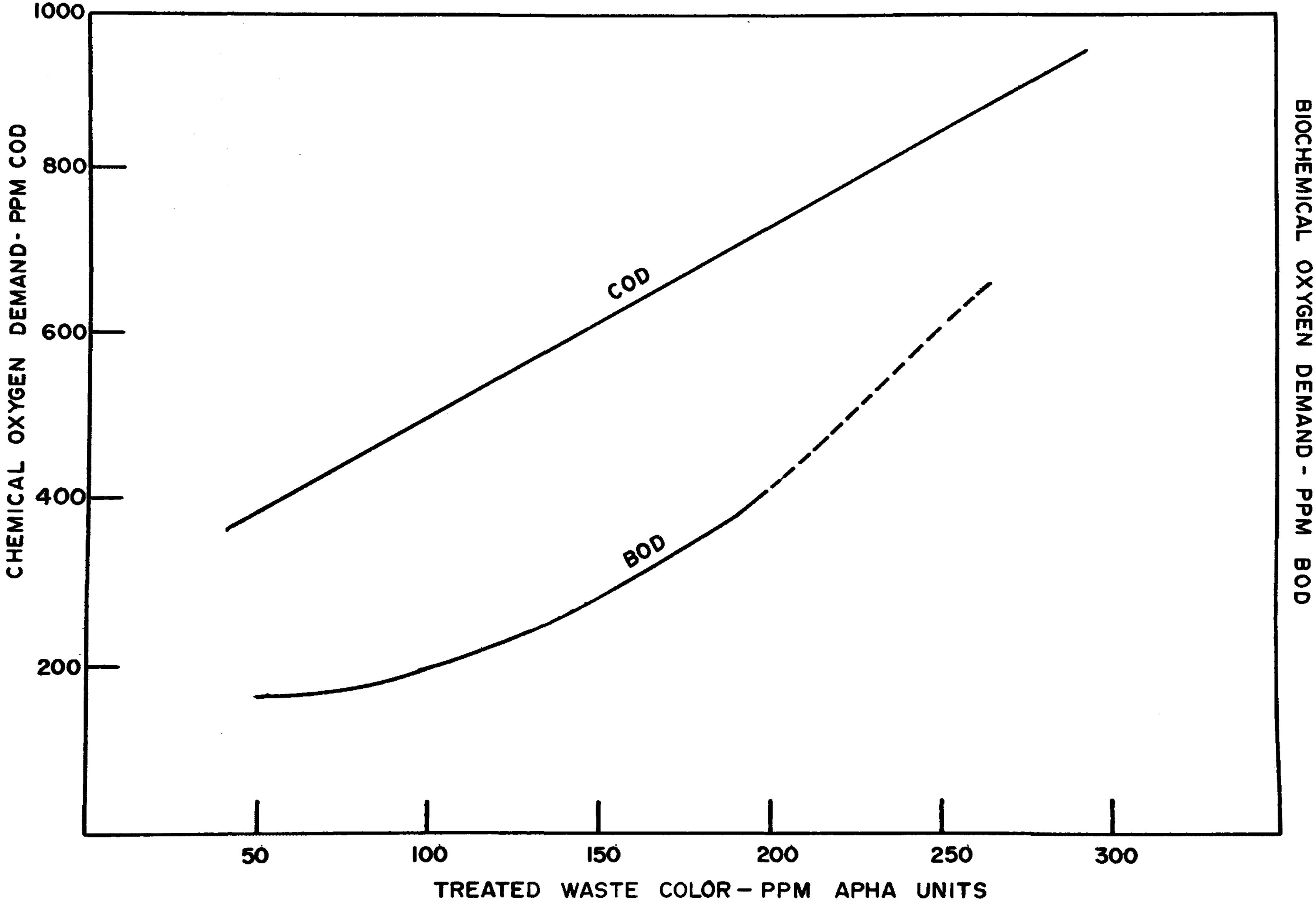


FIGURE 14

TREATED WASTE COLOR vs. - COD AND BOD



SECTION VII

WATER REUSE AND RECLAMATION

Throughout the years, the chemical pulping recovery processes have been improved to a very high degree as has water reuse both within the pulping and recovery systems themselves and by acceptance of paper mill wastewaters for use in pulping (20). Recovery improvements in kraft pulping are illustrated by the fact that sewer losses of soda in terms of Na_2O have been reduced from as high as 300 pounds per ton of product to less than 35 for modern units. This has been accompanied by similar reductions in suspended solids, BOD, COD, and color as pointed out elsewhere in this report. A TAPPI survey reported by Haynes (26) in 1965 revealed that the average use of fresh process water for a number of Kraft mills examined was two and one-half times before discharge and that in some mills this value was exceeded substantially (23, 188, 244, 348).

Water recycle in bleach plants has advanced remarkably in the last ten years, dropping as low as 15,000 gallons per ton for three-stage semi-bleaching. However, no reduction in pollution load accompanies water economy in bleaching since a given amount of material must be removed from the pulp. This is not recoverable because of its dilute nature and its high chloride content which is corrosive to recovery systems and which, in high concentration in the smelt, can cause explosions.

Less information on sulfite mills practicing recovery is available, partly because of their relatively small number and recent erection. However, since these are modern installations, they employ liquor separation and chemical recovery systems of similar inherent efficiency as kraft although the effluent from them differ in character and pollution load.

The major sources of sewer losses in kraft pulping are the filtrate from the final washing of the pulp on the deckers and the condensates from the digesters and evaporators. While there have been hypothetical plans for eliminating the decker filtrate by providing greater washing capacity (210), it has been pointed out by computations made by the Association of Swedish Steam Users (210), that this procedure, if carried too far, succumbs to the law of diminishing returns so that beyond a given range, the recovered liquor is diluted to a point where evaporation capacity and the attending heat requirement exceed the benefits derived. This limit is reached when soda loss amounts to 15 to 20 pounds per ton of pulp.

Reuse of condensates, which are responsible for the second largest sewer loss, has to some degree aided in reducing sewer losses (352, 214). Steam stripping, which has recently been installed at several mills, reduces BOD_5 loss in the condensate by stripping aliphatic compounds, mainly methanol, from them (22, 356). Since methanol is readily oxidized by biological oxidation, there is a valid question as to whether it is more economical to remove it by stripping or in the effluent treatment plant. It is likely that the answer to this question is different for particular mills and varies with consideration of the other materials removed.

Air stripping combined with biological treatment in packed towers has been tested on a large scale (67). While effective in achieving a measureable BOD_5 reduction, it releases odorous substances into the atmosphere, hence can represent a potential air pollution problem. It appears unlikely that a completely closed pulp mill water system can be achieved as has been suggested by some (350, 354).

The reduction in sewer losses from sulfite pulping by recovery systems is less effective than those of kraft because of the large quantity of acetates and formates appearing in the condensates. This formation is inherent to acid and neutral cooking of wood. Recovery of acetic and formic acid has been practiced by one NSSC mill (338) and a method for its recovery from acid sulfite pulp mills was developed by Lang, Clark, and DeHaas (299). However, the market for these acids is such that it does not represent a dependable means of solving the problem of its discharge on a continuous basis for more than an occasional mill.

Closed water systems in paper mills and paperboard mills have been an industry dream for many years. In a few cases this dream has been realized or approached (353). These have been mills manufacturing small quantities of special products from select furnishes in which extenuating circumstances necessitated and justified excessive costs attendant to very high degrees of recycling. While water recycling, fiber and filler recovery, and improved retention of raw materials in the paper have been achieved (25, 360, 337), there appears to be some fairly well-defined limits beyond which successful operation is either impossible, uneconomical, or fraught with serious operating problems. The increase in quality requirements by customers and consumers and the desire and effort to recycle more waste paper mitigate against reducing in-mill losses. It is true that increased water recycling results in lower fiber and chemical losses to a point. Beyond a certain level, it is not done since the build up of fines or dirt in the system by practicing recycling to too high a degree can lead to greater than normal loss of fiber, filler, and other papermaking chemicals.

Another factor involved in closing up the water cycle is the concentration of substances brought into the process as impurities in the water supply and the raw materials. Evaporation from the dryers causes these to accumulate rapidly to a point where they can affect sheet formation, machine speed, cause corrosion and scaling, or a host of other problems. This is particularly true in waste paperboard and deinking mills which receive sizing materials, adhesives, fillers, and other materials unsuitable for recycle.

In pulping, bleaching, papermaking, and attending operations, such as process water treatment, steam generation, chemical preparation, and by-products handling and rectification, a miscellany of wastes are produced in variable quantity and often at indeterminable frequence. Furnish cleaning as well as equipment wash-ups add to the wastewater stream as do leaks, equipment failures, and accidents occurring in mill operation. While the control of spills occurring from the latter are under good control at most mills, the residual streams require treatment and the chance of eliminating them is non-existent. On careful consideration of the above factors, it appears most unlikely that pulp and paper mills of the future will operate with completely closed water systems and with the need for effluent treatment eliminated. It is more likely that further progress and application will take place in mill recycling and treatment of effluent streams to a degree where their reuse is feasible.

Considerable progress in treating kraft pulping and bleaching effluents for reuse has been made by Berger, Thibodeaux, Smith, and others (349, 360, 361, 105). The former investigators present effluent quality data for removal of suspended solids, BOD, COD, color, and chlorides from pulping and bleaching effluents demonstrating that it is possible to produce waters that appear acceptable for some in-mill uses when judged by the quality requirements set forth by TAPPI (22) and Walter (23).

Berger and others (360, 365) reported on laboratory and pilot plant trials in which unbleached kraft pulping effluent was treated by lime precipitation, neutralization, biological oxidation, and filtration through activated carbon. Effluents were produced by the entire treatment sequence that contained less than ten mg/l of BOD_5, COD, and color. Total dissolved solids reductions were in the order of 65 percent and consisted almost entirely of salts, mainly sodium sulfate. These effluents also compared favorably with the characterization of the range of water quality suggested as desirable for kraft pulping by TAPPI (22) and Walter (23). Assuming that the lime and activated carbon could be recovered; that no additional unit processes, such as filtration prior to carbon treatment, would be required to make the process function on continuous basis; or that no insurmountable problems such as carbon sliming occurred, it was computed that water reusable for all process water or other uses could be produced at a cost of 14.5 cents per thousand gallons as of 1966. This figure compared with the 10 cents per thousand gallons then costing some mills for finished process water. It was pointed out that, considering effluent treatment cost, a substantial saving in overall water cost might be achieved by increasing the degree of treatment and drastically reducing the quantity of process water treated. This procedure would also reduce the pollution load substantially since the quantity of effluent would be reduced and its quality improved. It must be taken into account, however, that on repeated recycling a build-up of electrolytes and other substances will occur in the water within the system. This will determine the degree of recycle possible, the amount of make-up needed, and the quantity and quality of the treated effluent discharged.

Carbon filtration of kraft pulping effluent which has removed the bulk of the color and BOD on a demonstration basis appears worth pursuing. Such a development study should include reuse of a substantial quantity of the water in the mill, possibly at a selected point of introduction into the process. The cost estimate for achieving this ran in the range of 25 cents per thousand gallons (1967) for a two-MGD installation. Adding the cost of pretreatment a total of 40 to 45 cents per thousand gallons of water treated was estimated.

Considerable background information on carbon filtration is available upon which to base such a demonstration (365, 164, 362, 365). Tempe (167) reported high adsorption activity for carbon formed on the pyrolysis of kraft black liquor after a series of preliminary experiments. Rimer et. al. (368) conducted trials and proposed the use of activated carbon filtration for the treatment of specialty and white paper mill wastes with municipal sewage. Pilot plant treatment results on the mill waste above indicated that the BOD_5 and COD after settling could be reduced as follows by one, two, and three stages of treatment:

Stage	Raw Waste	1	2	3
Contact Time (min)		5.8	7.2	9.9
BOD_5 mg/l	13.2	7.6	2.6	1.7
COD mg/l	53.4	29.2	11.9	6.8

The low efficiency of this treatment for paper mill waste is evident from the small amount of BOD_5 and COD removed. This limits its use to the area of water reclamation, the cost being prohibitive on the waste treatment basis alone.

Interest has been expressed by EPA research and engineering specialists in this area (21).

Thibodeaux and Berger (349) experimented with advanced methods for removing the chloride ions from bleachery wastes treated for BOD, COD, and color removal, since it is this ion which limits reuse of such water in the process and disposal of concentrated waste obtained on recycle from introduction into the recovery system. This practice would result in severe corrosion of process equipment as well as giving rise to possible smelt tank explosions, as noted previously. Using a process developed by Kunin using weak electrolyte ion exchange resins and starting with treated effluent containing chlorides in the order of 500 to 1,200 mg/l, they were able to produce a water containing from 120 to 460 mg/l. Repeated regeneration was demonstrated without serious loss in capacity.

Sanks (171) and Walker (168) reported on liberating tests employing resinous zeolites in the treatment of kraft pulp mill wastes. They were concerned mainly with color reduction but state that they observed a high potential for the use of the resins for demineralizing pulping and bleaching effluents.

It must be pointed out that with ion exchange processes, the ions removed are not ultimately withheld from the plant effluent nor are the regenerating chemicals. Ions detrimental to the process are sequestered from the recycled stream and removed from the resin in a lower volume of water than that in which they originally were dissolved. Hence, such treatment will only permit a higher degree recycle when some means can be found for disposing of the spent regenerant and wash water other than the mill outfall.

Membrane processes have been the subject of a considerable amount of research and development work relative to pulp mill wastes over the last few years. Voelker (347) enumerated the advantages of such processes as the possibility of their eliminating effluents, producing very acceptable fresh process water, and possible recycling by-products. He sets forth the major disadvantage as the cost which he computes to amount to $1.17 per thousand gallons of water reclaimed by the reverse osmosis process at a daily inflow rate of 500,000 gallons.

Extensive laboratory and pilot plant investigation of membrane processes, including reverse osmosis and ultrafiltration, were conducted by Wiley et. al. (169,361, 369) both at the Institute of Paper Chemistry and with a portable unit operated at various types of mills.

Conclusions reached from these studies were that reverse osmosis and ultrafiltration processes had a possible application for processes producing relatively concentrated effluents, such as NSSC pulp and corrugating board mills practicing a high degree of recycle and producing a wastewater in the order of 0.5 to 1.0 percent solids. It was also concluded that improvement in membrane life, elimination of clogging problems, and improved support structures as well as increased flux rate were required to render these systems operable and practical cost-wise.

Nelson (362) and Leitner (366) report on the development of reverse osmosis for NSSC corrugating waste at a Wisconsin mill. This mill employs press washing evaporation and spent liquor incineration in a fluidized bed unit. The sodium sulfate produced by the fluidized bed is sold to a neighboring kraft mill for liquor system make-up. Very high degree of recirculation is practiced in the paper mill which runs at a very high temperature (140°C.). It was found possible to concentrate the waste stream, which amounted to close to ten percent solids. This was suitable for incorporation in the evaporator input for incineration of the organics and recovery of the chemical. Voelker (347) points out that reverse osmosis is feasible for carrying on this step in waste concentration, holding a decided cost edge over evaporation. He presents performance data for a tubular reverse osmosis unit that was successfully operated for a four-month period which is presented in Table 6. Beder and Gillespie (313) attempted to remove chlorides as well as color from bleaching wastes by ultrafiltration. The low flux rates obtained as well as the chloride in bleed-through led them to conclude that in its present state the process is not applicable for either water reclamation or solids concentration.

Table 6

TYPICAL PHYSICAL AND PERFORMANCE DATA FOR A TUBLULAR REVERSE OSMOSIS UNIT OPERATING ON WASTE WATER FROM A NSSC PULP AND PAPERBOARD MILL

Number of 36 tube modules (first stage)	24
Normal operating pressure, psi	650
Inlet flow rate, gal/day	14,200
Permeate rate, gal/day	6,800
Concentrate rate, gal/day	7,400
Percent rejection total solids	99.5
Inlet concentration, % solids	1.47
Exit concentration, % solids	2.71
Percent rejection of BOD	99.5
Percent rejection of Color	99.8
Temperature of feed, °F.	95
pH of Feed	7.1
Flux rate, gal/ft.^{2}/day	7.94
Pressure loss, first stage, psig	110

Note: Unit arranged for self-powered backflush 15 minutes every two hours at operation.

It can be concluded that, in their present state, the application of the membrane processes to pulp mill effluents is at best very limited since most of the wastes are too dilute to make the cost of such treatment in any way practical, assuming that the mechanical problems associated with them are solved. The three wastes to which these processes could apply are semi-chemical corrugated board waste, sulfite pulping recovery plant condensates, and caustic extraction waste from some bleach plants. In the first case a severe in-mill problem is involved in reducing the waste volume to the required level, hence obtaining a suitable waste solids concentration. The application to sulfite condensates necessitates a market for the acetic acid produced and its use for concentrating caustic extract is limited by the chloride content of the concentrate which can be undesirable for admission to a liquor recovery system.

Relatively complete process changes such as oxygen bleaching give promise of reducing kraft mill effluent losses especially with respect to color bodies and inorganic materials, particularly chlorides. Three references (258, 359, 351) indicate that the wash water from the oxygen bleaching stages can be introduced into the kraft recovery system without immediate untoward effects, since they are relatively free of chlorides. However, magnesia is added in this process and it could result in accumulative problems in the liquor system. If successful, this process could go far in reducing the color and to a lesser degree the BOD of bleachery effluents. How rapidly it might replace the present bleaching systems is a most difficult question, since its use involves high capital investment and the replacement of an established heavy chemical (chlorine). Also the large-scale production of another chemical (oxygen) largely on location must be undertaken. Since other bleaching stages continue to utilize chlorine compounds, all bleach plant effluent and attending sewer losses are not eliminated by it.

Rapson and Reeve (350, 357, 233) maintain that countercurrent washing--both in the bleaching steps and when washing brown stock--can make unnecessary the addition of any make-up water other than that needed to replace losses through evaporation to the atmosphere. In their proposed system, condensate from the evaporation, after steam stripping or chlorination to deodorize them, could be used to wash the bleached pulp. Bleach plant effluent would then be sent to the chemical recovery system modified in such a manner that it could extract sodium chloride from the liquor for sale or captive use in preparing bleaching chemicals. Rapson (350), in preliminary estimates, indicates that a capital cost of close to $4 million would be required to convert a 1,000-ton-per-day mill to the process but that such conversion could result in savings of as high as $5.80 per ton of bleached pulp. Such a change, however, involves a very considerable risk, since its success depends upon fractional crystallization, which to date no company has undertaken.

Such changes in process are generally evolutional rather than radical. However, improvements will result from the investigations and proposals evolved. These can result in considerably lower losses from bleaching operations.

SECTION VIII

THE HANDLING, TREATMENT, AND DISPOSAL OF SLUDGE

Introduction

The disposal of sludges obtained from the clarification of pulp and papermaking effluents is still a major problem despite many years of research, development work, field studies, and applications. In fact, the problem is of greater magnitude than ever, not only because of increased production but also because an increasingly larger percentage of this material, formerly discharged to surface waters, is now removed from the effluents. The great progress made during the last 30 years in water recirculation and fiber and filler recovery began to make it appear as though the immemorial dream of the completely closed paper machine system would eventually come true. However, these practices were found to reach a critical level beyond which a number of operational problems were encountered. Among them are:

1. Foaming in stock system
2. Sheet formation troubles
3. Slowing of the stock
4. Dirt in the sheet
5. Decreased felt life
6. Accentuated slime control problems
7. Difficulties with water clarification systems

The causes of these troubles were found to be primarily the accumulation of dissolved and colloidal substances entering the system with the furnish, or produced during the mechanical processing or chemical treatment of the fibers. The use of the many new paper additives, as well as the high quality and cleanliness standards required at the present time, have not improved this situation. Many mills operating with close to the maximum of water recirculation have found it necessary to reduce this practice somewhat, since one way or another the concentration of the offending substances must be kept below a tolerable level within the machine system. Hence, it can be reasonably concluded that some water will have to leave the system to carry the undesirable materials off, and with them is bound to come some fiber sizing, filler, and other additive materials.

As improved effluent quality was required, it was believed that filtration, sedimentation, or flotation devices would alone suffice to remove suspended solids, if properly designed and with the aid of coagulant addition. Indeed, in some instances where process water was in short supply or costly, it was believed that the expanded use of the cleaner recirculated water would justify the added cost of clarification. This conclusion was based on the assumption that the reclaimed material could be used back in the system quite as readily as that returned from a simple save-all arrangement, despite the finer division of fiber. This is where real difficulties arose and where the returned slurry gained the name of sludge rather than furnish.

The characteristics of such material changed altogether in that it was no longer free-draining but gelatinous in nature. More remarkable was the fact that on addition of a small proportion to a relatively free furnish, it was able to transmit its water-holding capacity to the entire fiber mass of the furnish to a very appreciable degree. Careful examination of the fibers revealed that the fines, frequently aided by coagulants, paper additives, and in the case of wastepaper furnishes, adhesive materials, plated out on the long fibers changing their physical characteristics (51).

The National Council for Air and Stream Improvement has published extensive literature on the various types of sludges. Reports have been made on sludges varying from 95-98 percent volatile solids for groundwood, to deinking and roofing mill sludges with ash contents varying from 40 to 70 percent. Between these extremes runs the whole gamut of kraft, sulfite, groundwood papers, and various specialties, so that it is almost impossible to generalize the type sludge to be encountered. Gehm (51) has given a summary of the complex nature of paper industry sludges. Activated sludge produced from the treatment of pulp and paper mill wastes is of similar hydrous nature to that of activated sludge derived from sanitary sewage. While that obtained from treating paper wastes high in inerts dewaters rapidly, that from treating mechanical pulping and board mill wastes has very different properties.

The handling of all types of sludges produced by treatment of pulp and paper mill wastes is described in detail in the NCASI Manual of Practice (148) and a variety of installations are described in NCASI Technical Bulletin #209 (60).

Gravity Thickening

There is probably no one single factor which affects the feasibility and end results of sludge dewatering, regardless of the method chosen, more than the degree of preconcentration of the sludge. With rare exception, it can be said that the higher the feed sludge solids content, the more efficient the dewatering operation, from the performance, operation, and economic standpoints.

Pulp and paper mill sludge can be thickened in the primary clarifier. However, in some cases, particularly when clarifier capacity is limited, the sludge cannot be thickened to a desirable consistency without creating problems. When this is true, the sludge is removed from the primary clarifier and thickened in a gravity thickener, two types of which are in common use. These are the conical tank and the "picket fence" mechanical unit.

Conical Thickening Tank:

The conical tank has generally been replaced by the picket fence thickener. However, it still has application, particularly for small installations. The conical thickener is frequently a fill and draw, or batch operation, but can be designed for continuous operation. Side slope of these units should exceed 60° so that sludge accumulation on the sides does not occur. In batch operation the tank is filled with sludge over a period of time and the sludge is allowed to settle for several hours. The liquid above the sludge (supernatant) is drawn off with a swing tube. The thickened sludge is then withdrawn. The tank is then refilled to start another cycle. For continuous operation, this type of thickener is equipped with a feed well and overflow weir similar to that of a clarifier.

Mechanical Thickener:

The mechanical, or picket fence, thickener is a continuous-feed operation. Sludge is fed continuously and thickened sludge removed from the unit continuously. The tank, rake mechanism, and other appurtenances are similar to those used in clarifiers, the difference being that a series of vertical vanes resembling a picket fence are attached to the rake mechanism. These serve to accelerate separation of water from the solids.

Figure 15 shows gravity thickening curves from three different types of paper mill sludges. It can be seen that these sludges approach their ultimate compaction in four to six hours. However, at the end of a thickening period of 12 hours, widely divergent solids contents of 2.6 percent in the groundwood sludge, 4.2 percent in the boardmill sludge, and 9.4 percent in the deinking sludge exist. This is due to variation in the degree of hydration and inorganic content, as illustrated in Table 7.

Thickener Installations:

There are not many thickener installations within the industry due to the fact that sludges are generally thickened in the primary clarifier. They are most frequently found at large mills having activated sludge treatment. Table 8 shows data obtained from some of those in use. It appears from these data and laboratory studies that detention times of four to six hours with solid loadings of 200-800 sq. ft./ton/day and hydraulic loadings of 200-400 gpd/sq. ft. will give good results. As can be seen from the wide loading ranges given, laboratory thickening tests must be made with many samples of the sludge to obtain the best design parameters for a given installation.

Both dissolved air flotation and vertical disc-type centrifuges have been applied to dewatering hydrous sludges by individual mills. The first of these methods is described by Katz (149) and a NCASI research report (150), Woodruff et al (151), Gehm (51), and Barton et al (152)

FIGURE 15
THICKENING CURVES FOR VARIOUS SLUDGES

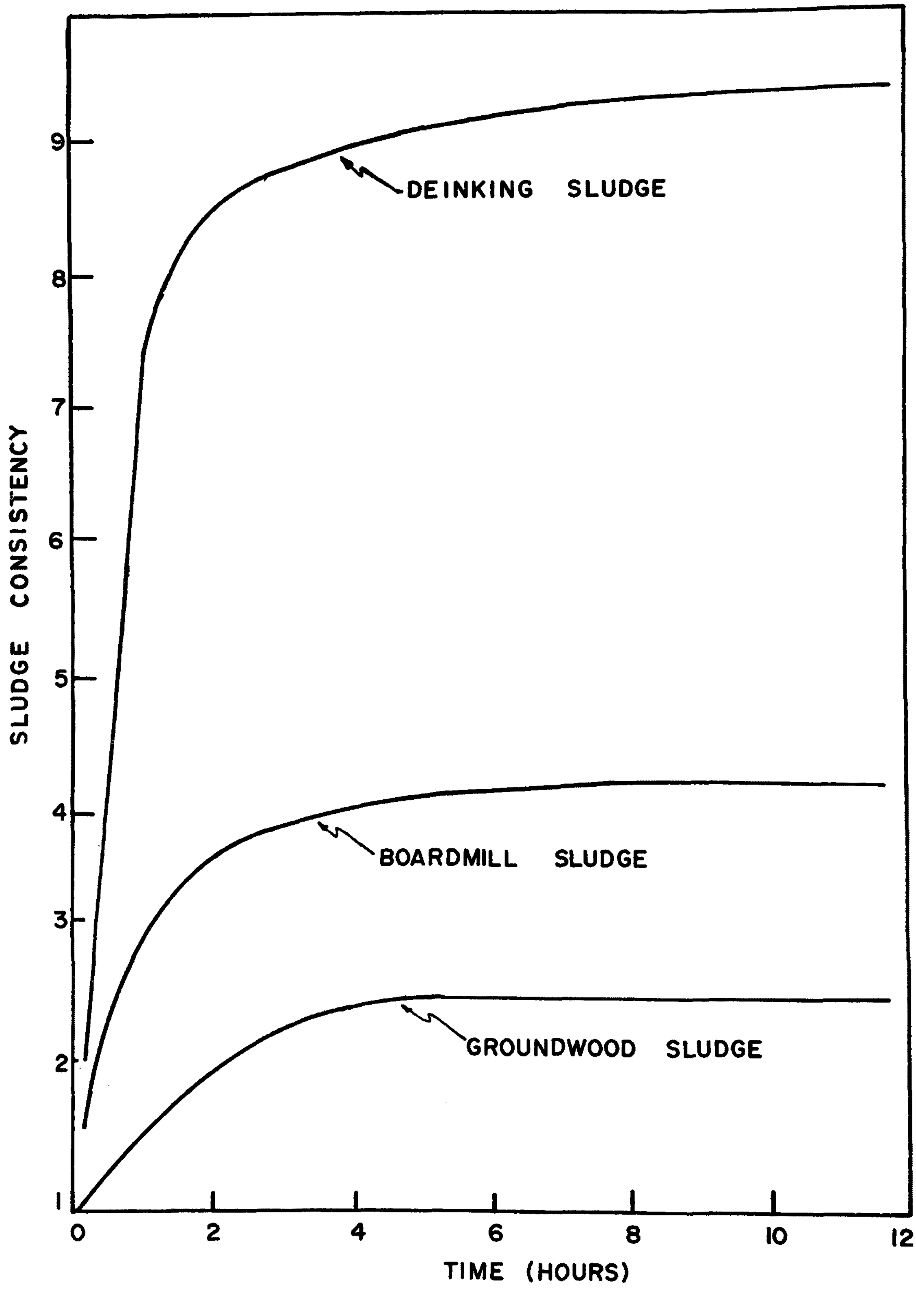


Table 7

PERFORMANCE OF MILL INSTALLATIONS OF GRAVITY THICKENERS

Type Waste	Feed Consistency %	Loading gpd/ft^2	Loading Sq. Ft./ton/day	Detention Hr.	Thickened Sludge Consistency %
Deinking	1	360	910	5.6	3-5
Glassine	0.5	50	1000	48	3-4
Biological Waste Seed Sludge	1.6	480	150	4	3-4

Table 8

THICKENER LOADING PARAMETERS

	Loading	Thickened Sludge Consistency
Papermill (Low ash)	600-800	1-3
Papermill (High ash)	400-600	5-9
Boardmill (Waste paper)	300-450	3-5
Activated Sludge	100-250	1-2
Primary Sanitary Sewage	85-200	3-7

discuss the centrifuge application. Use of these methods is confined to very slimy sludges such as those high in groundwood fines or of biological origin. Dissolved air flotation produces overflows up to 4.5 percent concentration while the centrifuge cake ranges from 7 to 12 percent depending upon the feed rate and initial consistency.

Vacuum Filters

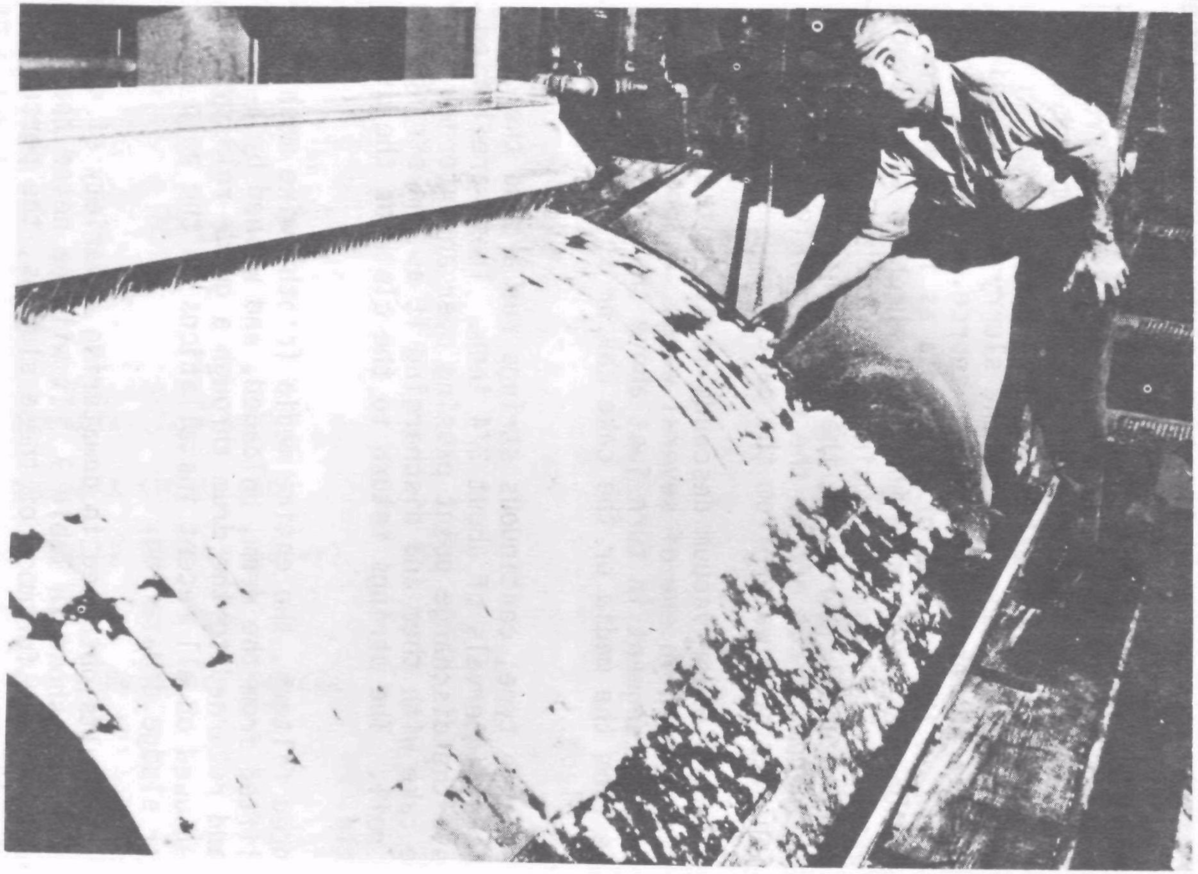
The continuous rotary vacuum filter is widely used for dewatering sludge and is similar to the drum filters used as pulp washers. It consists of a drum covered with filter cloth, wire mesh, or a series of endless coil springs and is arranged to rotate partially submerged in a vat of slurry. The periphery of the drum is divided into a number of compartments which are underdrained beneath the filter media and individually piped to a rotating valve located at one end of the drum. Hence, each compartment is an individual filter being sealed from its neighbor by division strips and functioning through its own drainage system as controlled by the filter valve. As the drum rotates, individual filter segments become submerged in the slurry at which point the valve connects this segment to the vacuum source. A cake of wet solids is then formed on the surface of the media as filtrate is removed through the underdrain system to the valve which in turn directs it to a receiving tank. The segment remains under vacuum after emerging from the slurry and until it reaches the top point of the drum's rotation where the vacuum is cut off by the rotating valve. During this stage air displaces more water from the cake.

As the segment no longer under vacuum descends in its rotation toward the vat the cake is removed in one of several ways. Compressed air can be admitted to each segment in turn just above the discharge point to loosen the cake from the media or the cake can be scraped from the drum with a doctor blade.

In the string discharge type, continuous strings run around the drum and over the media at intervals of about 3/4 inch. These are lifted from the drum above the discharge point passing over an external guide roll carrying the cake with them and discharging it as the strings pass around the guide roll. The strings return to the cloth on the drum to begin another cycle.

In the most advanced filters, the entire media (cloth, wire mesh, or coil spring) is lifted from the drum, unloaded, and washed by a high pressure shower and returned to the drum through a guide roll system. This type has been used on all recent installations in the pulp and paper industry for sludge dewatering.

Operation data and results obtained in dewatering a variety of sludges by vacuum filtration are shown in Table 9. It will be noted that the loading range varies widely for most of these sludges, the percentage of fiber present in them at any particular time being the determinant--the higher the fiber content the higher the loading.



Vacuum Filter Recovering Fiber

Table 9

CONTINUOUS VACUUM FILTRATION

Sludge Type	White Water	Decoating & W. W.	Boardmill	Deinking & W. W.	Felt Mill
Feed Solids %	1.33-4.70	5.85-10.02	0.87-2.36	5.89-7.15	5.20-5.27
% Ash	15.0-42.0	49.0-58.3	---------	45.6-51.9	---------
Drum Speed RPM	1.66-8.25	1.23-6.66	1.22-3.33	1.50-5.00	1.5-3.08
Filter Cake & Solids	23.3-33.0	34.6-42.9	26.1-30.7	31.4-36.4	21.4-25.8
Loading Rate #/ft^2/hr.	1.7-13.4	2.13-10.95	1.22-5.75	3.09-10.00	3.71-5.92
Ave. Filtrate Suspended Solids #/1000 gal.	3.99	26.1	4.68	22.5	---------
% Settleable Solids in filtrate	86.9	-----	86.6	94.1	---------
Filter Media	70 x 56 mesh fourdrinier wire	70 x 56 fourdrinier	Fourdrinier wire	Stainless steel	Stainless steel

It will also be observed that the filtrates produced varied in suspended solids content but that these were largely settleable. Since filtrates are returned to the system ahead of the clarifier these solids are recaptured.

The addition of activated sludge to clarifier underflows has a decidedly adverse effect on dewatering. (This is shown in Figure 16.) A recent installation employs bark as a filter aid. The effect of other additives such as fiber and fly ash and coal was studied (153) and none of these, with the exception of fiber, showed much promise of improving vacuum dewatering. Some sludges respond to conditioning with chemicals such as lime, ferric chloride, alum, or polymers. However, the response of a particular sludge is unpredictable. Precoating of filters with fly ash was tested with some success on hydrous sludges but the quality of ash was found to vary widely in respect to usefulness for this purpose. Recently, interest has developed in heat conditioning and partial wet air oxidation as methods of sludge conditioning.

Centrifugal Dewatering

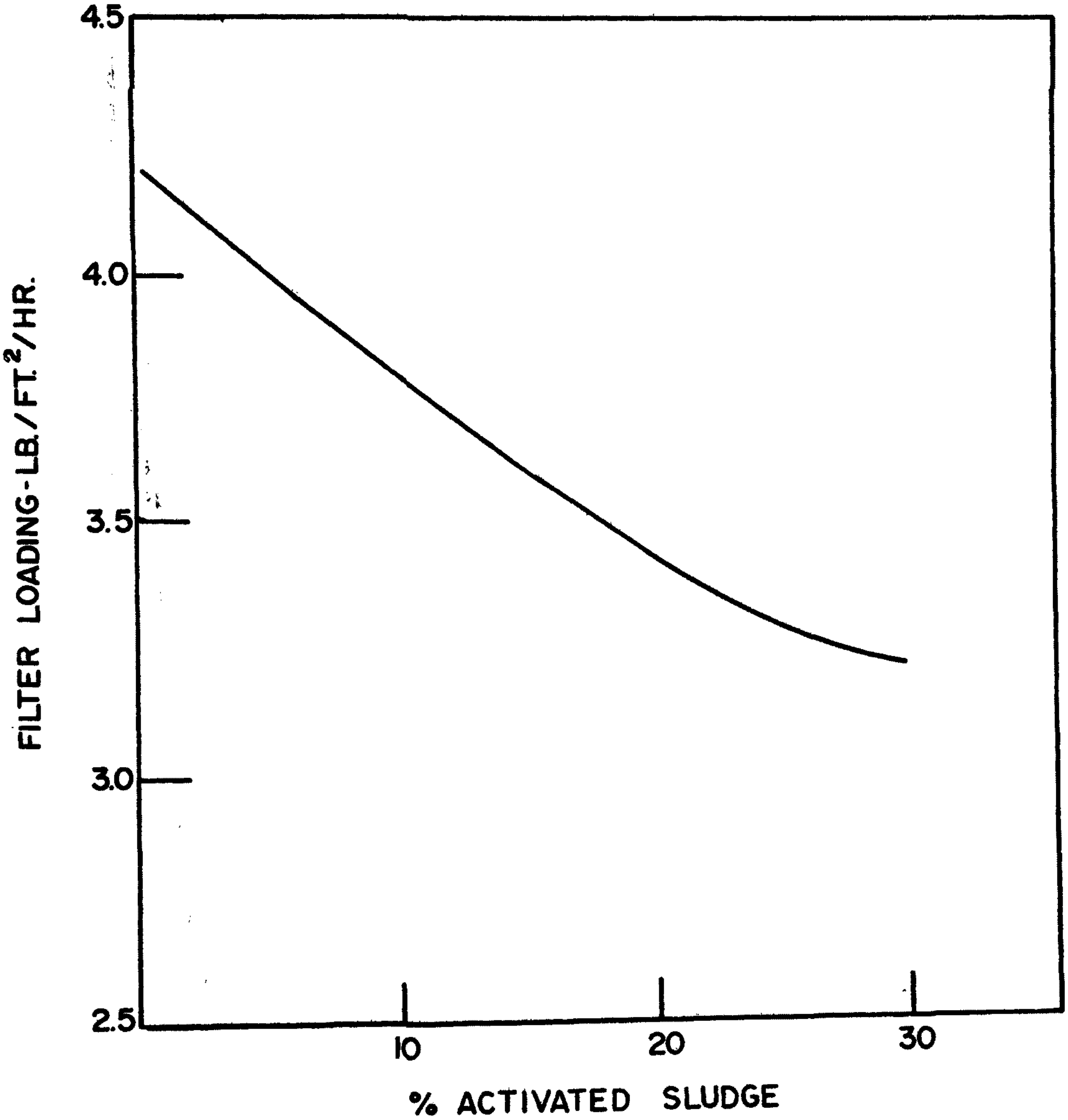
The critical review of literature on the dewatering of hydrogels conducted by Beck (154) at the University of Syracuse in 1954 indicated that centrifuging offered one of the best possibilities for mechanical dewatering of hydrous slurries obtained from the clarification of some white waters. This led to the evaluation of two bench-scale units and the experience and data obtained from them indicated that large-scale equipment of both types should be tested on various paper industry primary underflows. Field work conducted in cooperation with mills and equipment manufacturers resulted in the development of a suitable type of centrifuge for this job--a horizontal conveyor-type machine.

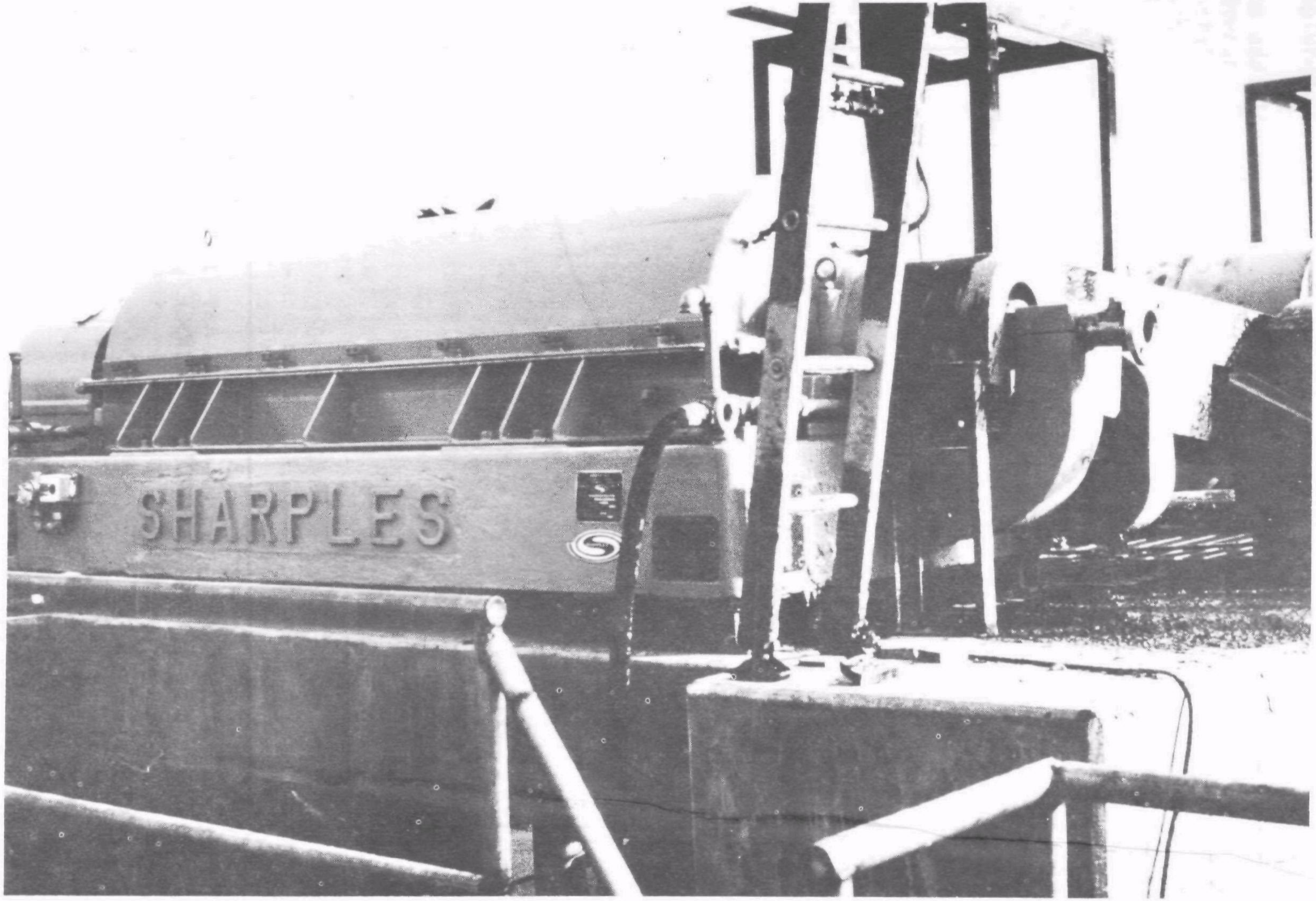
A horizontal conveyor-type centrifuge is essentially a settling device which induces an increased force of gravity. Dewatering is a function of the gravitational force applied and the detention time in the unit. The slurry is introduced into the bowl by means of a feed tube located in the hollow center shift. It is acted upon by centrifugal force, the solids being deposited against the wall of the bowl. The liquid, having a lower specific gravity, forms a concentric inner layer in the bowl. Inside the rotating bowl is a helical screw conveyor which rotates in the same direction, but at a slightly different speed than that of the bowl. This conveyor is pitched so that the solids, which are deposited against the bowl wall, are conveyed to one end of the bowl where they are discharged from suitably located discharge ports.

As in gravity settling, the liquid near the surface of the liquid layer has the greatest clarity. This clarified liquid continuously overflows adjustable weirs at the liquid discharge end of the bowl. Suitable partitions in the machine case form compartments for receiving discharge effluent and solids, guiding them into their respective hoppers.

FIGURE 16

EFFECT OF ACTIVATED SLUDGE ON DEWATERING BOARDMILL SLUDGE





Sludge Centrifuge Installation at a Pulp Mill, Sharples Corp.

Results of these tests indicated that the horizontal conveyor machine appeared capable of producing a cake of 25 to 35 percent solids at recoveries in excess of 85 percent.

Subsequent to these investigations the dewatering of sludges by centrifugation has become a common practice. Installations have provided the opportunity to evaluate this form of dewatering and establish some of the factors which affect solids content of the cake and solids recovery.

Feed consistency, rate of application, and slurry character all affect performance of these machines. Solids recovery efficiency must be maintained at a high level or fines build up in the clarifier to which the concentrate is returned. This was studied by Linsey et al (60) who concluded that this problem did not occur when recovery efficiency exceeded 85 percent. Description and performance data appear in NCASI Technical Bulletin #238 (155) covering a number of recent installations and are summarized in Table 10.

Pressing

After experiments had shown that additional water could be removed from vacuum filter and centrifuge sludge cakes by pressing (156), development work proceeded with commercial presses of different types in order to allow the application of this technique. Data, such as that presented in Table 11, indicated that cakes approaching 50 percent solids could be obtained. However, a wide variation in sludges and press performance was observed and a considerable amount of press development work was involved in applying them.

Their application to vacuum filter cake from pulp mill sludges is described by Bing (155), Fuller (59), Coogan and Stovall (310), and Linsey (60). In pressing sludges consisting primarily of fibrous organics, Bing, Fuller, and Coogan report operations producing press cake in excess of 40 percent dry solids. Linsey, however, handling a slurry containing variable quantities of lime, other inorganics, and some non-fibrous organics obtained very erratic and frequently unsatisfactory results.

Recently pressing has been successfully applied by Stovall and Berry (157) to clarifier underflows containing substantial fiber. Problems could develop with this procedure, however, due to fines which pass the press accumulating in the clarifier, hence, it must be applied with care.

Incineration

Three types of incineration are practiced in paper mill sludge disposal. These are: (1) burning in an incinerator designed specifically to handle sludge as described by Coogan and Stovall (156); (2) in a bark boiler as indicated by Stovall and Berry (157) and others (155)

Table 10

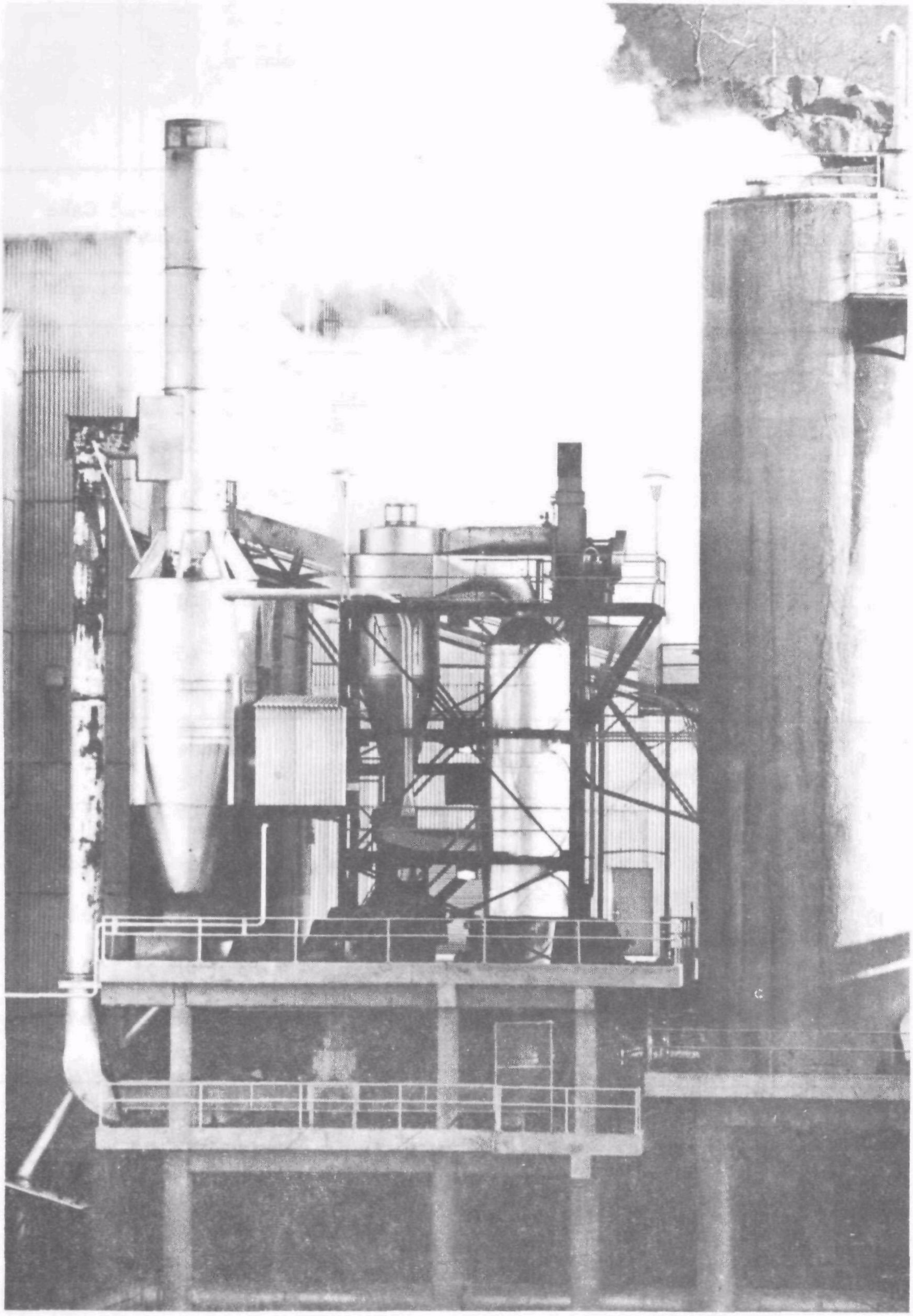
CENTRIFUGE INSTALLATIONS

MILL	SLUDGE TYPE	SPEED rpm	FEED: RATE gpm	FEED: CONSISTENCY %	FEED: ASH CONT. %	SOLIDS CAPTURE %	CAKE MOISTURE %
1	Fine Paper	1000	80-120	5-10	50-70	85-95	65-80
2	Bl. Kraft	1000	95-194	3.5-4.5	-----	80-92	82-85
3	Fine Paper	2400	60-62	3.5	60-70	95	76-84
4	Tissue	2250	25	2-3	5-10	80-85	78-79
5	Bl. Kraft	1200	240-320	1.0-2.2	-----	80-85	80
6	Fine Paper	1300	56	8-12	45	80	70-80
7	Tissue	4000	20-22	2-3	10-15	88	58-66
8	Hard Board	2000	43	2	-----	85	65-70
9	Tissue	1000	60-85	1-4	10-30	65-90	78
10	Tissue & Bark	1000	100-150	3-5	5-10	86-93	82
11	Kraft	3000	300	1-2	-----	88-95	60-75
12	Book	3000	150	5-12	60-70	85-92	55-60
13	Board	2600	97	4-6	30-40	88-95	52-65
14	Kraft	1200	120	1-2	20-25	90	76-80

Table 11

MECHANICAL PRESSING OF SLUDGE CAKE

Applied Pressures psi	Grams of Water Removed per Kilogram of sludge Pressing time, min.			Final Pressed Cake Solids Consistency Pressing time, min.		
	1	5	10	1	5	10
			Board Mill Filter Cake			
100	65	123	191	27.5	33.3	40.1
300	75	180	234	28.5	39.0	44.4
500	81	191	268	29.1	40.1	47.8
700	84	207	270	29.4	41.7	48.0
900	97	246	293	30.7	45.6	50.3
			Deinking Filter Cake			
100	85	190	235	38.5	49.0	53.3
300	103	231	280	40.0	53.2	58.0
500	108	265	310	40.6	56.4	61.0
700	135	285	335	43.3	58.5	63.0
900	150	300	344	45.0	60.0	64.3



Sludge Incinerator, Reitz Manufacturing Co.

(158); and (3) incineration in a power boiler burning fossil fuel. All these methods are successful. However, the high costs involved relative to land disposal at most mill sites have limited their use. Incineration is also limited to low ash sludges not only because of their low fuel value but due to technical problems with incinerators. Figure 17 is a curve showing the relation between moisture and organic content of sludge necessary to support combustion.

A number of other types of combustion have been tried including multiple hearth and kiln type units as well as wet air oxidation and the fluidized bed. Of these only the fluidized bed system appears promising of considerable application.

Summary

Figure 18 is a multi-path flow diagram showing the common mechanical methods of thickening, dewatering, and disposal of sludge from clarifier underflows. Which pieces of equipment are chosen for a particular installation and how they are arranged depends on the character of the particular sludge handled. The response of the sludge to these unit processes varies from day to day as pointed out by Linsey (60). Hence, careful pilot studies generally precede design of these systems.

FIGURE 17

SLUDGE CAKE CONDITIONS REQUIRED TO SUPPORT COMBUSTION

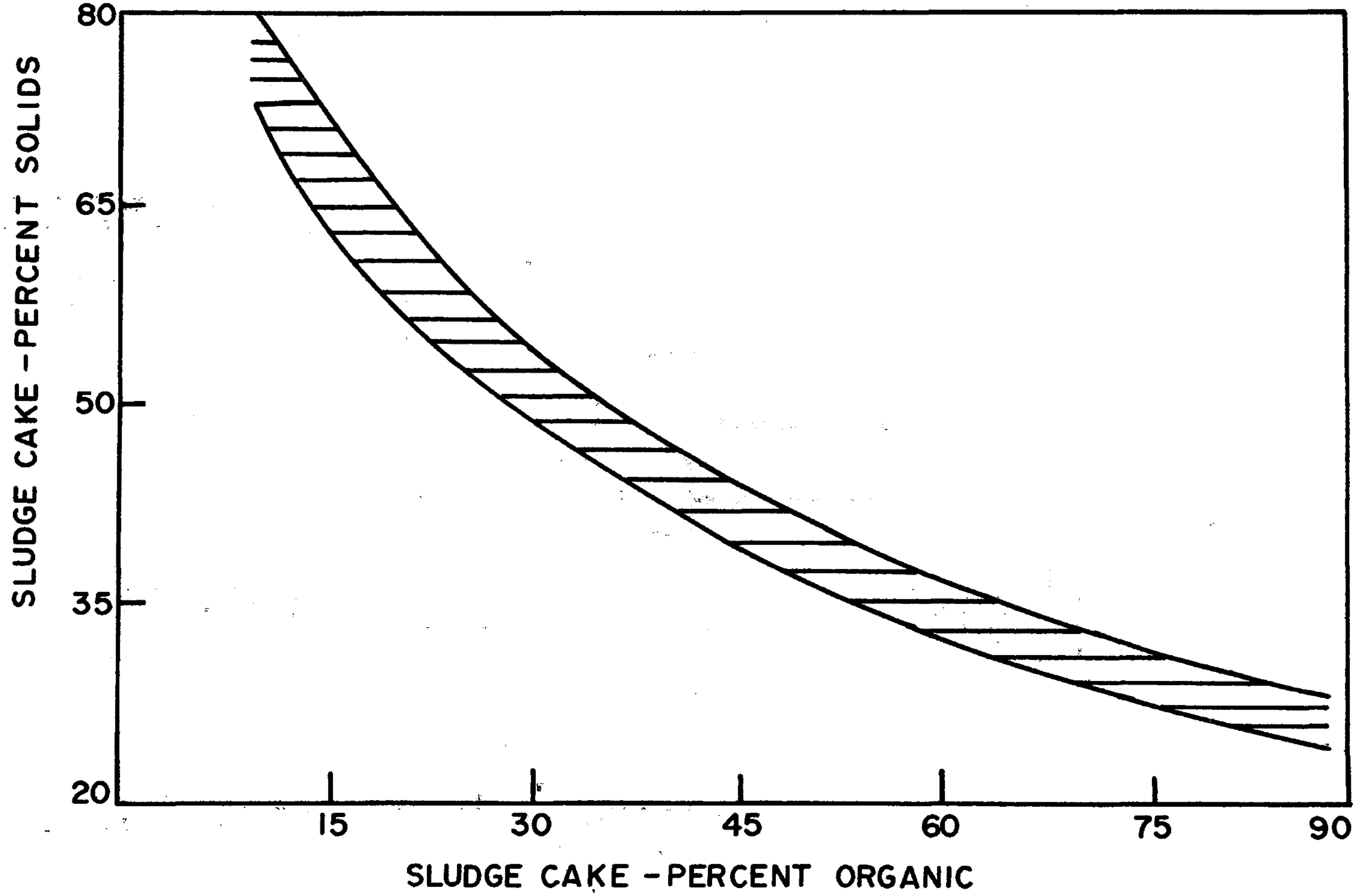
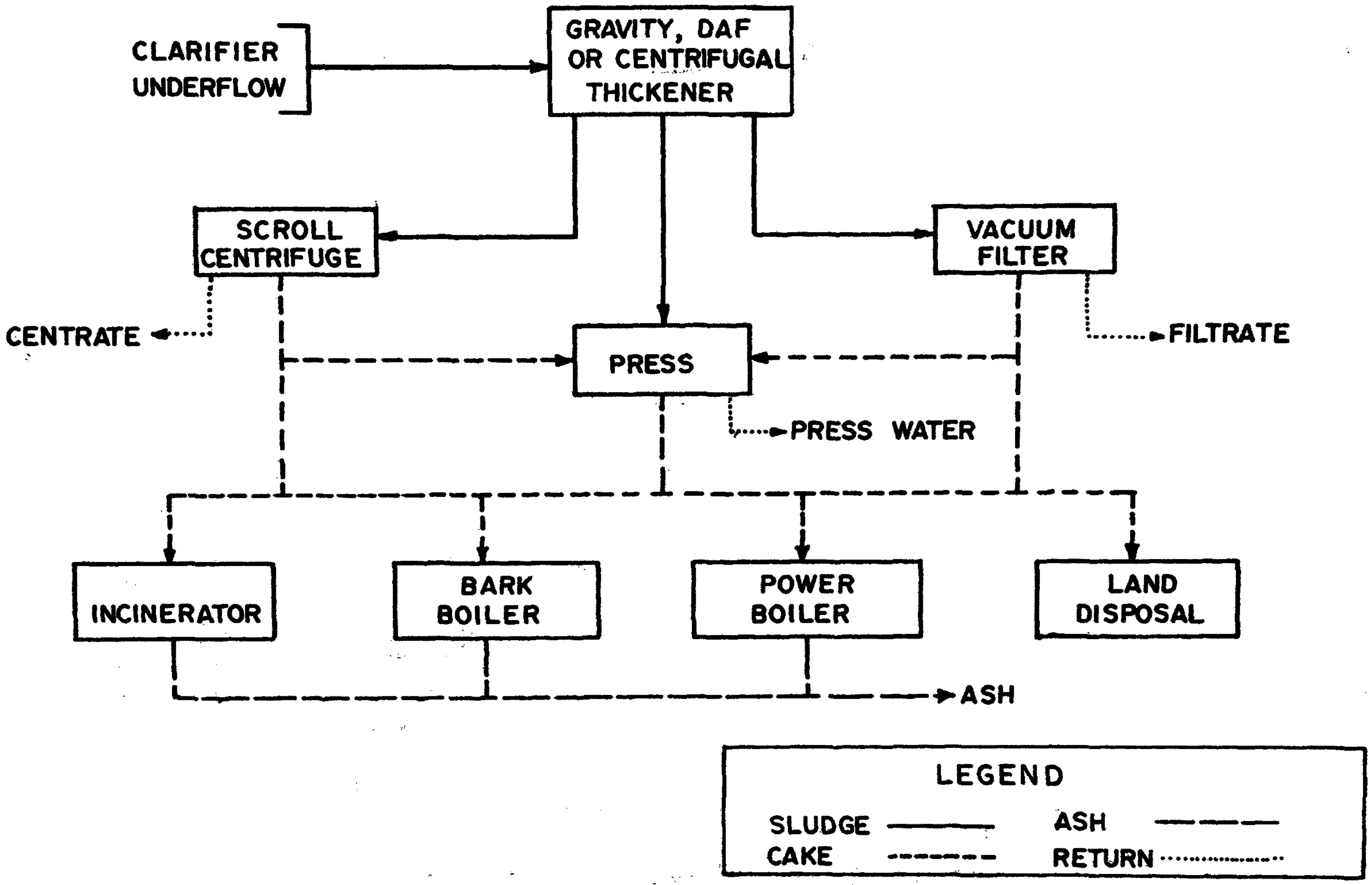


FIGURE 18

MULTI-PATH DIAGRAM OF MECHANICAL THICKENING, DEWATERING AND DISPOSAL OF SLUDGES



SECTION IX

TREATMENT IN PUBLIC FACILITIES

Sewage treatment plants encounter no problems in treating a reasonable proportion of pulp and papermaking wastes if they are adequately designed to handle the load imposed as pointed out by Pirnie and Quirk (178,182), Gehm (179), Faulkender (180), Opferkuch (181), and others. In some cases pretreatment is required as discussed by Swets et al (183). This is particularly the case where suspended solids loads are high. In any event, it is necessary for connected mills to practice good loss control since surge loads of spent liquors or fiber can disrupt operations at sewage treatment plants in a number of ways. Normal variations in process losses, however, have less impact on combined facilities than they would on a mill effluent treatment system because of equalization occurring in sewerage systems, and sanitary sewage provides nutrients needed in biological treatment frequently lacking in paper mill wastes.

Although few pulp mills are involved in public treatment projects, many waste paperboard mills in or close to large communities which serve as their source of raw material have for years been utilizing public facilities with satisfactory results. This is true of other small papermaking plants. The NCASI reports on this practice as follows:

> "It can be concluded that the trend toward treatment of the effluent from small mills in community sewage treatment works will continue and both small and large mills in metropolitan areas will probably join with the municipality and industries in joint treatment. However, the large outlying pulp mill will continue to provide its own waste handling facilities."

In 1968 NCASI published a study (184) dealing with treatment of pulp and paper mill wastes in public sewerage system. The data, summarized in Table 12, showed that 123 mills then discharged to sewage treatment works which represented 16 percent of the total number of mills operating at the time. About half of these were clustered in metropolitan areas. The total discharge represented 11 percent of the paper manufactured in this country. About half of the mills produced less than 100 tons daily, this being the median capacity. Only 12 mills exceeded 300 tons daily in capacity and 40 produced less than 50 tons. Eighty of the connected mills produced waste paperboard or building felts, thirty-nine fine papers, and only four were classed as integrated mills.

Treatment Received and Costs Allocation

Of the total, 59, or slightly less than half, received primary treatment. Treatment charges were reported as 20 cents to 65 cents per pound per ton for primary and secondary treatment for the waste paperboard mill, and 30 cents to 80 cents per pound per ton for all the mills surveyed. Three

Table 12

MILLS DISCHARGING TO PUBLIC SEWAGE TREATMENT FACILITIES

Number of Mills	123 of 753 or 16%
Capacity 10^6 TPD	5.5 of 50 or 11%

Major Locations and Number

Los Angeles County	13
Northern Metropolitan New Jersey	19
Philadelphia Area	6
Neenah-Menasha	6
Kalamazoo	5
Cincinnati	5
Chicago	4
Total	58 of 123 or 47%

Distribution by Size

TPD	
0-50	41
51-100	21
101-300	53
301-500	5
>500	3

Distribution of Type

	No. Mills
Waste Paperboard	64
Building Felts	16
Fine Paper Grades	39
Integrated Mills	4

methods for computing sewer service charges enjoyed approximately equal use. These were ad valorem property taxation, and rates based on flow alone, or flow plus effluent strength. Specially negotiated contracts accounted for only 7 percent of the rates, while each of the more prevalent systems were in use at approximately 30 percent of the mills.

Mills Considering Discharge to Public Facilities

This broad category covers mills known to have recently completed arrangements for public treatment, those where feasibility and rate schedule studies are still in progress, and some where such studies have led to a decision to proceed with independent treatment. The survey data presented in Table 13 shows that the entire group includes 91 mills, or 12 percent of those now operating. Their annual capacity totals 5.5 million tons, or 11 percent of the total for the industry. When this group is added to those already discharging to public facilities we find that use of public treatment facilities is more than an academic question for 28 percent of the industry's mills, accounting for 22 percent of its production capacity.

Table 13

MILLS CONSIDERING DISCHARGE TO PUBLIC FACILITIES

Distribution by Size

TPD	Number
0 - 100	44
101 - 200	57
201 - 500	23
>500	5

Median Size 100 TPD

Distribution by Type

	Number
Coarse Paper Grades	38
Waste Paperboard	32
Roofing Felt	6
Fine Paper Grades	38
Integrated Pulp & Paper	15

The largest concentrations of mills now considering public treatment are located in three states: New York, Massachusetts, and Maine. They account for 55 mills or 60 percent of the total. These are states where effluent treatment has only recently gathered momentum after extended periods of stream classification and development of abatement programs for both municipalities and industries, and where planning funds have been allocated by the legislatures to assist regional treatment feasibility studies.

The size distribution profile of these mills is similar to that for mills already in public systems. Nearly 25 percent are smaller than 50 tpd, and the median size is 100 tpd. The coarse paper grades account for a lesser fraction of the mills, being equalled in number by those producing fine grades. We also see a significant increase in the number of integrated pulp and paper mills involved in such studies. This is particularly true in Maine and New York. Most of the feasibility and rate studies are not far enough along to permit an analysis as to projected costs or financing procedures. The bulk, however, are predicated on providing secondary treatment in line with actual needs or regulatory policy.

SECTION X

ORIGIN OF SPECIFIC MILL EFFLUENTS AND RESULTS OBTAINED BY TREATMENT

Wood Preparation

Wood, the raw material for most of the pulps produced in this country, is received at the mills in various forms and for this reason must be handled in a number of different ways (185). Some mills receive chips from saw mills, or receive barked logs which can be chipped directly. In these instances little, if any, water is employed in preparation of the wood and no effluent is produced. Most mills receive round wood in short lengths with the bark remaining on it, and, since the bark interferes with both the pulping process and product quality, it must be removed.

Underwater Log Storage:

Some pulp mills store their wood supply in the water, and others spray log piles with water to prevent deterioration and maintain a uniform moisture content. The latter practice has taken precedence over the former because of its much lower cost.

The leaching effects of underwater storage were studied by Schaumburg (186) and Graham (187). In their experiments unbarked and barked logs were submerged for seven days in water containing sufficient mercuric chloride to prevent biodegradation of the leached substances. Data obtained for three species of wood are shown in Table 14 which gives the BOD_5 leached from each square foot of log surface exposed. From these data it was computed that a cord of unbarked wood will add from 0.5 to 7.0 pounds of BOD and 0.8 to 23 pounds of COD to the water in which it is stored, the species as well as the season of cutting determining the magnitude of these figures.

When roundwood is stored unbarked under water, wood solubles, silt, and bark debris are transferred to the water. As much as ten pounds of BOD_5 per cord of wood stored can be contributed depending upon the length of the storage period. Since the same water is usually used repeatedly with only make-up being added, the water can accumulate a high BOD value and require treatment prior to its discharge. Hence, rather than discharging during a short interval coinciding with basin cleaning, it is good practice to bleed the storage basin to the waste treatment facility on a continuous basis in order to prevent the overload that slug discharge would ordinarily produce, and make up evaporation and out-carriage water losses continuously or at frequent intervals.

Log Washing:

Logs are frequently washed before dry or wet barking by a water shower in order to remove silt (188). In most installations the water shower

TABLE 14

OXYGEN DEMAND OF WATER AFTER SEVEN DAYS CONTACT WITH WOOD

WOOD SPECIES	BARK	BOD_5 GM/FT.^{2}	COD GM/FT.^{2}
Douglas Fir	+	0.9	3.2
	-	0.9	3.2
Ponderosa Pine	+	0.8	4.2
	-	1.4	2.8
Hemlock	+	0.3	1.8
	-	0.9	2.0

TABLE 15

WOOD WASHING

Effluent Flow	100 to 300 Gal./Ton/Prod.
BOD_5	1 to 8 #/Ton/Prod.
Total Suspended Solids	5 to 55 #/Ton/Prod.
Color	< 50 Units

is activated by the log itself while on the conveyer so that a minimum of water is used. The actual quantity discharged per unit of wood handled or pulp produced is most difficult to ascertain because of the wide weight variation in stick size and the fact that all the wood barked at some installations is not pulped, a portion going to lumber. However, the limited data available indicate that this flowage amounts to about 100 to 300 gallons per cord of wood washed.

It is established that this effluent is very low in color and BOD (189) and that its suspended solids content is largely silt. Hence, it is generally disposed of on the land together with grits and dregs from the pulp mill and/or ashes from the boiler plants, or combined with the general flowage to the treatment works. Storage oxidation and seepage account for considerable reduction in residual BOD when this waste is lagooned and the solids settle rapidly and do not decompose. Effluent flowage and range of losses from such operations are shown in Table 15.

Barking:

Most of the pulpwood used in the United States is small in diameter and it is barked dry in drums. However, when large diameter or long wood is used, wet barking is commonly employed. The latter operation is pretty much limited to northern mills and its use is presently declining.

Wet barking of logs is accomplished by one of three methods: by drums, pocket barkers, or hydraulic barkers as described in Volume I of "Pulp and Paper Manufacture" (185) and by Kronis and Holder (190). Slabs are generally handled by hydraulic units as is the larger diameter and long roundwood.

The wet drum barker consists of a slotted drum equipped with internal staves which knock the bark from the wood as the drum rotates in a pool of water. The bark falls through the slots and is removed with the overflow of water. These units handle from 7 to 45 cords of wood daily. Frequently the water supplied to them is spent process water and recycling within the barking unit itself is often practiced. Barkers of this type contribute from 15 to 20 pounds of BOD per ton of wood barked, and from 30 to 100 pounds of suspended solids. Examples of the BOD_5 and suspended solids concentration of this wastewater with the barkers using fresh process water are shown in Table 16.

Wet pocket barkers are stationary machines which abrade bark from timber by jostling and gradually rotating a confined wood stack against an endless chainbelt equipped with projections called "dogs" which raise the wood pile allowing bark to pass between the chains. Water is sprayed through apertures in the side of the pocket at rates of between 330 and 600 gpm for pockets of 2.8 and 5.7 cords per hour, respectively. The use of this process is rapidly declining in the United States.

Hydraulic barkers employ high-pressure water jets to blow the bark from the timber which is either conveyed past them or rotated under a moving jet which traverses the log. The volume of water employed is generally from 5000 to 12,000 gallons per cord of wood barked depending upon log diameter.

TABLE 16

ANALYSIS OF WET DRUM DEBARKING EFFLUENTS

MILL	TOTAL SUSPENDED SOLIDS mg/1	NON-SET SOLIDS mg/1	% ASH OF S. S.	BOD_5 mg/1	COLOR UNITS
1	2017	69	--	480	20
2	3171	57	21	605	50
3	2875	80	18	987	50

Water discharged from all three types of wet barking is generally combined with pre-wash water from sprays, which give the logs a preparatory cleaning, and then coarse screens are used to remove the large pieces of bark and wood slivers which are conveyed away continuously. The flowage then passes to fine screens. These are of the drum, fixed vertical, or horizontal vibrating type, having wire mesh or perforated plate media with openings in the range of 0.05 to 0.10 inches. Screenings are conveyed away and mixed with the coarse materials from the initial screenings, the mixture being dewatered in a press prior to burning in the bark boiler. Press water, which is combined with the fine screen effluent, is very minor in volume. The total waste flow, which amounts to about 5000 to 7000 gallons a cord, generally carries from one to ten pounds of BOD_5 and 6 to 55 pounds of suspended solids per ton of product.

The combined discharge contains bark fines and silt, the latter varying greatly in quantity since its presence is due mainly to soil adhering to the logs. In dry weather the percentage of silt in relation to bark fines is low as is the case when logs are stored in or transported by water. However, attachment of mud in wet weather can make this material a major percentage of the total suspended matter passing the fine screens.

Fine screen effluent following hydraulic barkers has been analyzed by several investigators (191,192,193,194) and examples are shown in Table 17. It can be concluded from the data included in these publications that these effluents have a total suspended solids content ranging from 521 to 2350 mg/l with the ash content running from 11 to 27 percent. The latter is generally below 15 percent for clean logs. BOD_5 values range between 56 and 250 mg/l. These low values are due to the fact that the contact of the water with the bark is short and no grinding action on the wood takes place. Hence leaching of wood and bark solubles are minimized. The water originally employed is all fresh process water, since the close clearances of the high pressure pumping systems supplying water to the jets will not tolerate the presence of suspended solids in the water.

Such low values are not the case with drum and pocket grinding where attrition in contact with water over an appreciable period of time takes place. Also, spent pulping and bleaching process waters already high in BOD and color are not infrequently used for these barking processes which raise further the ultimate level of organics in the screened effluent. While wet drum and pocket barker fine screen discharge is not greatly different from that of hydraulic barkers in suspended solids content, the BOD_5 can be considerably higher (195,189,191).

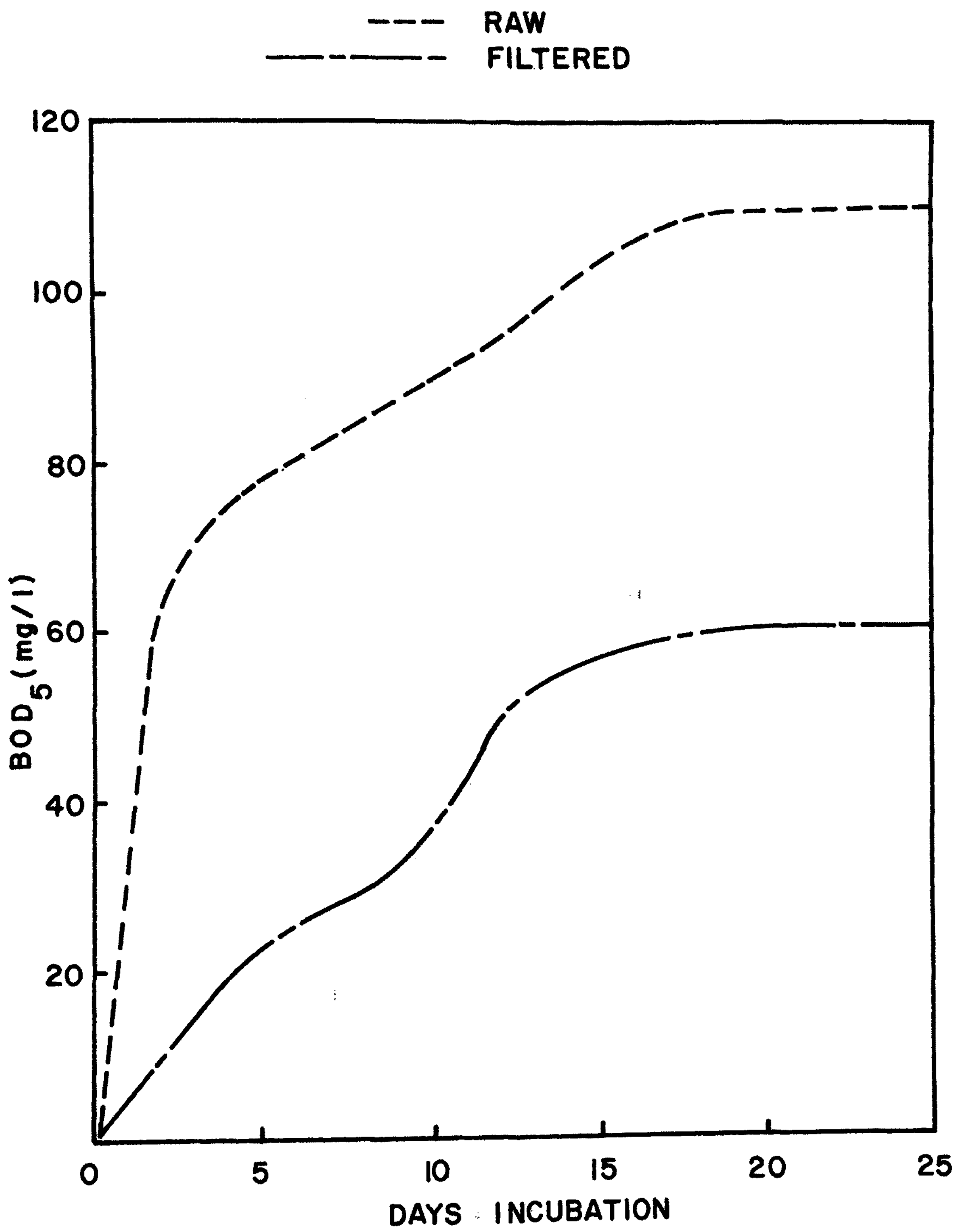
BOD values are also greatly affected by the species of wood barked and the season in which the wood was cut since wood juices and water extractables are responsible for it. That contributed by the suspended matter present is a minor fraction of the total BOD. Curves presented by Blosser (192), as shown in Figure 19, indicate that the 15-day values are about twice those of the 5 day with little further demand exerted

TABLE 17

ANALYSIS OF HYDRAULIC BARKING EFFLUENTS

MILL	TOTAL SUSPENDED SOLIDS mg/1	NON-SET SOLIDS mg/1	% ASH OF S.S.	BOD_5 mg/1	COLOR UNITS
1	2362	141	27	85	< 50
2	889	101	14	101	< 50
3	1391	180	17	64	< 50
4	550	66	11	99	< 50
5	521	53	13	121	< 50
6	2017	69	21	56	< 50
7	2000	< 200	19	97	--
8	600	41	10	250	35

FIGURE 19
LONG TERM BOD OF BARKER EFFLUENT
(AFTER FINE SCREENS)



after this period. The oxygen demand rate over five days was demonstrated to be similar to that of paper mill wastes (190). A process flow diagram of wet barking operations is presented in Figure 20.

Treatment:

Settling will remove from 70 to 90 percent of the total suspended solids present in barker wastewater and is essentially complete in 30 to 60 minutes.

Settling curves were published by Draper and Mercier (191) and Blosser (192) and a typical one is presented in Figure 21. Because of the good settling characteristics of the screened effluent, sedimentation is employed for clarification. Also, because of this attribute, coagulants are not needed (196). Settling is sometimes accomplished in alternating earth embanked basins from which the settlings, which compact well, are dredged.

More modern practice is the use of circular, heavy-duty type clarifiers or thickeners. These are designed for a rise rate of 1000 to 1200 $gal/ft^2/day$ of surface area and to provide a retention period of about two hours. They are equipped and piped to handle dense sludge such as that produced when considerable silt is present in the underflow, as well as a skimmer to collect the ever-present floating materials. The underflow is removed by means of diaphragm, plunger, or screw pumps and transferred to drying beds or to a vacuum filter for dewatering. Filters can be of the disc or drum type, and because of the freeness of the solids can operate at high submergence producing a thick cake. Drum speed is variable so that variations in cake freeness can be accommodated and a vacuum of about 15 inches is desirable. Filter media frequently consist of 120-mesh stainless steel wire cloth. Filter cake produced contains about 30 percent solids and loadings range from 10 to 12 $\#/ft^2/hr$ of dry solids. Such cakes are either disposed of on the land or sold as mulch. A diagram of the treatment process is presented in Figure 22.

Effluents from clarifiers are not treated further separately but combined with pulp mill and other wastes for biological treatment when this process is practiced. As can be judged from the BOD rate curve, their treatment by biological means presents no problems.

Pennsylvania established raw waste standards for wet barker effluents in the early 1950's (195). These allowed 50 to 70 pounds of total suspended solids and 15 to 20 pounds of BOD_5 in the effluent from fine screens. The State of Washington, however, has set an effluent standard of less than 200 mg/l of volatile suspended matter (197), a value which can only be met by clarification installations of good design and operation.

It is difficult, because of the many variables involved, to set a fixed number for the volume, pounds of BOD_5, and total suspended solids discharged per ton of pulp produced. However, a single hydraulic barker of the usual size operating on common sizes of logs can generally service a 200 to 300 ton per day pulping operation and employs between 900 and 1200 gpm of water. Effluent flowage as well as BOD_5 and total suspended solids losses per ton of pulp produced are presented in Table 18.

FIGURE 20

WET BARKING PROCESS DIAGRAM

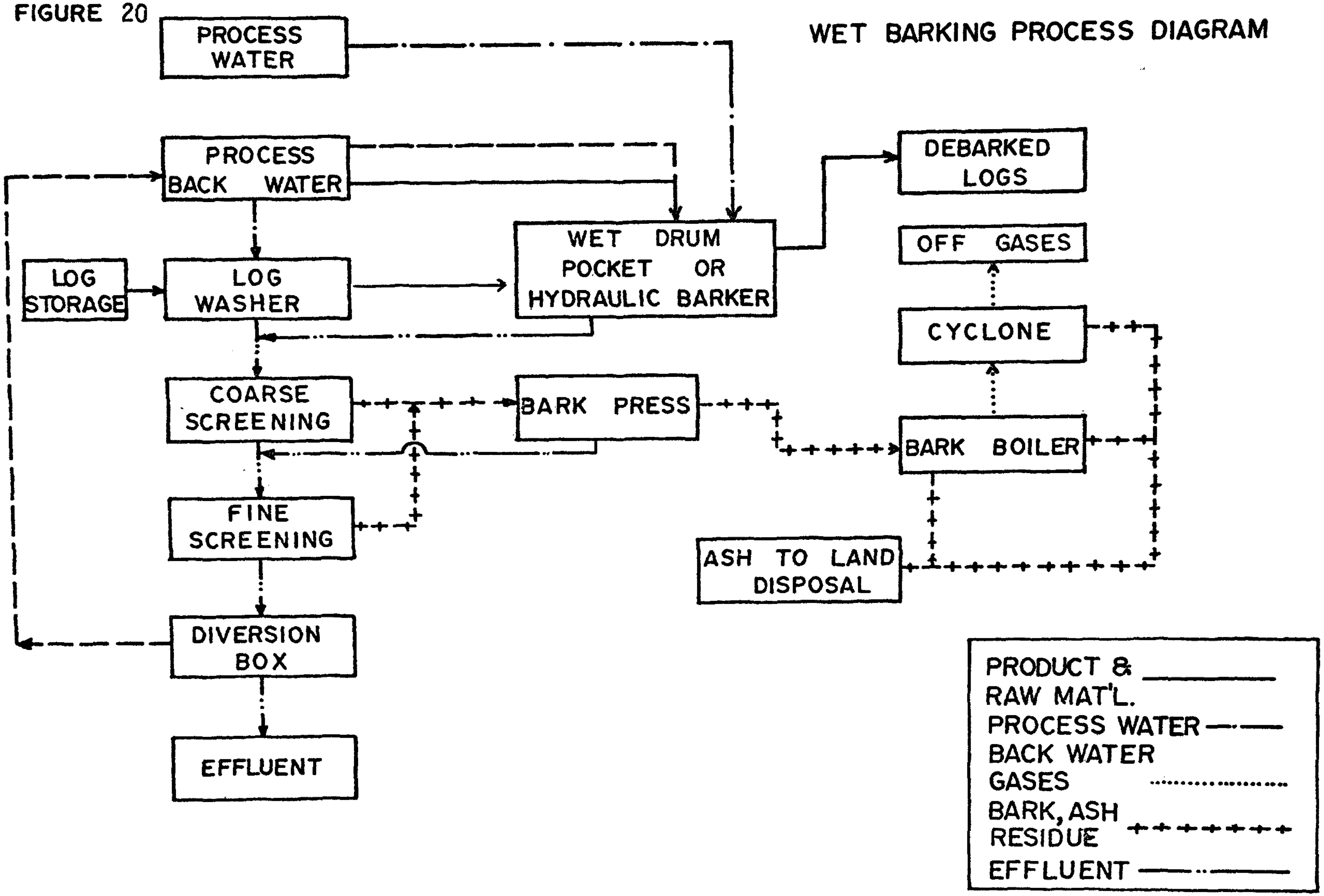


FIGURE 21 SETTLING RATE OF BARKER SCREENING EFFLUENT

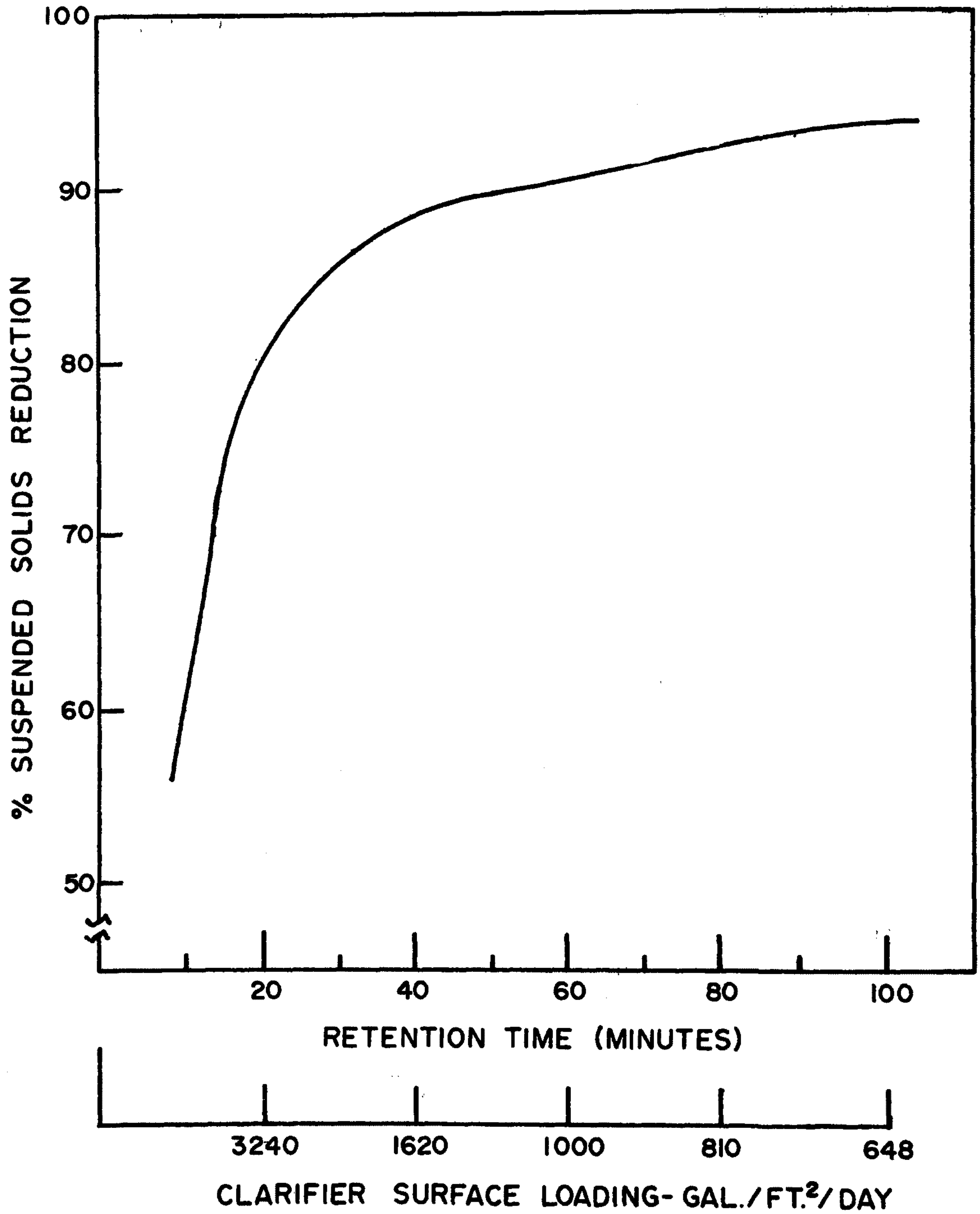


FIGURE 22

TREATMENT OF WET BARKING EFFLUENTS

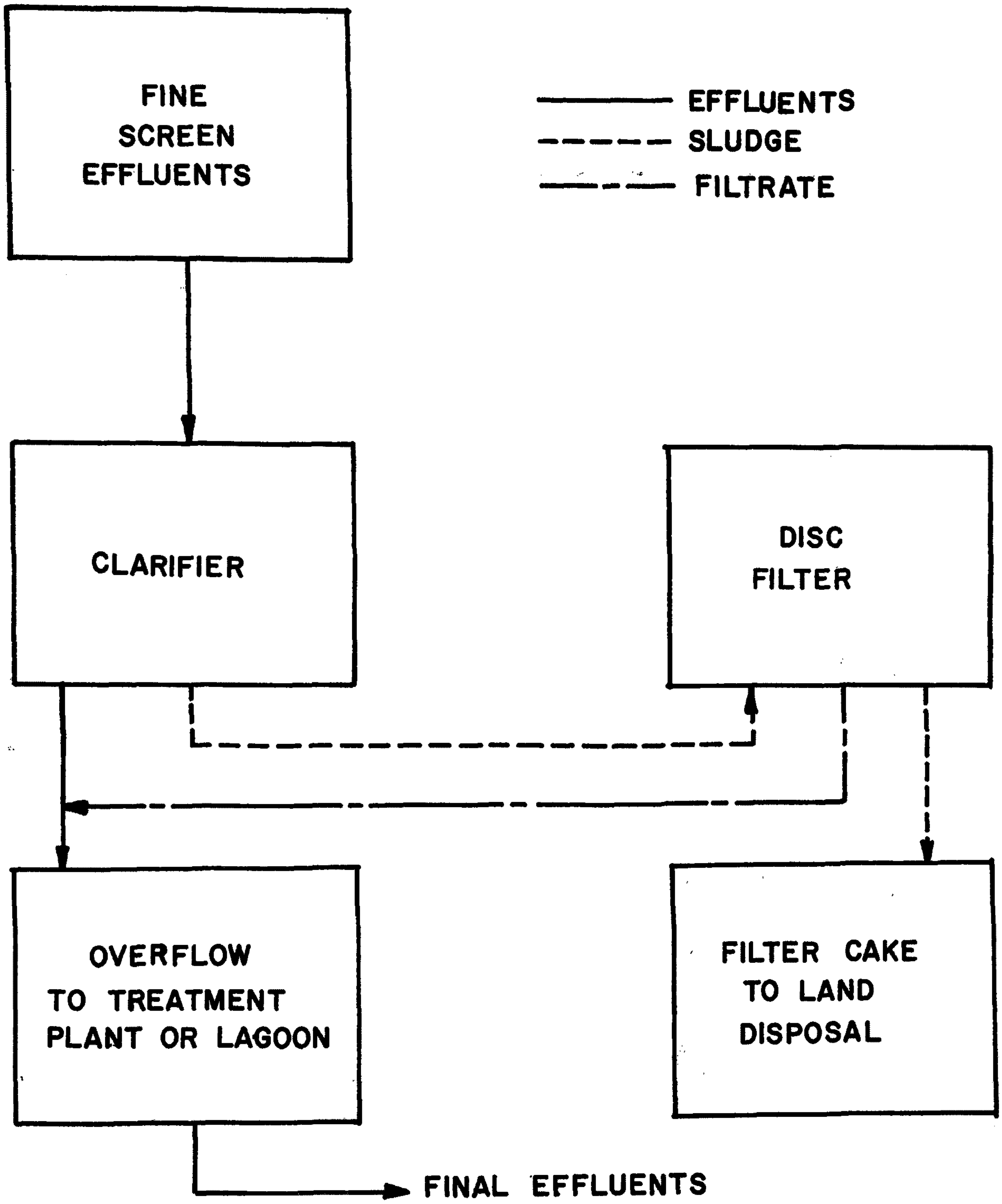


TABLE 18

SEWER LOSSES FROM WET BARKING OPERATIONS

Mill #	Eff. Flow Thous. Gal./Ton Prod.	BOD_5 #/Ton Prod.	Total Susp. Solids #/Ton Product
1	2.7	1.2	6.4
2	2.4	1.8	7.6
3	3.5	12.0	5.5
4	6.0	6.0	30.0
5	3.0	2.5	22.8
6	1.0	2.0	10.0
7	5.6	19.0	18.0
8	1.0	11.5	30.0
9	7.5	20.1	34.0

Groundwood Pulping

Groundwood pulp is employed mainly in the manufacture of newsprint, toweling, tissue, wallpaper, and coated specialty papers such as that used for some illustrated magazines (185). Since it contains practically all the wood substance, yields generally exceed 90 percent. Most of it is produced by the large newsprint mills in the South from southern pines. In all, about 60 mills with a daily capacity of approximately 14,000 short tons, produce this type of pulp in the United States, of which about 20 are large operations. This is distinct from pulps produced by other mechanical processes which are generally employed for building or molded products.

Groundwood pulp is produced from both roundwood and chips. In the older process roundwood is pressed against large rotating grindstones by hydraulic rams while water is sprayed on the stone (198). On discharge from the grinder the pulp is screened free of wood slivers and other coarse debris and thickened on deckers. The thickened pulp is then discharged to a stock chest for use in the paper mill or lapped for shipment. After clarification by sedimentation, filtration, or flotation, the filtrate from the deckers is largely returned to the process but a portion is sewered to prevent the buildup of solubles in the system with attending slime problems. The overflow rarely exceeds 10,000 gallons per ton of bone-dry pulp and in some instances is as low as 2000 gallons (199,27,188). A flow sheet of this process is shown in Figure 23.

In some modern newsprint mills the groundwood operation is completely closed, all effluent appearing in the paper machine effluent. In this event, the raw waste load is the sum of typical losses from both the groundwood pulping and papermaking.

FIGURE 23

GROUNDWOOD PULPING PROCESS DIAGRAM

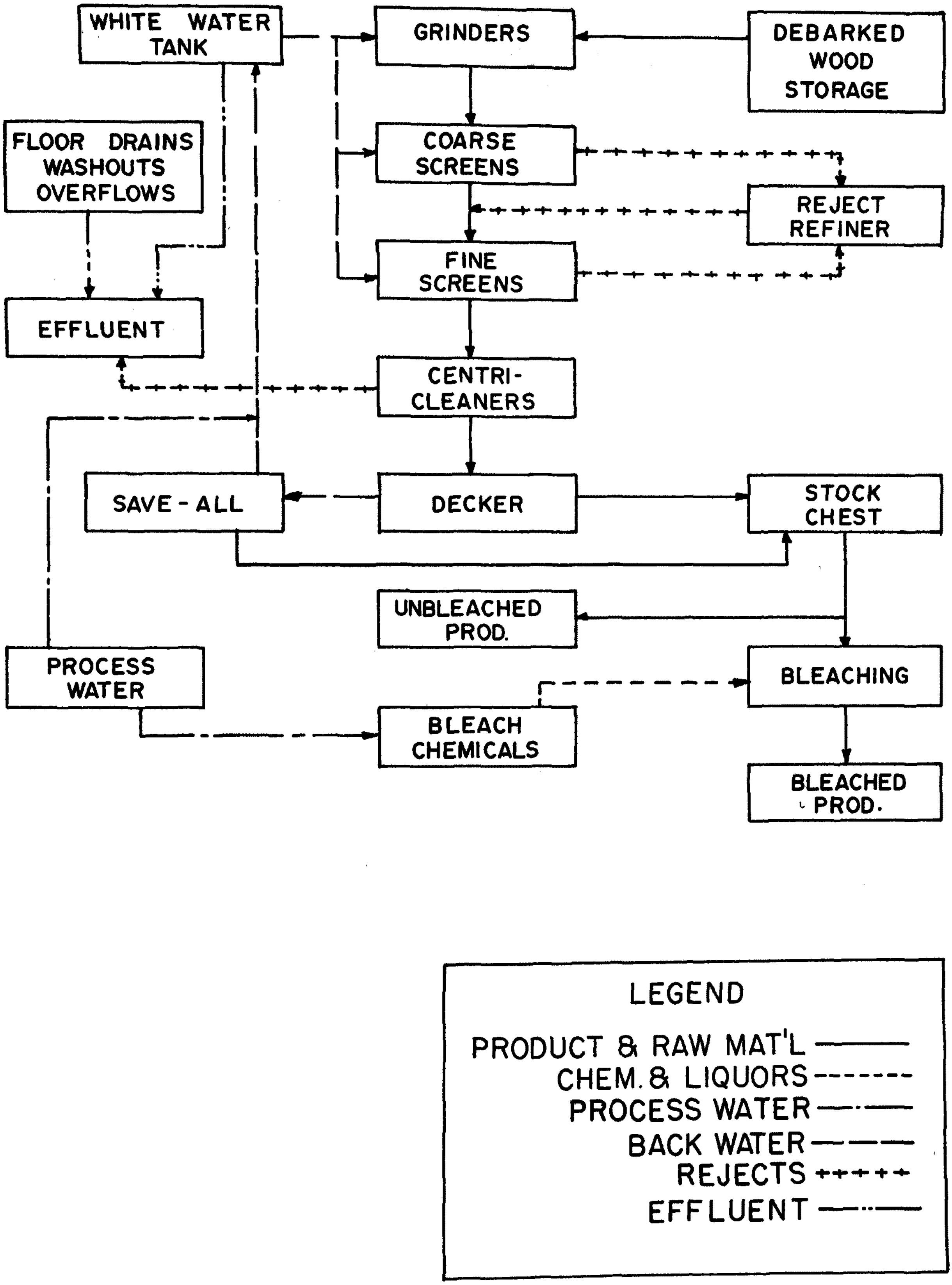


TABLE 19

EFFLUENT CHARACTERISTICS OF STONE GROUNDWOOD PULP MILLS

Mill	Eff. Flow Thous. Gal./Ton Prod.	BOD_5 #/Ton	T.S.S. #/Ton
1	6.3	11	16
2	1.9	8	14
3	4.4	11	11
4	5.4	9	12
5	8.3	18	11
6	2.7	19	16
7	2.2	4	42
8	2.6	14	21

TABLE 20

EFFLUENT CHARACTERISTICS OF REFINER GROUNDWOOD PULP MILLS

Mill	Eff. Flow Thous. Gal./Ton Prod.	BOD_5 #/Ton	T.S.S. #/Ton
1	2.6	26	105
2	4.3	120	100
3	5.8	15	110
4	6.7	18	59
5	4.4	15	30
6	1.7	32	35
7	5.9	30	35

In recent years a considerable amount of groundwood has been produced by passing wood chips through refiners of the disc type (185). Two stages of refining are employed in the pulp mill, a third taking place as part of the papermaking operation. The refiners contain fixed and rotating discs between which the chips pass together with a stream of water. The pulp is discharged as a thick slurry, after which it is handled in a manner similar to stone groundwood. Generally less water is required with refiners. Figure 24 represents the process diagram of a typical refiner groundwood operation. Effluent volume, BOD_5, and suspended solids losses for all groundwood pulping are shown in Tables 19 and 20.

Chemi-groundwood and Cold Soda Pulps:

Some groundwood-type pulps are produced by first soaking barked logs or wood chips in dilute chemical solutions which soften the wood, thus reducing the power required for grinding. When caustic soda is employed as the chemical the pulp is referred to as "cold soda" pulp and when sodium is used the product is called "chemi-groundwood" pulp. Both products are manufactured by both stone and refiner grinding. Chemical treatment results in higher BOD_5 losses than occur in ordinary groundwood operation as indicated in Table 21.

TABLE 21

EFFLUENT CHARACTERISTICS OF COLD SODA AND CHEMI-GROUNDWOOD PULPS

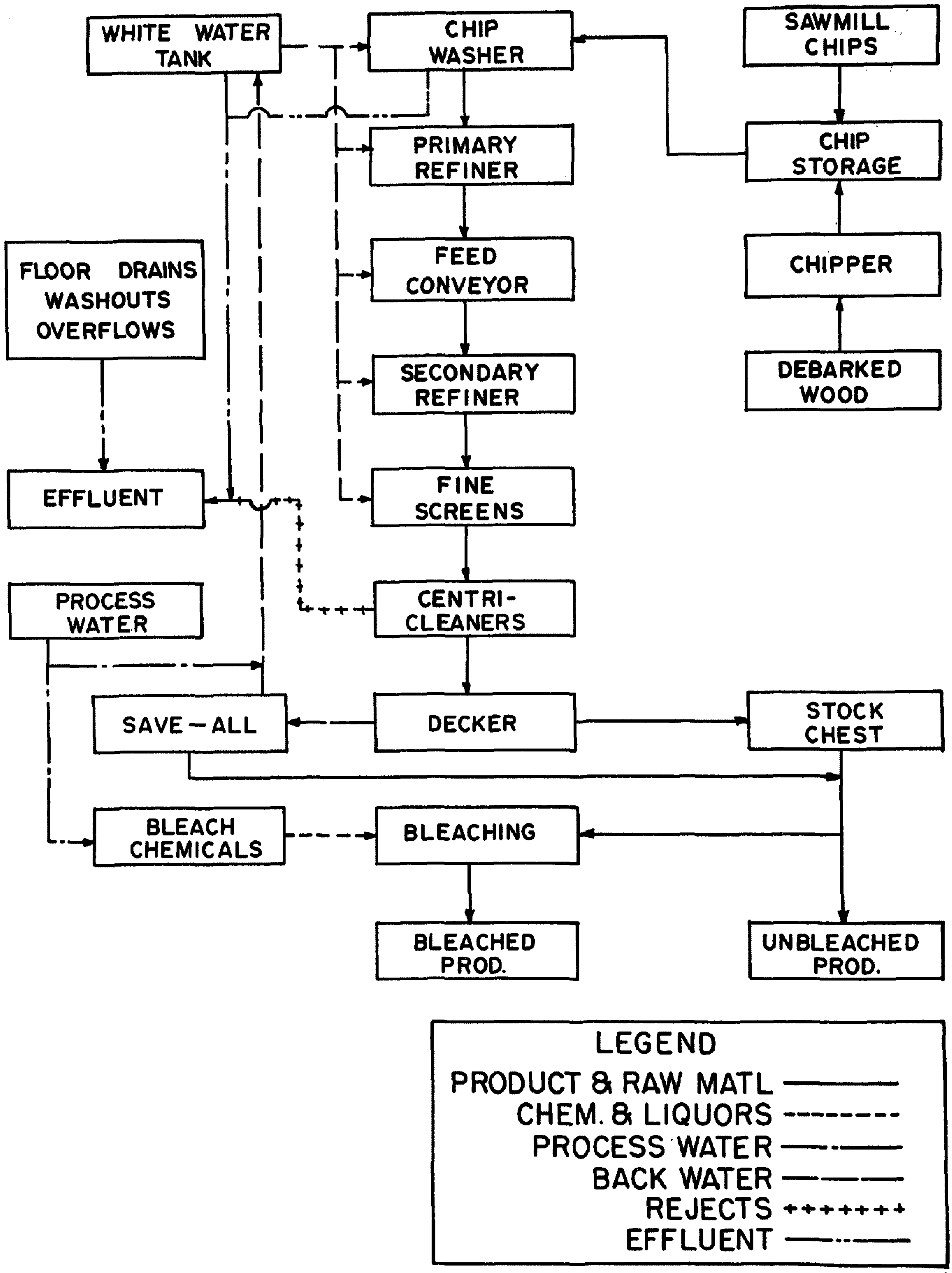
	Eff. Flow Thous. Gal./Ton Prod.	BOD_5 #/Ton	T.S.S. #/Ton
Cold Soda Pulping			
1	2.0	73	15
2	3.7	92	26
3	5.5	101	32
Chemi-Groundwood			
1	2.4	81	24
2	3.3	69	37

Bleaching of Groundwood Pulp:

Groundwood pulp is generally bleached with hydrogen or sodium peroxide, sodium or zinc hydrosulfite, or sodium sulfite (200,201). Interest has recently developed in the use of peracetic acid, sodium borohydride, and amine borides for this purpose, but their use has not become established practice (202).

FIGURE 24

REFINER GROUNDWOOD PROCESS DIAGRAM



In practice, the pH is generally adjusted to between 4.5 and 7.0 depending upon the bleaching agent and sometimes complexing chemicals are added to overcome the effect of heavy metals, such as iron and manganese, that may be present. Buffers and catalytic agents in trace quantities are also sometimes used. Since groundwood can be bleached at high consistency, it is frequently accomplished at stock chest levels without washing. Hence, the residues of bleaching appear in the white water of the paper machine system.

Since the zinc content of effluents from the zinc hydrosulfite process is generally less than 10 mg/l it does not cause a problem when diluted with other effluents and receiving waters.

Treatment:

The large integrated mills, as well as paper mills alone, treat the groundwood effluent in combination with the total discharge. Thirty-eight mills which manufacture 9,750 tons daily provide treatment. Of these, 12, representing a daily production of 5,000 tons of groundwood, provide secondary treatment. Storage oxidation basins, aerated lagoons, and activated sludge are all employed.

The effluent from groundwood pulping can be clarified to a high degree by settling, particularly if other effluents containing fiber and fillers are combined with it, since 90 percent of the suspended solids present are settleable. However, the sludge produced is extremely hydrous, often averaging only 0.5 percent consistency and is most resistant to dewatering. It can be dewatered only on combination with other less hydrous waste slurries. Flotation is equally as effective as settling or clarification.

Groundwood mill effluent is responsive to biological treatment both alone and in combination with other pulping wastes. Lower oxidation rates have been observed for it than for chemical pulping effluents according to Bishop and Wilson (84), but when combined with kraft pulping effluent the rate becomes normal.

Some modern newsprint mills clarify the groundwood pulping effluent and employ it for dilution on the paper machine. Hence, losses from both pulping and papermaking are contained in a single discharge which is then mixed with other pulp mill waste prior to treatment.

Cold soda and chemi-groundwood effluents present no problem when combined for treatment with other mill effluents (71) for as previously pointed out, they represent a higher BOD_5 loading than ordinary groundwood. The settling characteristics of the suspended solids contained in them are very similar to those of groundwood.

Since there is presently no case where groundwood effluent is treated separately, data for this category are not available. However, data for kraft newsprint waste treatment are presented in the section on kraft pulping.

Neutral Sulfite Semi-chemical Pulping

Approximately 12,000 tons of NSSC pulp are produced in the United States daily. A two-stage process is employed in which the wood chips are softened by a short cook with a neutral sodium or ammonium sulfite solution, then defibrated in a refiner (185). Pulp yields from the wood range from 60 to 80 percent on a bone-dry basis for use in a variety of products. Most, however, goes to the coarser products such as corrugating board which consumes 75 percent. The bleaching of this type of pulp will soon come to an end in this country.

While some mills buy the cooking chemical, most prepare liquor by burning sulfur and absorbing it in soda ash or ammonia. This part of the process produces little liquid wastes other than floor drainings, equipment wash-up, and cooling waters which can frequently be used as process water.

Chips are cooked in either batch or continuous digesters and passed through disc refiners prior to washing. Digester-relief and blow gases are condensed, and in some mills the condensate is used for pulp washing. Pulp wash water together with drainings from the blow tank are delivered to the recovery or liquor burning system. Since many of these mills are adjunct to kraft pulp mills the spent liquor is recovered in the kraft recovery system, the organics cooked from the wood being burned in the furnace, and the residual chemicals supplying chemical make-up for the kraft mill.

From the washers the pulp is conveyed to an agitated chest where it is diluted with white water from the paper mill to the desired consistency for feed to the secondary refiners serving the papermaking operation. In making corrugating board a small percentage of repulped waste paper is added to give the product the desired charactertistics. Other than spent liquor, the pulping and washing operations discharge little wastewater since the small amount of residual liquor solids present in pulp is carried through the machine system passing out with the overflow white water (203). Figure 25 is a process diagram of a modern operation.

Spent liquor is commonly fed to triple-effect evaporators after which it is burned with bark in the bark boiler, in a fluidized bed unit, or in a special furnace if chemical recovery is practiced (204,205). The latter practice, however, is limited to a few large mills. The fluidized bed units produce sodium sulfate suitable for use in kraft mill liquor systems. One mill produces acetic and formic acids from the liquor and sends the residual raffinate to a kraft mill for makeup since it contains a substantial amount of sodium sulfate (103).

The final effluent from NSSC mills is low in volume because of the high degree of recirculation commonly practiced. For the same reason it is usually high in BOD_5 ranging from 1500 to 5000 mg/l with a suspended solids content of from 400 to 600 mg/l. The color and COD content are correspondingly high (176). Overall process losses in BOD_5 and total suspended solids without recovery in relation to pulp yield are shown in Figures 26 and 27.

FIGURE 25
NEUTRAL SULFITE SEMI-CHEMICAL
PULP PROCESS DIAGRAM

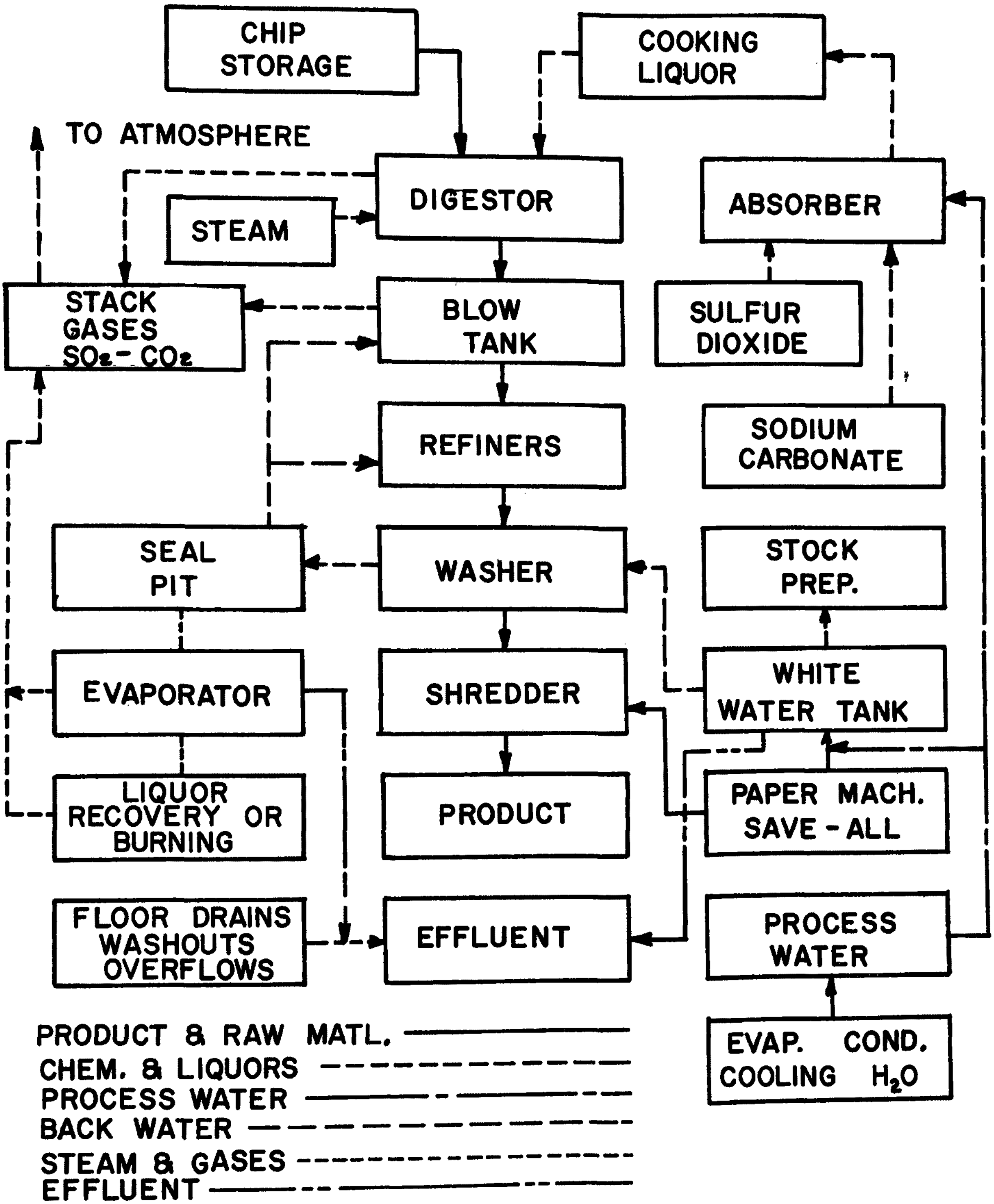


FIGURE 26 BOD LOAD OF NSSC PULPING

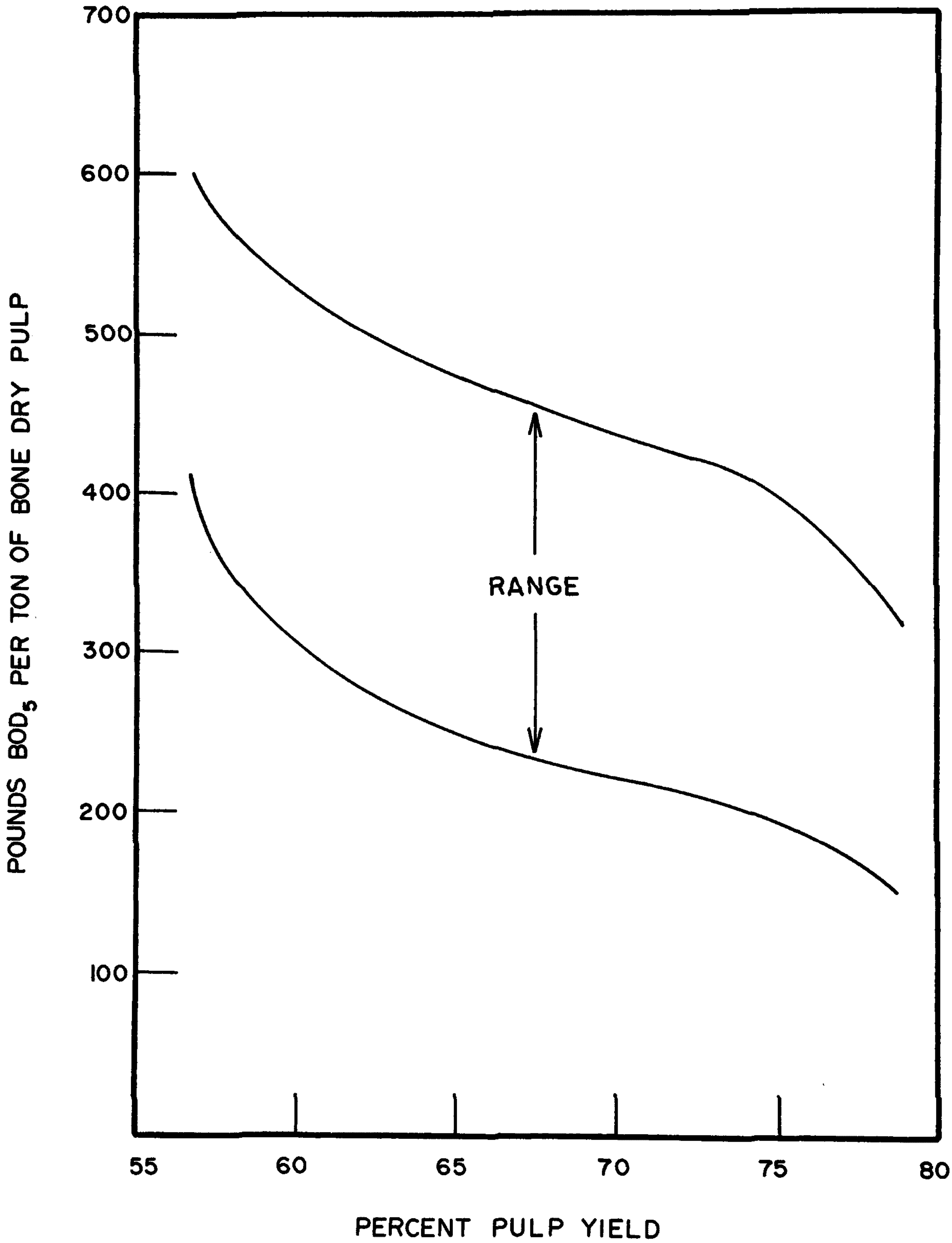
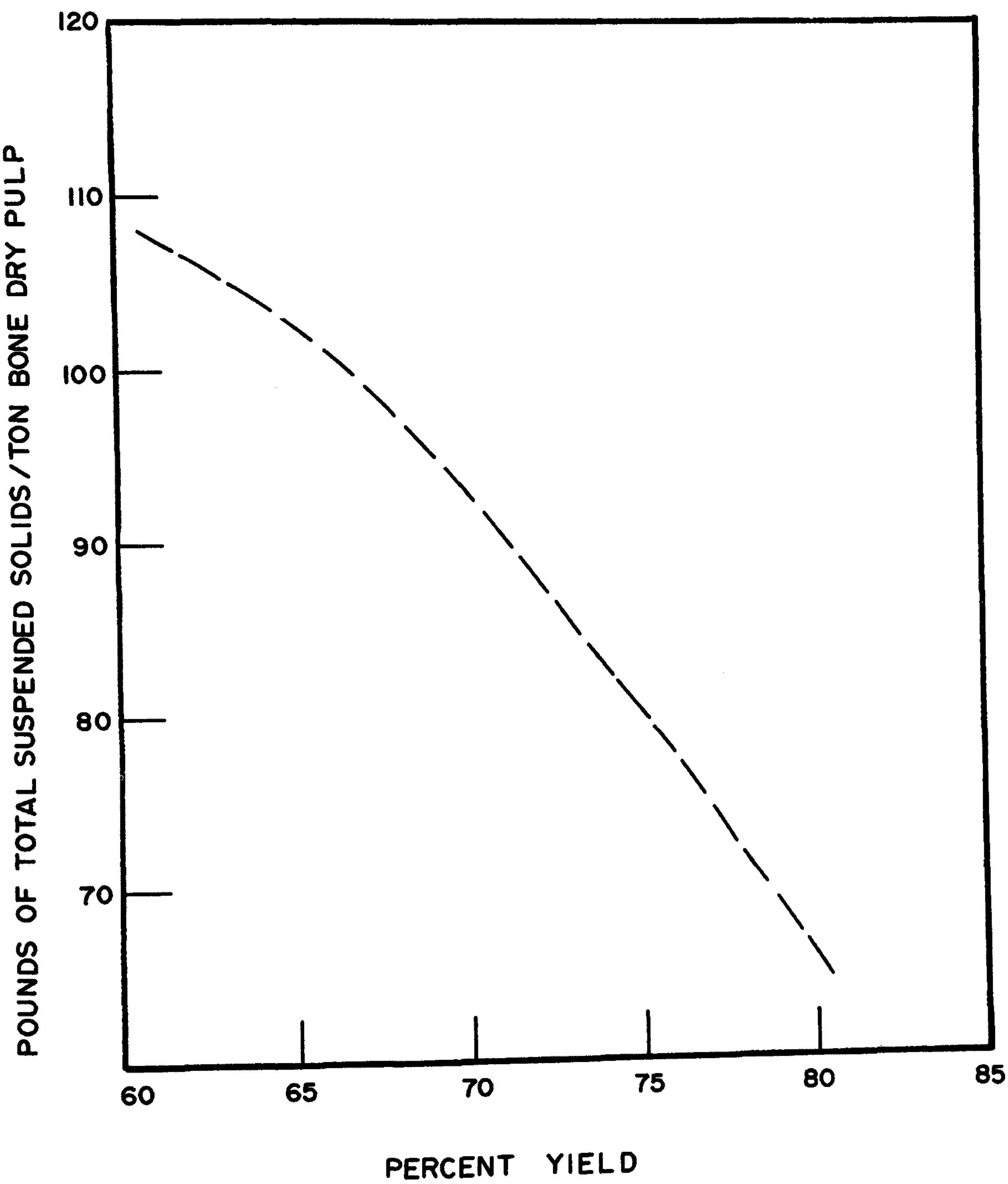


FIGURE 27 SUSPENDED SOLIDS LOSSES FROM NSSC PULPING



In corrugating board NSSC mills the white water system can be closed to a very high degree. Lowe (206) demonstrated that satisfactory operation was possible at an effluent flow of less than 2000 gallons per ton of product. The mill white water flow pattern employed by him is presented in Figure 28. Recently this practice has been followed successfully at other mills.

Data regarding effluent volume as well as BOD_5 and suspended solids losses for 13 NSSC corrugating board mills having liquor handling facilities are shown in Table 22. The methods employed for handling NSSC wastes by mills in the United States are tabulated in Table 23.

Treatment:

Dilute NSSC wastes are treated in aerated stabilization basins at six mills in combination with unbleached and bleached kraft effluents. Another employs the activated sludge process to handle the combination wastes (92). Two mills treat this effluent alone by aerated stabilization basins (206). No difficulties have arisen in oxidizing these wastes biologically either alone or in combination with others since both the rates and degrees of oxidation observed are normal when they are neutralized and nutrients added. The only effect it has had on treatment systems in general is to increase the quantity of primary sludge collected and decrease dewaterability. This is due to the high suspended solids loss in the form of fines attendant to the manufacture of this pulp. Biological treatment of dilute NSSC effluents, especially where these are mixed with kraft wastewaters, is expected to increase considerably using conventional methods whose effectiveness are well established. Production of this type of pulp is showing a linear expansion as a result of the addition of new mills and expanded production at existing ones.

Land disposal of weak NSSC wastes, which is practiced by two mills, can be successful if properly laid out and well managed (138,207). However, a large area of suitable land is required (146). Even for small operations one-sixteenth inch of waste per day is the maximum quantity that can be applied. Crops are not grown on these disposal areas.

Extensive research and development work on other methods for reduction of the pollution load after recovery is underway in the States.

As was discussed in the Advanced Waste Treatment section of this report, considerable attention has been given to the use of activated carbon for treating dilute NSSC mill wastes since this material can adsorb most of the color and a part of the BOD (208). However, its application to neutral sulfite wastewaters is likely to be limited because of its relatively low capacity for adsorbing materials responsible for the BOD in relation of its high affinity for color bodies.

On the other hand, reverse osmosis processes show promise for both BOD and color removal. A study of their application for concentrating the dissolved solids in weak sulfite wastes is discussed on Page 56 .

FIGURE 28
WATER RECYCLE IN A NSSC MILL

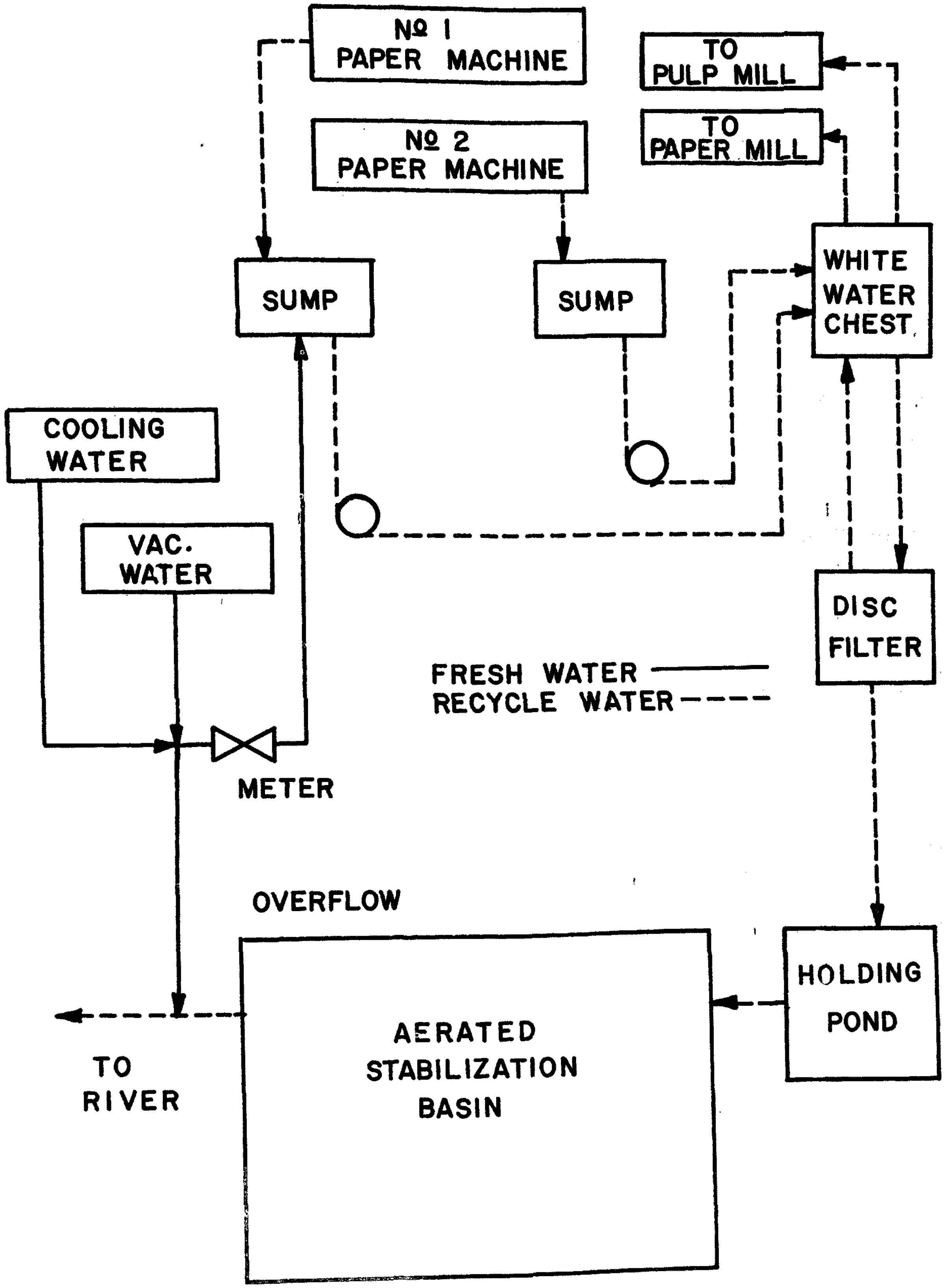


TABLE 22

NEUTRAL SULFITE CORRUGATING BOARDMILL EFFLUENT CHARACTERISTICS

(Mills with Liquor Recovery)

Mill #	Effluent Volume Thous. Gal./Ton	BOD_5 #/Ton	T.S.S. #/Ton
1	9.1	30	15
2	4.8	64	12
3	7.2	43	9
4	6.0	27	17
5	1.7	57	8
6	11.3	71	43
7	10.0	90	28
8	10.4	42	33
9	25.6	47	23
10	20.0	69	46
11	7.0	43	100
12	10.3	22	37
13	24.0	150	40

TABLE 23

METHODS OF HANDLING NSSC SPENT LIQUOR IN THE UNITED STATES

Method of Handling	No. of Mills	Cap. T/D
Cross recovery	17	4,880
Recovery	3	1,375
Incinerate (Fluidized bed or bark boiler)	6	1,650
By-Product Mfg.	2	625
To Sewage Plants	3	615
Land Disposal	2	475
None	2	320
Total	35	9,940
Total Burning Liquor (All methods)	26	7,800

Opferkuch (181) and others (209) demonstrated both in the laboratory and in pilot plant operations that NSSC wastes could be treated to a high degree in conjunction with sanitary sewage. In reaching this conclusion it is assumed that adequate plant capacity is provided to handle the combined flowage and loadings. As with other pulping wastes, such treatment does not remove color to a high degree.

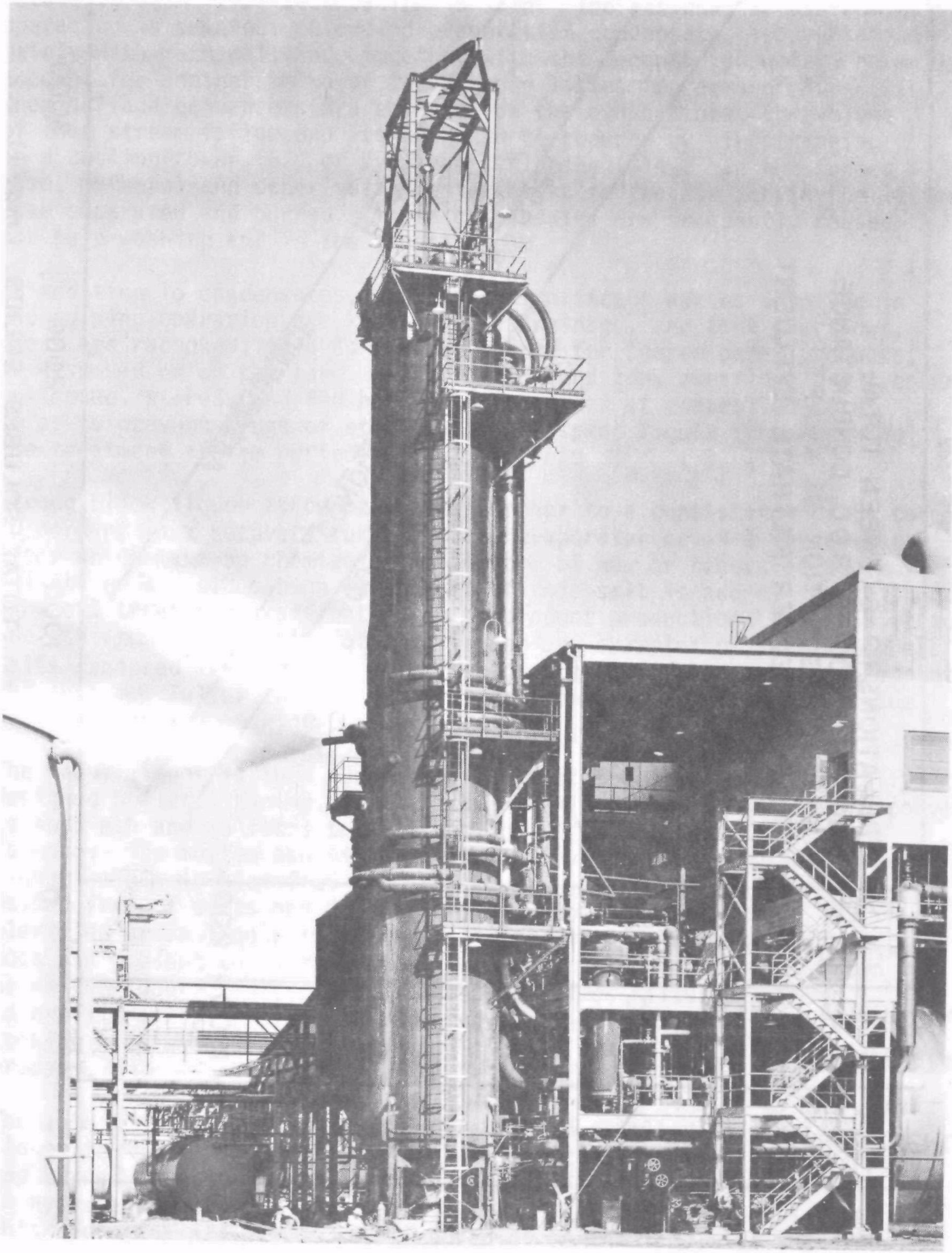
Kraft and Soda Pulping

About 80 percent of the chemical pulp produced in this country is manufactured by alkaline pulping methods, namely kraft or sulfate and soda processes. In alkaline pulping the wood chips are cooked in either batch or continuous digesters with, in the case of kraft pulping, a mixture of caustic soda and sodium sulfide, and in soda pulping, caustic soda alone. Because of the high cost of these chemicals and the high concentration required, a chemical recovery system has always been inherent to the processes (185).

Recovery necessitates separating the spent liquor from the pulp to a high degree after digestion, and in as high a solids concentration as possible (185,210) in order to minimize evaporation heat requirements (211,212). The separation is accomplished by counter-current washing on vacuum drum washers or continuous diffusers. In some recent installations a combination of the two is employed (211). Some continuous digesters contain liquor separation and diffuser washing zones within the digester body. Three stages of washing are common but in some cases four are used. The pulp is then diluted, screened, and used directly for paper production or deckered to high consistency for bleaching, storage, or lapping for shipment. The separated spent cooking liquor, known as weak black liquor, has a consistency of 12 to 20 percent solids and is collected in tanks for recovery.

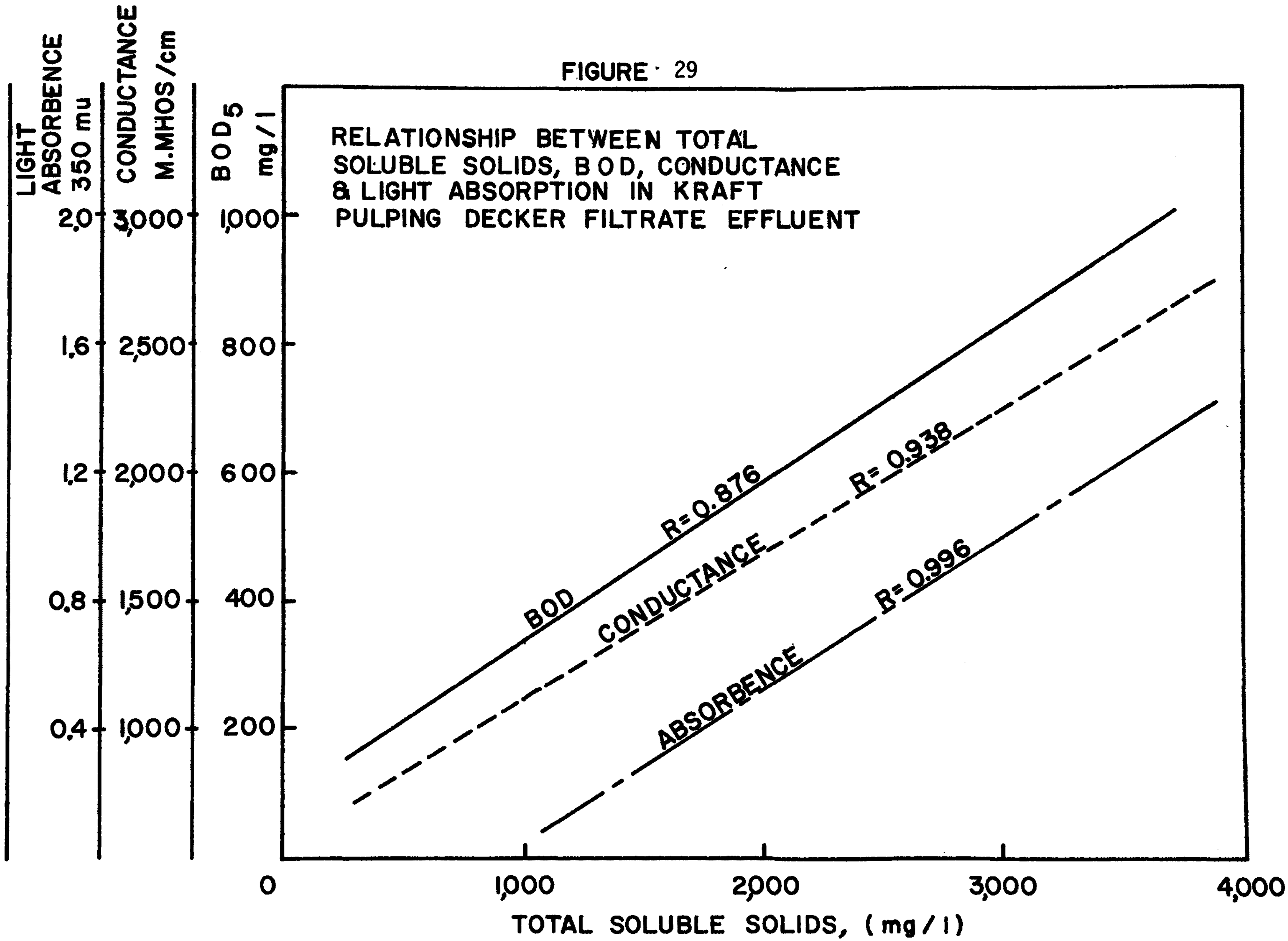
Effluent from the separation stage consists mainly of decker filtrate water which accounts for about one-third of the BOD_5 load from most alkaline pulp mills (314). Relationships between solids concentration of this wastewater and BOD_5, light absorbence, and conductivity were reported by South (213). These relationships are shown in Figure 29. It is obvious that the relationship of dissolved solids to the three other parameters of waste strength is linear and of very similar slope. From this it can be concluded that effluent strength as measured by these parameters is a direct function of pulp washing efficiency and that conductivity can be employed as an accurate monitoring index for the pulp washing operation. (See Page 187.) The magnitude of this relationship can be disturbed somewhat by loss of liquor to the vacuum system or to floor drains due to foaming on the washers.

Weak black liquor is concentrated to about 40 to 45 percent solids in long-tube multiple-effect evaporators and is then known as strong black liquor. In the case of fatty woods, tall oil soap is skimmed from the tanks holding this strong black liquor prior to oxidation (if this operation is practiced). The liquor is then concentrated further and



Continuous Pulp Digester at a Kraft Pulp Mill, Kamyr, Inc.

FIGURE 29


RELATIONSHIP BETWEEN TOTAL SOLUBLE SOLIDS, BOD, CONDUCTANCE & LIGHT ABSORPTION IN KRAFT PULPING DECKER FILTRATE EFFLUENT
LIGHT ABSORBENCE 350 mu
CONDUCTANCE M.MHOS/cm
BOD5 mg/l
2.0
1.6
1.2
0.8
0.4
3,000
2,500
2,000
1,500
1,000
1,000
800
600
400
200
0
1,000
2,000
3,000
4,000
TOTAL SOLUBLE SOLIDS, (mg/l)
BOD
R= 0.876
CONDUCTANCE
R= 0.938
ABSORBENCE
R= 0.996

the skimmings sold as soap or first acidified to produce tall oil itself. Spent acid from the latter procedure consists mainly of a solution of sodium sulfate and is returned to the recovery system as chemical make-up.

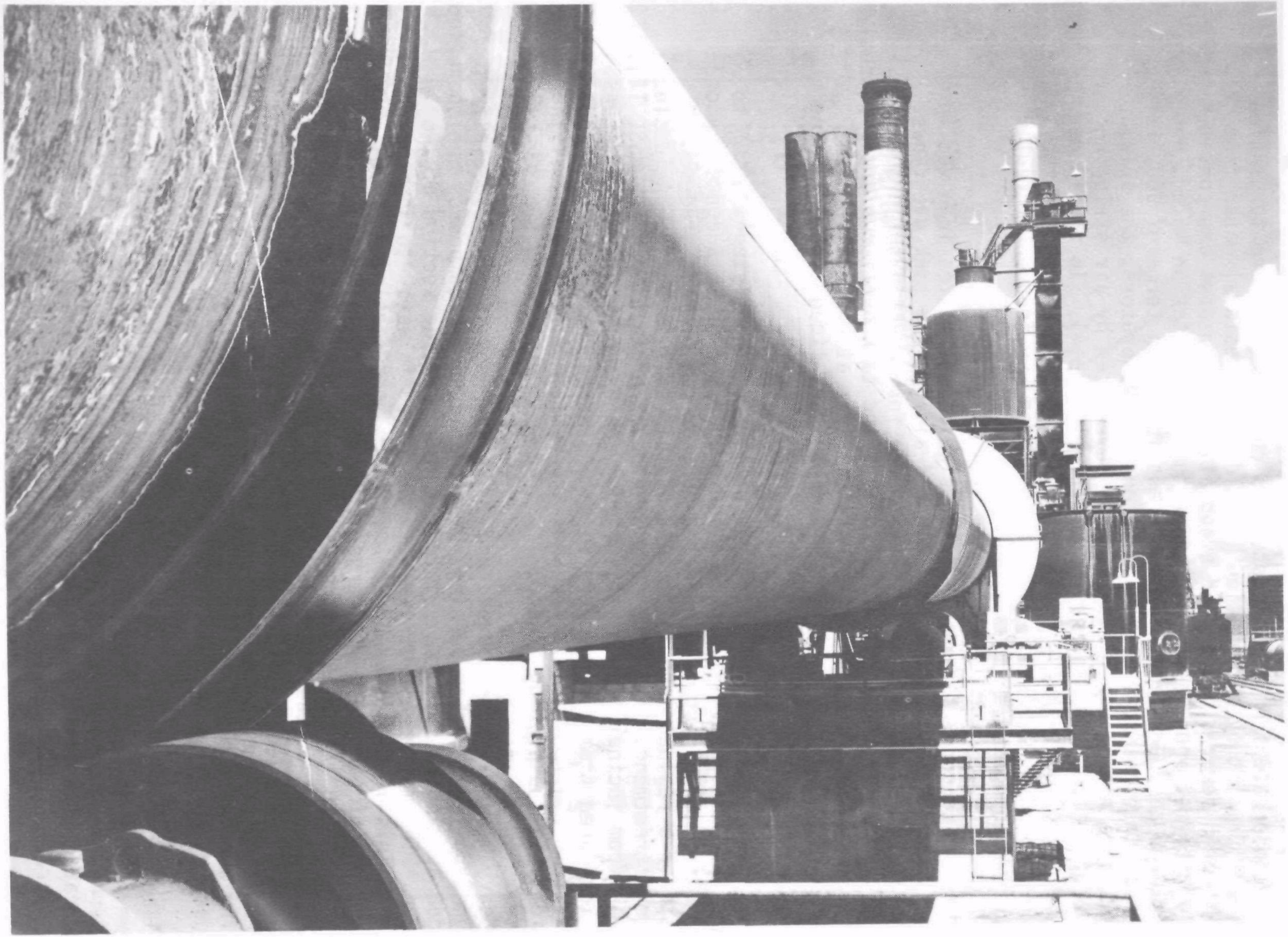
Relief condensate from the digesters is condensed and the turpentine recovered from it by decantation is sold. The residual water from this operation is sewered. Blow and evaporation condensates are contaminated mainly with methanol, and, together with the decantation water, normally account for another third of the process losses in terms of BOD_5 (214). When surface condensers are employed on the evaporators, the volume of this stream is low and its BOD_5 can be reduced by air stripping in a cooling tower (67) or by steam stripping (314). In the former case, methanol and other volatiles are lost to the air and in the latter case separated and burned. These condensates are frequently reused for pulp washing and in the caustic room.

In addition to condensates, the other significant wastes involved in the pulping operation are knots, floor drainage, and tank overflows. Knots are recooked, sold as a fiber source for coarse paper products, or disposed of on the land. Floor drains and tank overflows are frequently collected, stored, and fed back into the sewer at controlled rates so as to prevent slugs of strong waste or spent liquor from reaching the treatment system periodically.

Strong black liquor is concentrated further to a consistency of 65 to 70 percent in a recovery furnace stack evaporator or in a concentrator after which make-up chemicals in the form of new or recovered sodium sulfate or a residue high in content of this salt is added. Acid sludge from oil treatment, raffinate from by-product production, from NSSC liquor, and ash from incineration of this liquor are examples of such residues. Salts captured from the recovery furnace stack are also reintroduced into the system. Sulfur and caustic soda are sometimes used to adjust the sulfidity in the cooking liquor.

The heavy liquor is then burned and the heat recovered in a specially designed boiler. During burning, the organic sodium compounds are converted to soda ash and sulfates to sulfides in the reducing section of the furnace. The molten ash or smelt is dissolved in water to form green liquor. This is clarified by sedimentation, the settled residue washed free of salts and discharged to a land disposal area. The clarified green liquor is then causticized with lime to convert the soda ash present to caustic soda, after which treatment it is known as white liquor. This is settled and sometimes filtered through anthrafilt pressure filters, adjusted to the desired strength for cooking with weak black liquor, and stored for use in the pulping process.

The lime mud (calcium carbonate) obtained on settling this white liquor is washed and dewatered on rotary vaccuum filters or centrifuges and burned in rotary or fluidized kilns to form quick lime. This is hydrated with green liquor in slakers. The residual grits from this operation are washed and disposed of on the land with the dregs.



Lime Kiln at a Kraft Pulp Mill, Allis-Chalmers

The following equations described the chemical recovery process.

Reduction:

$$Na_2SO_4 + 2C \rightarrow Na_2S + CO_2$$

$$Na_2 + CO_2 \rightarrow Na_2CO_3$$

Causticizing:

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3\downarrow$$

Reburning:

$$CaCO_3 \rightarrow CaO + CO_2$$

Slaking:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Chemical recovery together with other minor losses constitutes the last third of the BOD_5 loss from kraft pulping. It should be noted that the designation of loss proportions presented here are those from modern mills operating at nominal production capacity. Operating abnormalities such as washer foaming or evaporation carry-over can seriously upset this balance.

Losses per ton of product from kraft pulping itself are difficult to determine because of the common practice of reusing water from integrated papermaking operations in the pulp mill. Such reuse is described by Haynes (26).

The best pulp mill loss evaluation can be obtained from linerboard operations in which kraft pulp is produced and the integrated papermaking involves a minimum of additives resulting in low paper mill losses. Data from fourteen mills indicate the following losses:

	BOD_5 #/Ton Prod.		Total Susp. Solids #/Ton Prod.
Max.	101	Max.	139
Min.	18	Min.	12
50	12	30	7
35	9	50	8
Avg.	41	Avg.	45

Since about five pounds of BOD can be attributed to the papermaking operation itself, these values are a bit lower for pulping alone. Figure 30 is the process flow diagram of a kraft pulp mill and recovery system. Figure 31 shows the recovery system alone.

FIGURE 30 KRAFT PULPING PROCESS DIAGRAM

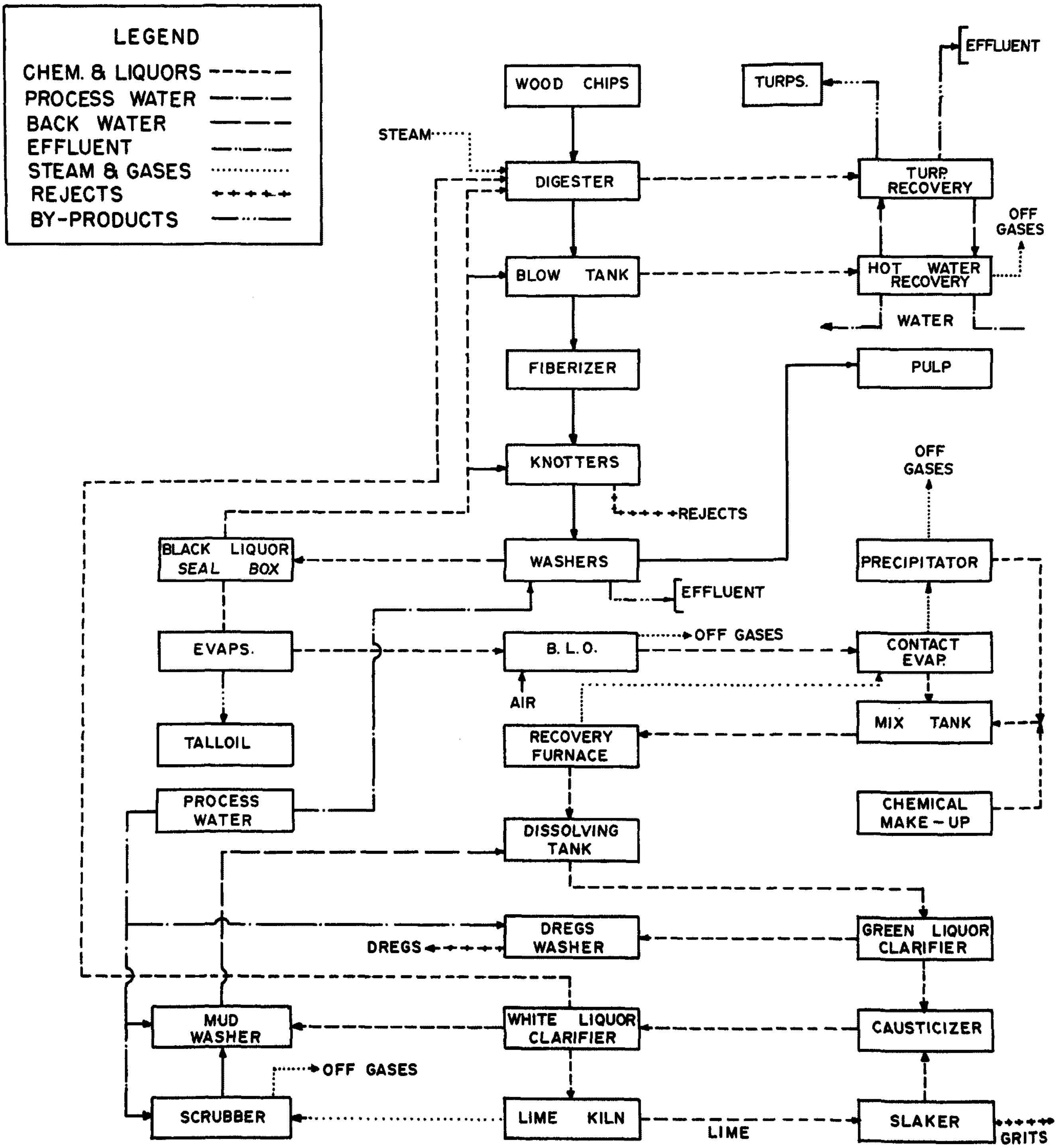
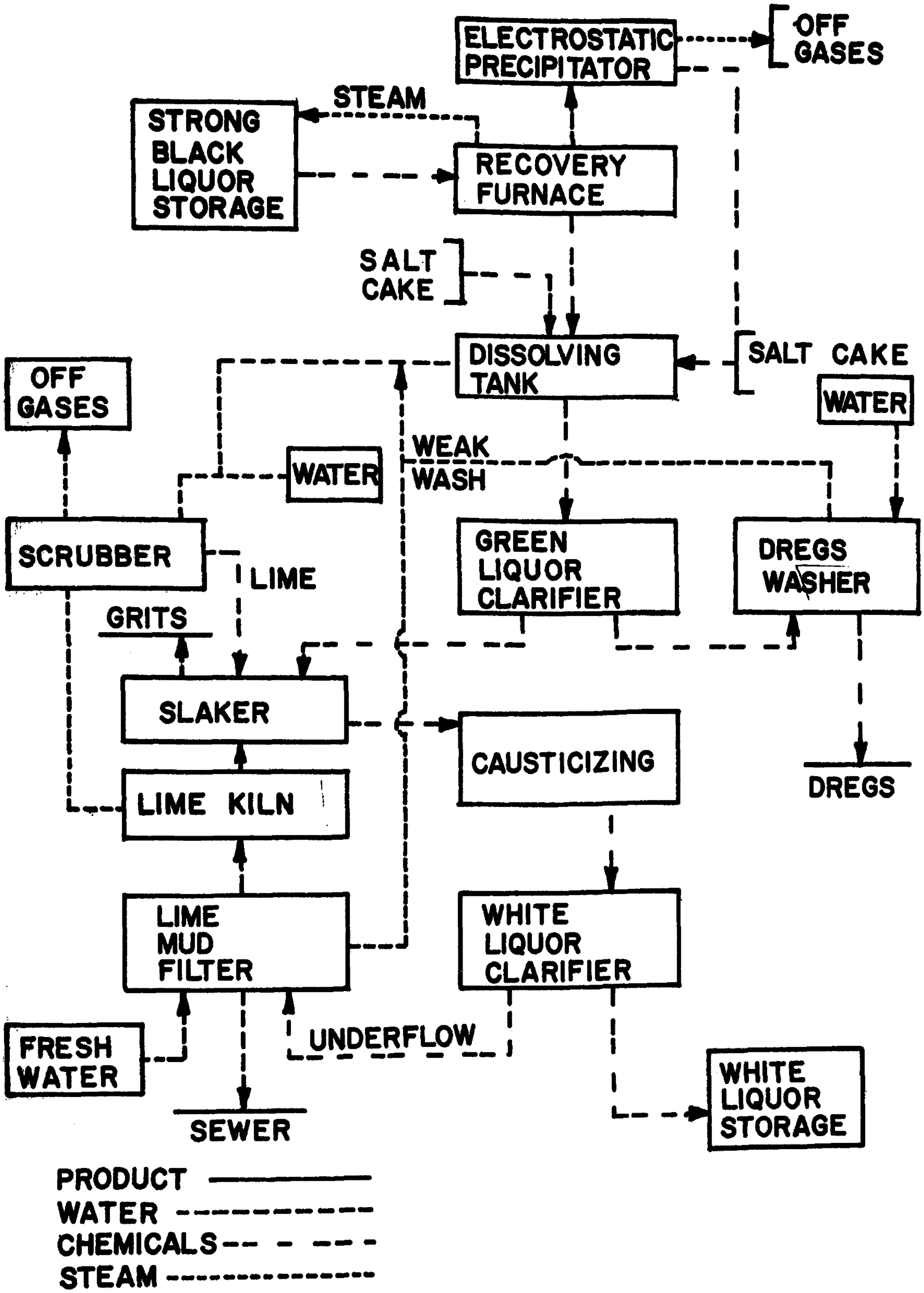


FIGURE 31

KRAFT RECOVERYSYSTEM
PROCESS FLOW DIAGRAM



Soda pulping is carried out in the same manner as kraft except that the wood is cooked with caustic soda alone which is recovered by dissolving and cauticizing the smelt from the recovery boiler. Only a minor quantity of this pulp is manufactured at three mills in this country. Effluent characteristics are also similar to those of kraft.

Combined kraft mill effluent generally ranges between 150 and 300 mg/l BOD_5 and contains a similar concentration of suspended solids together with 750 to 1500 mg/l of color. Total solids run normally from 1200 to 2070 mg/l; the inorganic portion consists mainly of sodium and calcium sulfates. The effluent under normal operating conditions is slightly alkaline and the COD ranges between 350 and 500 mg/l (188).

Treatment:

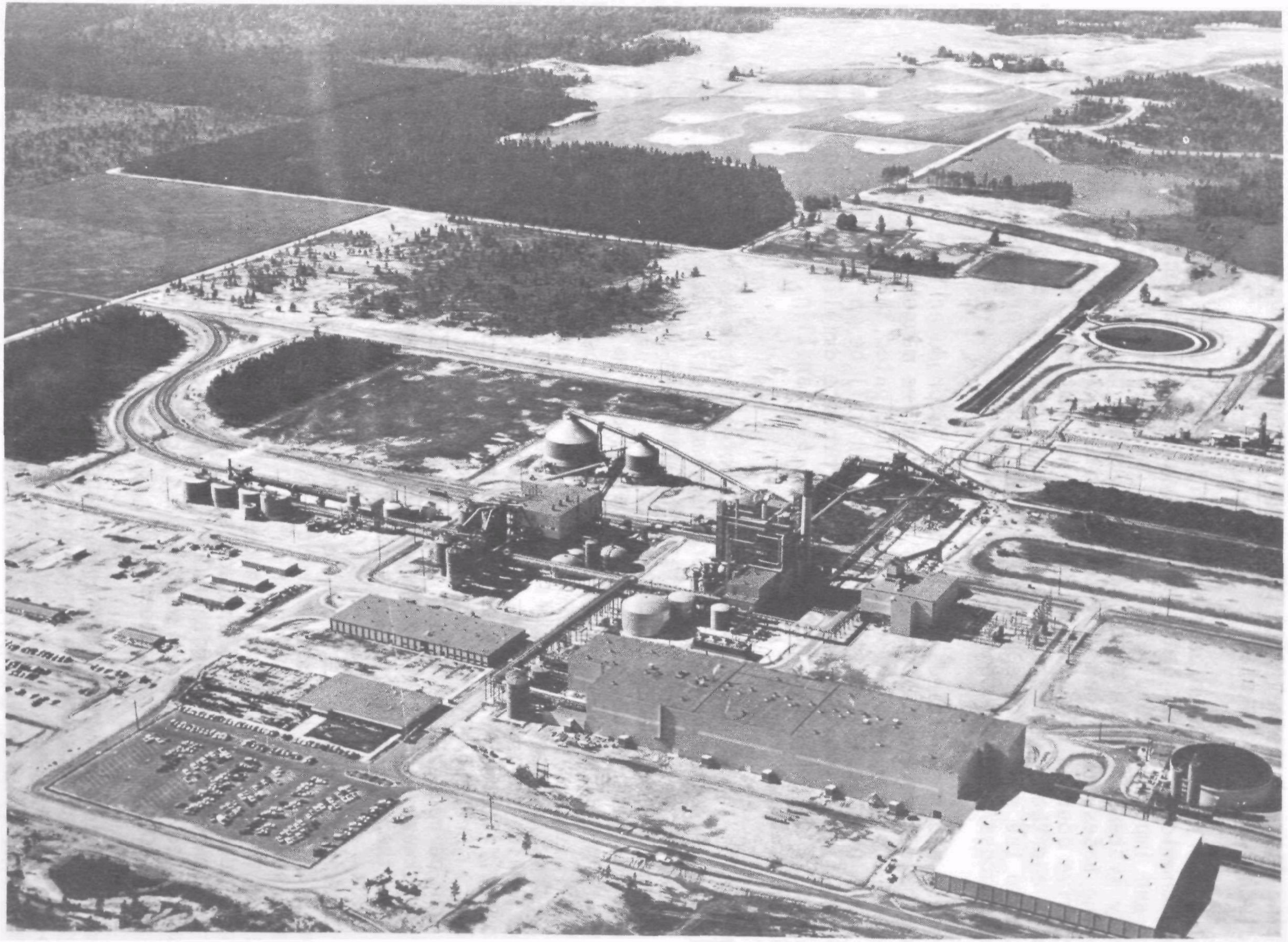
Most kraft pulp mills treat the total mill effluent by sedimentation in mechanically-cleaned clarifiers. This treatment removes from 80 to 85 percent of the total suspended solids yielding an effluent averaging around 25 mg/l of total suspended solids, the settleable solids removal exceeding 95 percent. Accompanying BOD_5 reduction ranges from 10 to 20 percent. This number is highly variable due to the constantly changing suspended solids and dissolved solids content of the raw waste. Settled effluents from linerboard operations normally range from 100 to 300 mg/l BOD_5 and average from 20 to 40 pounds of BOD_5 per ton of product.

BOD reduction in these effluents is commonly obtained by the use of holding lagoons or aerated stabilization basins. One soda mill is installing a plastic media trickling filter designed for high rate operations and one linerboard mill has a similar roughing filter ahead of aerated stabilization basins. The degree of BOD_5 reduction obtained depends upon the basin detention period. The period ranges, in the case of holding lagoons, from 2 to 12 months and, for aerated lagoons, from 5 to 12 days. Data from four mills employing holding lagoons indicate effluent BOD_5 values of from two to seven pounds per ton of product with a total suspended solids content of from 0.4 to 7 pounds. Ten aerated stabilization basins at linerboard mills produce effluent BOD_5 values of from 2 to 28 pounds per ton of product at a suspended solids content of from 1 to 20 pounds, the former depending upon the retention time and the temperature of the waste under treatment (117, 118).

One linerboard mill removes color, which ranges from 460 to 2120 units, with an average of about 750 units, from the wastewater. This is accomplished by lime precipitation (111) and reduction amounts to over 90 percent. This process is described in detail in the Advanced Waste Treatment section of this report.

Acid Sulfite Pulping

Acid sulfite mills in the United States have the capacity to produce in the neighborhood of 10,000 tons of pulp daily. Manufacture of this type of pulp has been declining because of the depletion in supply of



Integrated Kraft Pulp and Paper Mill and Effluent Treatment Facilities, Boise Cascade Corp.

suitable wood species, the age and small size of many of the mills producing it, and the severity of stream pollution problems arising from discharge of the wastes.

Since recovery of calcium base spent sulfite liquor is both difficult and uneconomical, it has been frequently discharged directly to the stream and imposed a very large load as compared to processes employing recovery systems for the spent liquor. As new processes have been developed employing bases other than calcium, sulfite mills have been confronted with alternative courses of action. Recovery was not practical for the small old mill and these are rapidly being dismantled. Larger mills have either shifted to the kraft process or have installed recovery systems, or are in the process of doing so.

At present about two-thirds of the tonnage is produced by mills employing soluble base recovery systems, half of which are magnesium base, one soda base, and the remainder ammonia. It is anticipated that within the next five years practically all the spent liquor will be burned (216). The remaining five to ten percent is used to produce drilling mud, additives, adhesives, and chemicals, such as ethanol and vanillin, as described by Pearl (217) and others (218).

The pollution load in terms of BOD_5 and total suspended solids of a number of calcium mills not burning liquor are compared in Table 24. Process losses vary widely with the species of wood cooked, the season in which it is cut, and the degree of cooking employed. The latter is determined by the pulp characteristics required. The yield from acid sulfite pulping is low, ranging from 35 to 45 percent.

In this process, cooking acid is made by reacting the base with sulfur dioxide, which is usually produced by burning sulfur. The finished acid is cooled, filtered, and adjusted to suitable strength for use in cooking the chips. Practically all the water leaving this step is cooling water which can be reused elsewhere. The remainder comes from floor drainage, filter backwash, and other equipment cleaning operations, and the impurities contained therein are largely inorganic in nature.

After cooking, the pulp is blown to a tank or blow pit and washed either in the pit itself or counter-currently on drum washers. In some calcium base mills where the spent liquor is utilized, countercurrent washing is practiced in the blow pit which necessitates the addition of weak and strong liquor storage tanks and accessory pumping equipment. Final wash water is sewered together with relief and blow condensates when the latter are collected. The combined weak wastes account for about one-third the total BOD_5 lost from the process (180).

Spent liquor, called red liquor, is evaporated in multiple-effect longtube evaporators and subsequently in a contact evaporator. Condensates from the evaporation step are high in acetic acid and account for over 50 percent of the BOD_5 of the combined mill discharge.

TABLE 24

EFFLUENT FLOW AND POLLUTION LOADS

FROM

CALCIUM BASE ACID SULFITE PULP MILLS

(Without Liquor Recovery)

Mill #	Eff. Flow Thous. Gal./Ton	BOD_5 #/Ton	T.S.S. #/Ton
1	79	465	12
2	67	620	87
3	66	1130	176
4	69	1150	86
5	87	1240	50
6	90	1003	46
7	61	1290	75

The liquor is burned for its fuel value in special furnaces and, in the case of magesium and sodium, the chemicals are recovered from the ash or smelt. Sulfur dioxide recovered from the off-gases is employed in liquor preparation.

The total effluent from acid sulfite pulp mills employing liquor separation and burning range from 1000 to 2000 mg/l in BOD_5 and from four to five times this value in COD. Disposition of the BOD_5 load within a modern ammonia base mill is shown in the table below:

	BOD_5 #/Ton Prod.
From Digester	700
Collected in Liquor	595
Burned in Boiler	475
Condensates	120
Uncollected Liquor	105
In sewer Effluent	220

These process effluents are acidic, running from pH two to three. The recovery of liquor solids can be anticipated to reach about 85 percent for soluble base operations, some exceeding this value where multistage vacuum pulp washing is employed. Typical losses from soluble base mills employing recovery are presented in Table 25. Figure 32 is a process flow diagram of calcium base acid sulfite pulping and Figure 33 illustrates the magnesium base recovery process.

TABLE 25

EFFLUENT FLOW AND POLLUTION LOADS FROM SOLUBLE BASE ACID SULFITE PULP MILLS

(With Liquor Recovery)

Mill #	Eff. Flow Thous. Gal/Ton	BOD_5 #/Ton	T.S.S. #/Ton
1	70	195	20
2	65	225	32
3	59	237	51
4	80	287	49

The solubles contained in sulfite pulp mill effluent consist of organics and inorganics, the former group containing both biodegradable and refractory substances. Examples of the degradable type are wood sugars, fatty acids, alcohols, and ketones and of the refractory, lignins and tannins. Tyler and Gunter (219) give the following table of constitutents of spent sulfite liquor:

	gm/l
Formic Acid	0.63
Acetic Acid	4.68
Methanol	1.26
Ethanol	0.17
Acetone	0.13
Furfural	0.29
Pentose	2.55
Hexose	17.50
Lignin	61.50
Miscellaneous	29.30

FIGURE 32

ACID SULFITE PULPING PROCESS DIAGRAM (CALCIUM OR AMMONIA BASE)

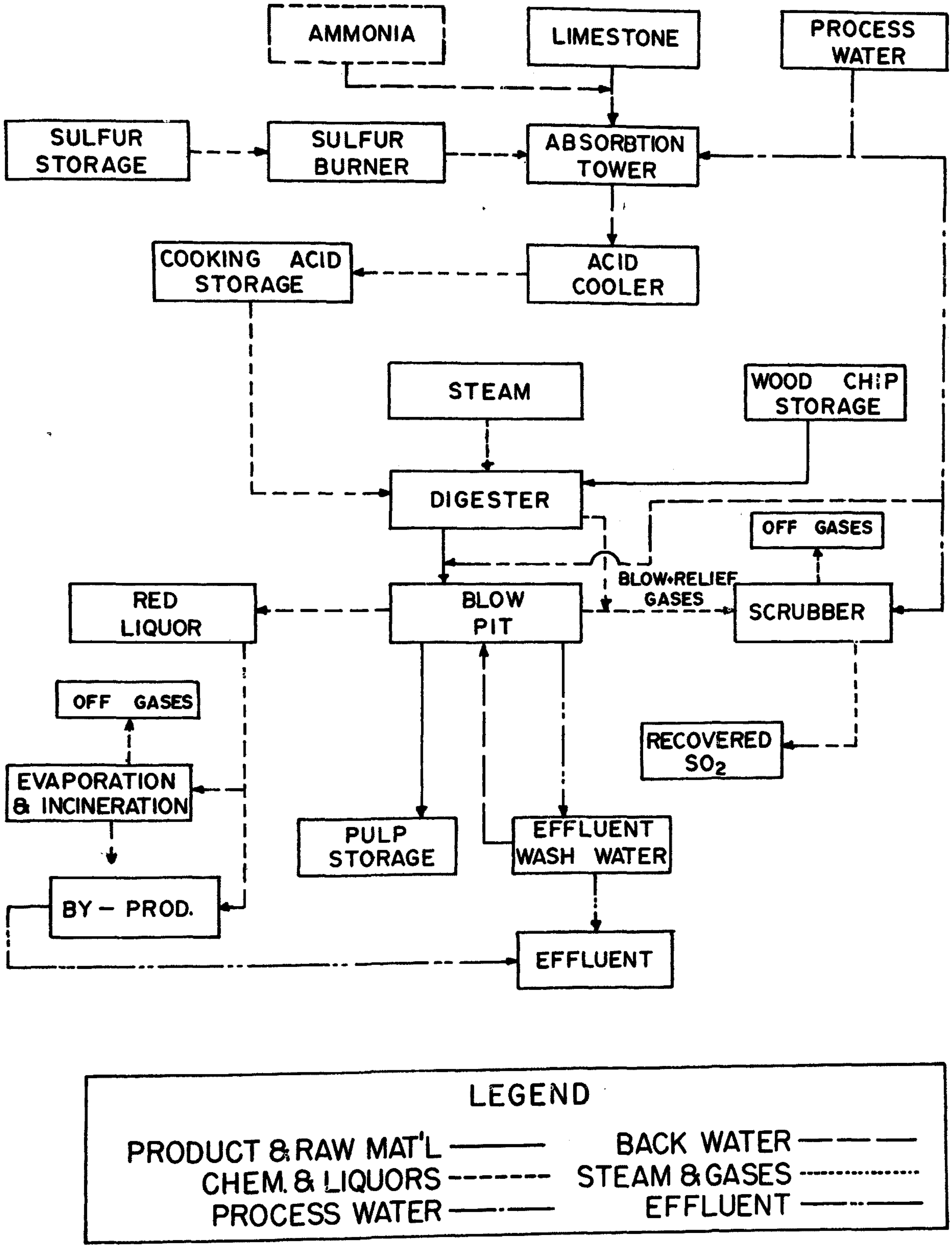
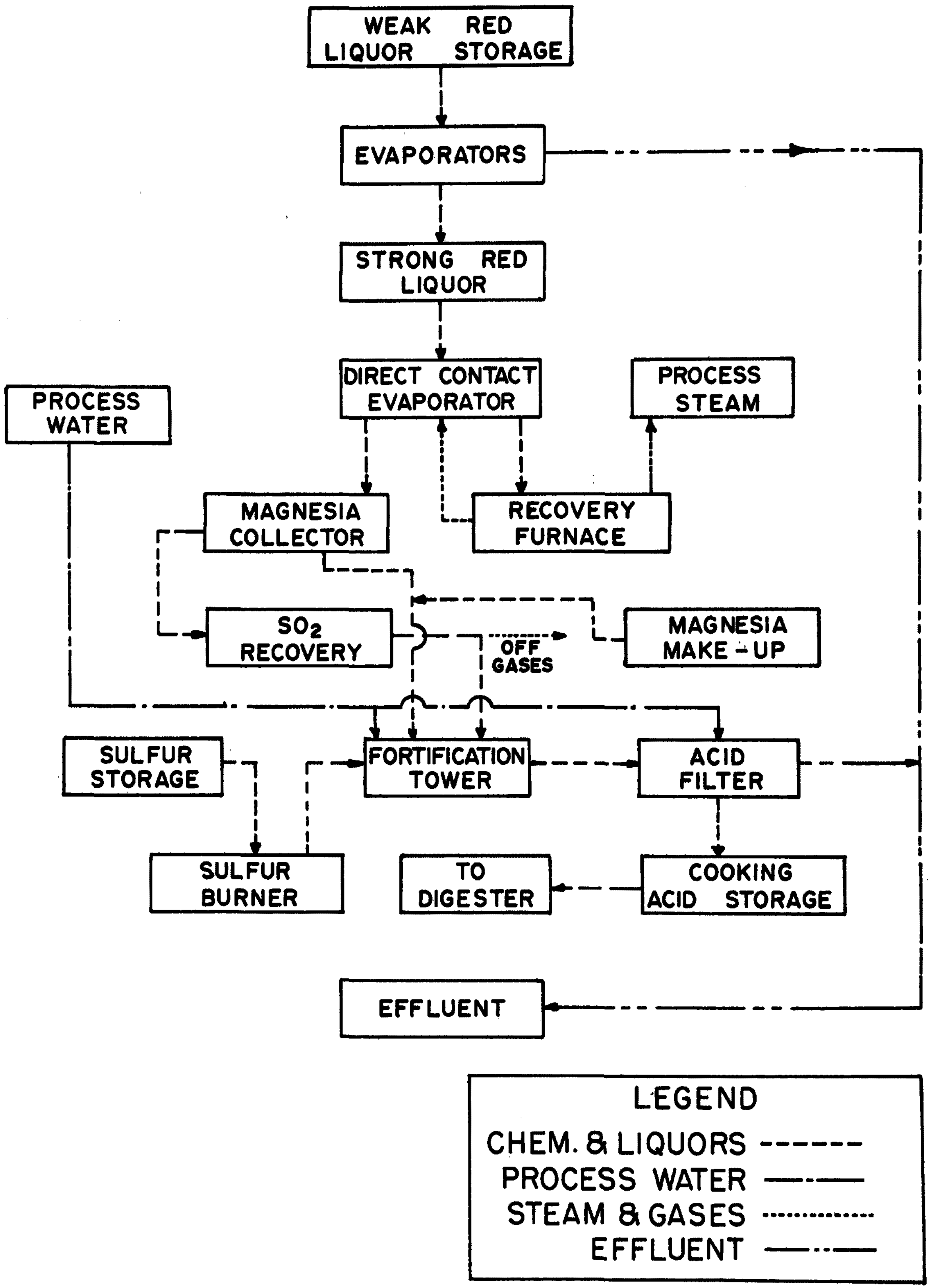


FIGURE 33

MAGNESIUM BASE SULFITE RECOVERY SYSTEM PROCESS DIAGRAM



Lawrance and Fukui (28) studied the decomposition of calcium lignosulfonate establishing its biorefractory nature in the presence of actively decomposing carbohydrates.

Treatment:

Fifteen acid sulfite mills, representing about half the total United States tonnage, now provide treatment to remove suspended solids from their effluents. These systems handle bleaching and paper mill effluents as well since these wastes are combined before treatment. Three mills provide biological treatment (152, 97, 220, 221); two of which are ammonia base mills. The third, a magnesium base, treats a mixture of bleaching wastes and condensates alone. One of the ammonia base mills uses the activated sludge process (152) and the second aerated stabilization basins (221). The magnesium base mill provides extended aeration treatment (97) with seed sludge return. Results obtained with the ammonia base effluents are presented in Table 26. These indicate BOD_5 reductions in excess of 80 percent with the volatile suspended solids content in the effluent in the order of 30 mg/l.

TABLE 26

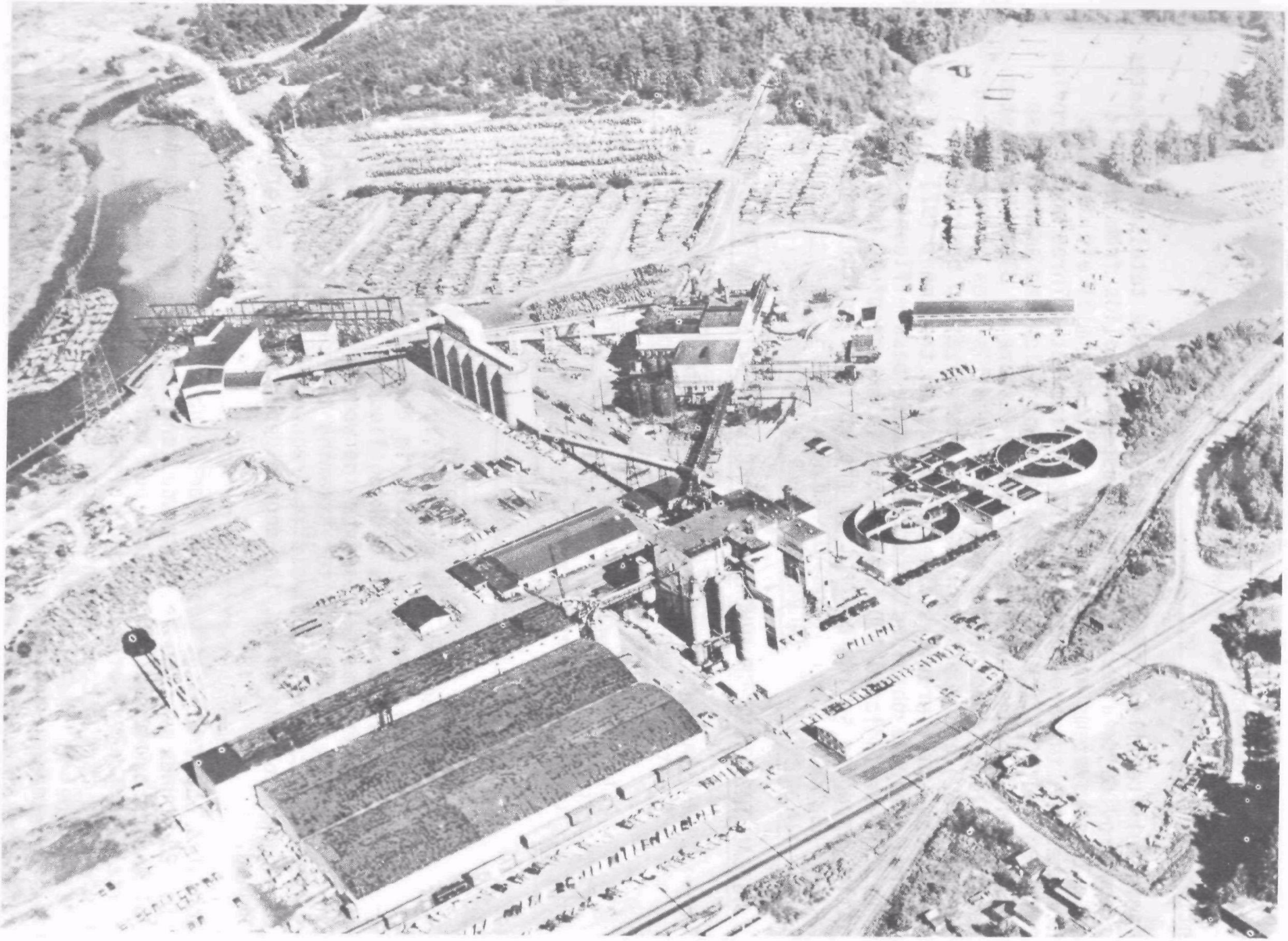
BIOLOGICAL TREATMENT OF AMMONIA BASE ACID SULFITE PULP MILL EFFLUENTS

Mill #	Type Treatment	Effluent Volume MGD	BOD_5 #/Ton Inf.	BOD_5 #/Ton Eff.	TSS #/Ton Eff.
1	Activated Sludge	2.5	235	35	30
2	Aerated Lagoon	4.0	160	28	21 (Volatile)

Pre-hydrolysis

In order to obtain a bleaching pulp more easily from the chemical pulping processes, the chips are sometimes steamed in the digester for a short period prior to the addition of the cooking liquor (198, 185). This serves to remove readily soluble materials from the wood which have a detrimental effect on the cooking process. After steaming the chips the digester is relieved and drained. Pre-hydrolysis is frequently practiced in the manufacture of dissolving pulps, the degree depending upon the grade of pulp produced.

The condensates and drainings contain wood solubles with a BOD_5 value of from 60 to 120 pounds per ton for softwoods and 180 to 200 for hardwoods and amount to approximately 300 gallons per ton in volume (222). They contain little in the way of suspended solids. Frequently this procedure is coupled with a "soft" cook which reduces bleachery losses since more organic matter goes to the recovery furnace with the spent cooking liquor. In some instances the pre-hydrolysate is added to the weak black liquor as a means of disposal. Because of the low solids content of the hydrolysate, this is a relatively high cost practice and requires that higher than normal evaporator capacity be provided.



Magnesium Base Sulfite Pulp Mill with Effluent Treatment Plant, Weyerhaeuser Company

Kraft and Sulfite Pulp Bleaching

The most important bleaching operations from the effluent standpoint are those applied to kraft and sulfite pulps (201, 185). This is because a considerable amount of organic material, both oxidizable and refractory, is removed from the pulp in the process and a substantial quantity of inorganic matter is discharged because of the addition of bleaching reagents. These are most commonly chlorine, chlorine dioxide, and calcium or sodium hypochlorite. Because of the dilute nature of these wastes and their chloride content they cannot be introduced into the recovery systems. Ordinarily no control of bleach plant losses can be exercised other than external treatment. An exception is that a C-H-H-D sequence is used by a few mills for reducing color of this effluent. Not only is this process more costly than the usual bleaching sequence, but its use is limited because of the low-strength pulp produced. Suspended solids content is generally low with the exception of effluents produced on high-degree bleaching of hardwood pulps. Concentration of the wastes is a function of water use and reuse in the bleachery. It is becoming common practice to recycle the latter-stage wash waters to the rigorous initial stages which are chlorination and caustic extractions.

Sulfite pulps are more readily bleached than kraft and the effluent is much lower in both BOD and color. However, the degree of bleaching of all pulps affects the pollution load generated. Since treatment of pulp to produce alpha cellulose involves the most extensive bleaching procedures, the very high losses incurred in producing these pulps are reflected in the effluent values. Shrinkage in pulp weight in the production of these grades is in the order of 25 percent as compared to around five percent for other paper-making grades and sewer losses are correspondingly high. This is particularly the case for the oxygen demand values since considerable hydrolysis of cellulosic material takes place when shrinkage is high.

While there can be many process steps in a bleach plant, the important ones from an effluent standpoint are the chlorination and alkaline extraction stages (40). The finishing steps such as those involving hypochlorite and chlorine dioxide usually produce a wash water that can be recycled to the chlorination and extraction stages, but if discharged make up a minor part of the BOD and color load. This is particularly true of chlorine dioxide stages with regard to color since this chemical either bleaches out or produces materials lower in color than do other bleaching chemicals. A process diagram of a four-stage bleachery employing recycle of the finishing stage wash waters is depicted in Figure 34.

Effluent volume, pH, color, BOD_5, and suspended solids ranges for kraft and sulfite pulping are presented in Table 27. Chloride losses can be computed from the quantity of chlorine and related compounds added and the chloride content of the raw water.

These wastes are commonly treated together with pulping and papermaking effluents for the reduction of suspended solids and BOD and their response to such treatment is satisfactory. Neutralization of the acid stage effluent is sometimes necessary. This is accomplished with caustic soda, calcium hydrate, or carbonate obtained from the chemical recovery system of the mill in the case of kraft pulping operations.

FIGURE 34 FOUR STAGE PULP BLEACHERY PROCESS DIAGRAM

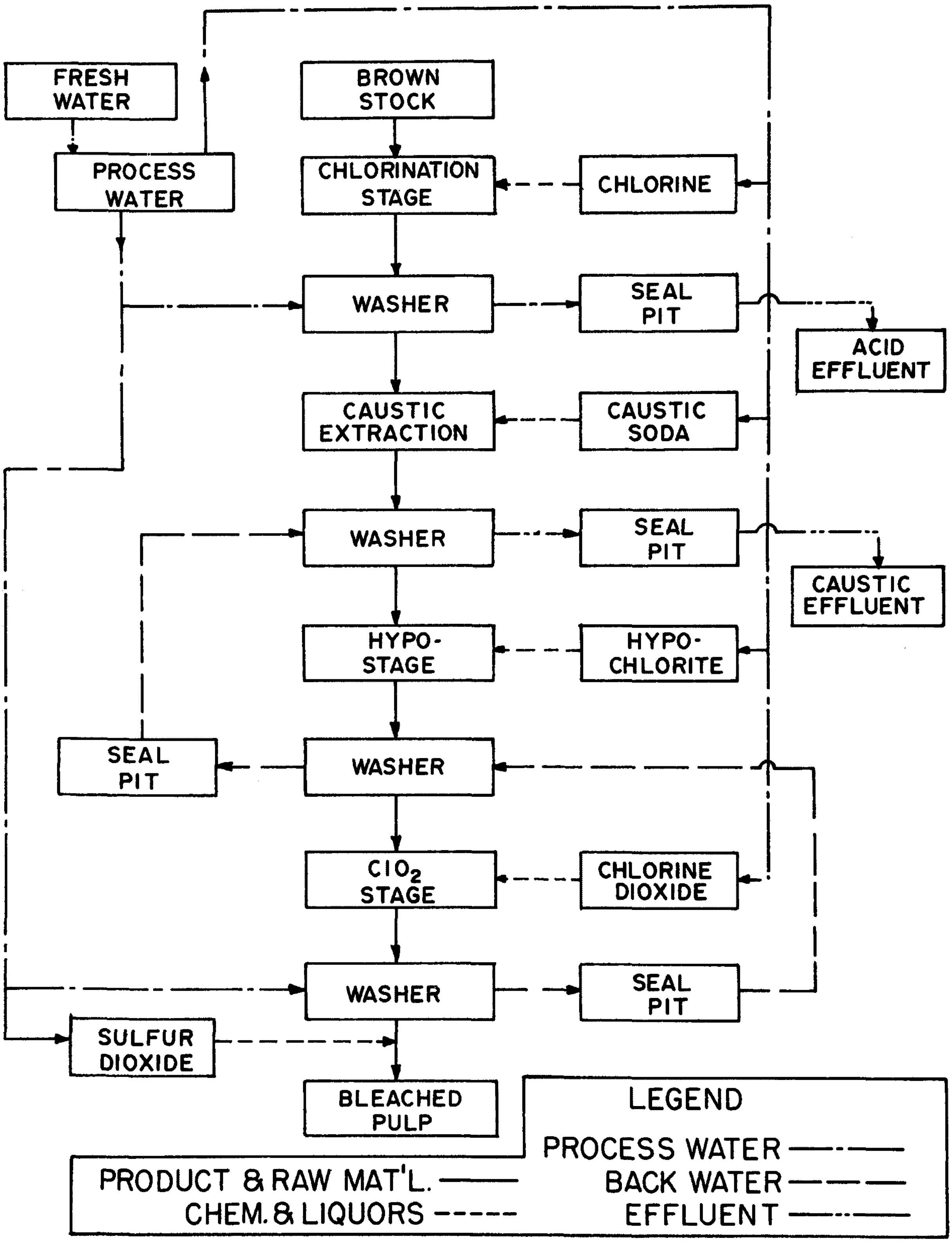


TABLE 27

VOLUME AND CHARACTERISTICS OF KRAFT AND SULFITE BLEACHERY WASTES

Kraft Bleaching	Effluent Volume 1000 gal/Ton Prod.	BOD #/Ton Prod.	Total Susp. Solids #/Ton Prod.	Color mg/l	pH Range
Semi-Bleaching	18-25	30-35	15-20	2500-3000	4-5
High-Bleaching	25-35	40-60	20-30	4000-6000	3-4
Dissolving Pulp (Soft Wood)	50-60	120-150	130-150	> 5000	2-3
Dissolving Pulp (Hard Wood)	55-70	500-700	190-200	> 5000	2-3
Sulfite Bleaching					
Paper Grades	15-20	10-18	8-10	1000-2000	2-3
Dissolving Pulp	45-60	200-450	100-200	> 3000	1-3

Chemicals Used in Cooking Wood and Bleaching Chemical Pulp

Sulfite and Bisulfite Pulping:

Sulfite and bisulfite pulping liquors are prepared by contacting sulfur dioxide--produced by burning sulfur or delivered to the mill in tank cars in liquified form--with a base such as calcium or magnesium oxide, ammonia, sodium carbonate, bicarbonate, or hydroxide (223). In the case of sulfite liquors, the amount of base used is insufficient to neutralize the quantity of sulfur dioxide introduced into the absorption system so that an excess of sulfur dioxide remains in the cooking liquor. The following table gives the range of ratios of free-to-combined sulfur dioxide present in sulfite liquors of the four common bases and the quantities of chemical required:

	Free-to-Combined Sulfur Dioxide	# Chemical per Ton AD pulp	
		Sulfur	Base
Calcium	5 to 1	200-300	260-370 as CaO
Ammonium	3 to 5	120-170	100-175 as NH_3
Magnesium	1 to 4	175-250	180-270 as MgO
Sodium	1.2 to 7	140-200	170-250 as Na_2O

In the case of bisulfite liquors, all the sulfur dioxide is reacted to form the salt and the cooking liquor consists of the bisulfite of the base rather than a mixture of this with sulfurous acid.

The reactions involved are as follows:

$$CaO + 2\ H_2SO_3 \rightarrow Ca(HSO_3)_2 + H_2O$$

$$MgO + 2\ H_2SO_3 \rightarrow Mg(HSO_3)_2 + H_2O$$

$$NH_3 + H_2SO_3 \rightarrow NH_4HSO_3$$

$$Na_2CO_3 + 2\ H_2SO_3 \rightarrow 2\ NaHSO_3 + H_2CO_3$$

$$NaOH + H_2SO_3 \rightarrow NaHSO_3 + H_2O$$

$$NaHCO_3 + H_2SO_3 \rightarrow NaHSO_3 + H_2CO_3$$

Neutral sulfite semi-chemical liquors are prepared in the same manner as sulfite liquors (204, 205). Sodium carbonate or bicarbonate is the usual base although ammonia has been used. The quantity of chemical varies widely depending upon the quality of product required and affects the pulp yield inversely. Yield ranges from 70 to 85 percent on the oven-dried wood basis and from 300 to 500 pounds of chemical is used per ton of AD pulp. In general, the base is completely neutralized but in some cases a small excess of alkali is carried in the cooking liquor. This amounts to 60 to 110 pounds of sodium and 180 to 380 pounds of sulfur per ton of air-dried pulp.

Calcium base acid is produced by passing pre-cooled gas through a bed of crushed limestone contained in an absorption tower. Liquor strength is controlled by the flow of water into the tower and sulfur dioxide through it. Overflow from the tower is cooled and adjusted to the desired strength for cooking. In another system, milk of lime is used to absorb the gas as it passes upward through a bubble-cap absorption-type tower. A similar system is employed for preparing magnesium base liquor. The MgO used is initially in the form of a dry powder, most of it coming from the chemical recovery system. It is slurried and passed to the absorption towers. The liquor is sometimes fortified with process off-gases.

Because of the high solubility of ammonia and sodium salts and their rapid reaction rate with sulfur dioxide, liquors having these bases are readily prepared. In the case of ammonia, it is received either as the hydroxide or anhydrous form in tankers. In the latter case, it is dissolved on delivery to the absorption towers. Sodium salts are in the form of dissolved smelt from mill recovery systems or a caustic soda solution delivered in tankers. Sodium carbonate and bicarbonate are delivered dry and must be dissolved for use.

Kraft Pulping:

The chemicals used in the kraft pulping system are essentially caustic soda and sodium sulfide (211). These chemicals are continuously reconstituted, their losses restored, and recycled through the pulping process. The make-up chemicals employed are sodium sulfate, caustic soda, calcium carbonate, and, in some cases, elemental sulfur, these being converted to the desirable end-products within the system. For example, the lime kiln converts the make-up calcium carbonate to calcium oxide used to convert sodium carbonate to hydroxide in the causticizing system. Sodium sulfite is reduced to sulfide in the recovery furnace and sulfur reacts with caustic soda to form the same compound. Table 28 shows the typical chemical content of the various streams involved in terms of the major constituents.

The analysis of cooking liquor commonly employed for pulping pine is presented in Table 29.

TABLE 28

CHEMICAL COMPOSITION AT VARIOUS POINTS IN CAUSTICIZING

Chemical content, lb/AD ton of pulp

Description	CaO	$CaCO_3$	Inert	CO_2	Total Na_2O	The following as Na_2O				Volume ft^3
						NaOH	Na_2S	Na_2CO_3	Na_2SO_4	
Green liquor from smelt-dissolving tank			2		944	97	211	629	7	114
Clarified green liquor					919	94	206	612	7	111
White liquor and mud		746	46		924	565	208	144	7	111
Clarified white liquor to digesters					758	463	170	119	6	91
Lime to slaker	418		46		5	3	2	Tr.	Tr.	Solids
Mud		746	46		166	102	38	25	1	20
Weak wash					185	100	43	41	Tr.	105
Washed mud		746	46		10	8	2	Tr.	Tr.	15
Thick mud to kiln		746	46		5	5	Tr.	Tr.	Tr.	8
Wash water										9
Wash water										44
Filtrate					5	3	2	Tr.	Tr.	16
Dregs from green-liquor clarifier			2		25	3	5	17	Tr.	3
Wash water										29
Dregs to waste			2		1	Tr.	Tr.	1	Tr.	2
Recovered soda					24	3	5	16	Tr.	40
Reburned lime	418		46		5	5	Tr.	Tr.	Tr.	Solids
Lime kiln stack gas				304						Vapor

TABLE 29

SOUTHERN PINE KRAFT LIQUOR

Consistency of stock, %	8.03
Liquor solids, %	22.9
Liquor Baumé at 60°, °Bé	16.6
pH of liquor	11.6
Na_2S, as Na_2O, g/liter	3.87
NaOH, as Na_2O, g/liter	5.26
Na_2CO_3, as Na_2O, g/liter	32.66
Na_2SO_4, as Na_2O, g/liter	0.88
NaCl, g/liter	0.17
Na_2SO_3, as Na_2O, g/liter	0.00
$Na_2S_2O_3$, as Na_2O, g/liter	5.42
Total titratable alkali, g/liter	41.79
Active alkali, g/liter	9.13
Total sodium, spectro, g/liter	68.73
Total sulphur, $HClO_4$ oxidation, g/liter	11.42

Miscellaneous Pulps:

In cooking rags, from 25 to 50 pounds of sodium hydroxide per ton of rags is employed and discharged with the cooking liquor as carbonate, bicarbonate, or combined with organic matter (175). Cold soda pulping employs from 20 to 100 pounds of sodium per ton of oven-dried wood. Chemi-groundwood employs a treating liquor containing 60 to 180 pounds of Na_2O with a sodium sulfite to sodium carbonate ratio of from 6:1 to 3:1 (223).

Straw and other grass and agricultural residue pulps are cooked with either caustic soda, sodium sulfite, or mixtures thereof. A range in sodium quantity employed in cooking these pulps is generally from 120 to 150 pounds per ton of air-dried raw material.

Bleaching:

The chemicals commonly used in bleaching chemical pulps are chlorine, caustic soda, calcium and sodium hypochlorites, chlorine dioxide, calcium hydroxide, and peroxide (201). The first bleaching stage is almost invariably chlorination which normally employs from 40 to 110 pounds of chlorine per ton of air-dried sulfite and kraft pulps (201). The gas is delivered directly to the chlorination towers from tank cars. Evaporators and regulating equipment are installed in the gas lines. A few mills produce their own chlorine in electrolytic cells.

Chlorination is generally followed by an alkaline extraction stage in which sodium hydroxide or calcium hydroxide are employed to dissolve out reaction products formed in the chlorination step. The quantity of alkali used depends upon the wood source, the type of chemical pulp and how it was cooked, and upon the degree of chlorination in the first bleaching stage. The range of caustic soda dosage in relation to the alpha cellulose content of the bleached chemical pulps is presented in Table 30.

TABLE 30

RANGE OF CAUSTIC SODA DOSAGE IN RELATION TO THE ALPHA CELLULOSE CONTENT OF THE BLEACHED CHEMICAL PULPS

% Alpha Cellulose in Bleached Pulp	Pounds of NaOH per Ton AD Pulp Treated
89	10 to 40
92	50 to 120
96	150 to 300

Caustic soda is delivered in liquid form in tank cars or trucks, stored, and diluted for use in the mills.

Calcium hydroxide is occasionally used for semi-bleached pulp, its effectiveness and application being limited by its low solubility. The quantity of CaO applied in this process amounts to 75 to 100 pounds per ton of air-dried pulp. In kraft mills, the lime used is obtained from the chemical recovery process.

Hypochlorites of sodium and calcium are very commonly used in the finishing stages of bleaching. An equivalent of five to six pounds of chlorine is used for the intermediate stages and two to four pounds for finishing stages. Sulfamic acid (NH_2SO_3H) amounting to two to six percent of the active chlorine dosage is sometimes used to accelerate the process. The chemical applied frequently contains residual alkali over that required to react with the chlorine for pH control purposes.

Sodium and calcium hypochlorites are frequently prepared at the mills by reacting a solution or suspension of the base with gaseous chlorine in reaction towers to process specifications, stored, and diluted for use.

Chlorine dioxide (ClO_2) has come into common use in recent years as a bleaching agent because of its specific reaction with lignins and lack of adverse reaction with cellulosic materials. It is generally substituted for one or more of the hypochlorite stages and between 0.3 and 1.2 percent chlorine dioxide is employed per stage. This amounts to 6 to 12 pounds of ClO_2 per ton of air-dried pulps of the usual types. Its use is indispensable for the production of dissolving grade pulps from kraft pulp.

This chemical is ordinarily produced at the mills because of its explosive properties when compressed or liquified. The production units deliver a 10 g/l solution for storage and use. This high dilution of the gas is due to its low solubility in water. It is manufactured by several processes, all of which produce wastes (consisting largely of sulfuric acid and sodium sulfate) which demand effluent utilization processes. Fortunately, these chemicals can be used as make-up in the kraft process. These and their disposition are described in a bulletin on the subject (335).

Hydrogen peroxide is sometimes used in one of the latter stages in bleaching kraft pulp. The quantity employed is small, ranging from two to five pounds per ton of air-dried pulp (223).

Caustic soda, sodium silicate, and magnesium sulfate are sometimes used in the preparation of a peroxide bleaching reagent to control pH value and the reaction rate. A typical reagent dosage per ton of air-dried pulp would contain three pounds of hydrogen peroxide, six pounds of caustic soda, 20 to 40 pounds of sodium silicate, and 0.2 pounds of magnesium sulfate.

Acidification is sometimes practiced after the last bleaching stage and most bleach plants are equipped to accomplish this (223, 201). The purpose is to remove traces of metal ions such as calcium, magnesium, iron, copper, and manganese originating in the wood or water or dissolved from the equipment. Sulfurous, sulfuric, or hydrochloric acid is used but sulfurous is preferred because of its reducing properties and volatility which mitigates against overdosing. Five to ten pounds of sulfur dioxide on the air-dried pulp basis is commonly sufficient to accomplish the desired purposes.

Sulfur dioxide in sulfite mills is drawn from the pulp cooking liquor preparation system and in kraft mills is supplied from tank cars of the liquified gas. At some mills the gas is used in this form to supply the chlorine dioxide manufacturing plant.

Additional sources of the data presented in this section are contained in references (336, 198, 200, 233) from which further details regarding cooking and bleaching liquor preparation can be obtained. These also contain detailed process flow diagrams for the various steps in the kraft, sulfite, and bisulfite chemical recovery processes.

Deinking Pulp

Waste papers are deinked for recovery of their fiber content primarily at ten large mills in the United States. Seven of these deink magazine, ledger, and other various grades of raw stocks and three mills deink newsprint only. A large number of small mills deink a variety of waste papers on a small scale and frequently on an intermittent basis. Some board and tissue mills do likewise, either to provide liner fiber or supplement virgin pulp in the furnish. Some mills also reclaim pulp from trimmings, broke, and other unused waste papers derived from the manufacturing process itself (223).

The deinking process involves cooking the papers in an alkaline solution. Soda ash, caustic soda, sodium silicate, and, at times sodium peroxide, are used. Some employ dispersing agents as well (224, 225, 226). The chemicals saponify the ink vehicles and solubilize coating adhesives allowing the ink, coatings, and fillers to be subsequently washed from the pulp. In the case of newsprint, which consists only of fiber and ink, a detergent is used to separate the ink so that it can be washed out (227).

Washing is accomplished on Lancaster washers, in beaters, and in the case of some small operations, on side-hill screens. With some magazine stocks as much as 40 percent of the bale weight of the paper is lost to the sewer in the washing operation (228).

After washing, the recovered pulp is generally given a light bleach with a hypochlorite or peroxide. The pulp is washed again after bleaching on drum washers in large mills, but small ones usually wash in the beaters. Losses from bleaching are very small as compared to cooking and washing losses. Since the effluent from bleaching is generally employed for pulp washing it is included in the sewer loss from the entire washing operation.

Since the range of losses from the deinking of magazine and ledger type stocks is so wide and newsprint so constant, separate figures are presented for each in Table 31. The ash content of the suspended matter contained in the former is generally high and in the latter low.

The suspended solids concentration of deinking wastes from magazine and ledger stocks runs from 1000 to 3100 mg/l of suspended solids and the BOD_5 in the order of 300 to 500 mg/l. Combustibles present in the suspended solids range from 28 to 61 percent and in the total solids from 1900 to as high as 10,800 (224). Losses in terms of pounds per ton of product is shown in Table 31.

Figure 35 shows a deinking of waste paper process flow diagram for a modern large operation.

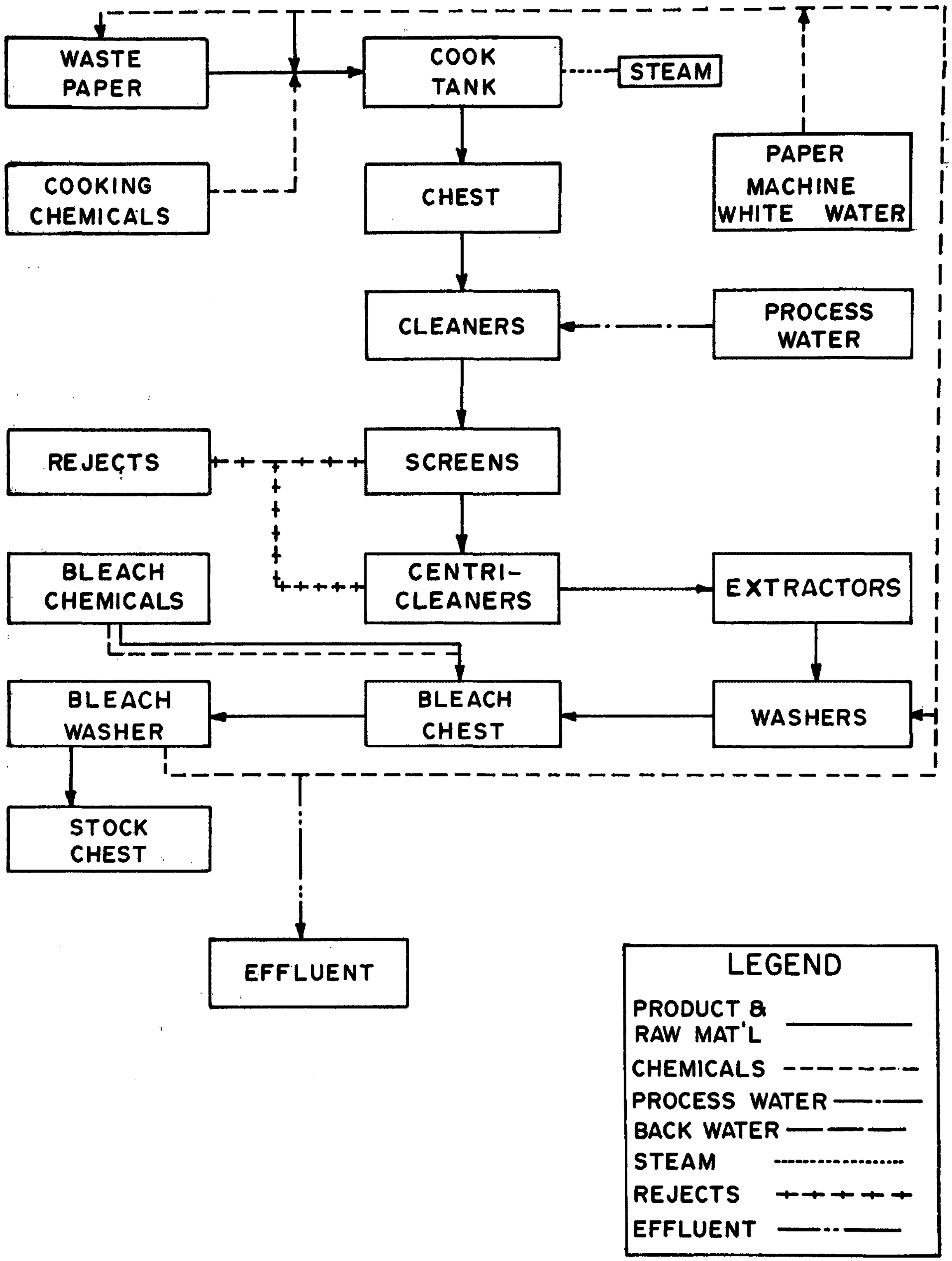
TABLE 31

DEINKING MILL EFFLUENT CHARACTERISTICS

MILL #	EFFLUENT VOL. THOUS. GAL/TON*	BOD_5 #/TON	T.S.S. #/TON
Magazine & Ledger Stock			
1	30.7	80	508
2	29.2	41	59
3	65.0	40	237
4	31.3	75	171
5	48.7	44	294
6	42.2	64	366
7	43.3	91	301
8	58.7	114	355
9	54.0	83	152
10	14.7	97	139
11	30.0	101	740
Newsprint			
1	9.7	101	233

*Includes paper mill white water with which it is combined in mill partially through recycle.

FIGURE 35
DEINKING WASTE PAPER PROCESS DIAGRAM



Treatment:

Sedimentation results in the average removal of close to 70 percent of the total suspended solids from deinking waste. This figure can fluctuate widely because of the variety of waste papers deinked and the use of dispersing agents in the process. Removal of the settleable solids is generally accompanied by a BOD_5 reduction in excess of 40 percent. The sludge produced from the deinking of coated papers is readily dewatered mechanically but represents a serious disposal problem because of the large amount produced and its great wet bulk.

Also sedimentation leaves an overflow which is high in turbidity. Chemical coagulation has not proven an effective means to date for removing this. Although some chemical agents have been demonstrated experimentally, cost of their application is prohibitive. The extent of sludge production can be visualized from the bale weight loss figure which can run as high as 50 percent.

All newsprint deinking waste is discharged at present to public sewerage systems for treatment.

Six white paper mills deink old papers on a large scale and five treat their wastes for the reduction of BOD. Four have aerated stabilization basins, one being supplemented by spray disposal on the land. The fifth uses storage oxidation which is accomplished in two large basins. Treatability of this waste was first determined on a demonstration scale by Palladino (229) using the activated sludge process. Limitations of this process led Blosser (230) to experiment with aerated stabilization basin treatment. This in turn led to the successful applications described by Laing (231), Haynes (232), and Quirk and Matusky (234). Flower (235) described land disposal following partial aerated basin treatment at the storage oxidation installation.

Table 32 summarizes the treatment and performance of the three biological oxidation installations for which data were available. Two of these are aerated lagoons and the third a holding basin. Influent figures are on the basis of settled waste because of the inaccuracies inherent to sampling raw waste for BOD determinations because of its suspended solids content. Also, the deinking waste has been combined with paper machine white water prior to treatment which accounts for its low BOD_5 value. It should be noted that the BOD_5 in the effluents averaged as low as 6 pounds per ton of product for one of the aerated basins and 36 pounds per ton of product for the storage lagoon. Detention time is the major determinant of performance and it can be presumed that results equivalent to those observed for the best installation in operation can be duplicated.

TABLE 32

BIOLOGICAL OXIDATION OF DEINKING WASTE

Mill #	TYPE TREATMENT	FLOW M.G.D.	BOD_5 #/TON INF.*	BOD_5 #/TON EFF	TOTAL SUS.SOLIDS #/TON INF.*	TOTAL SUS.SOLIDS #/TON EFF.
1	Aerated Lagoon	7.5	95	21	523	23
2	Aerated Lagoon	1.2	71	6	170	17
3	Holding Lagoon	7.0	197	36	255	26

*Influent data are for settled waste.

The suspended solids content of the effluents which were all of the same magnitude indicates resistance of the extremely fine suspended matter, such as titanium dioxide, to removal by settling or coalescence by bacterial activity in the oxidation lagoons.

Manufacture of Paper

Coarse Papers:

Newsprint, groundwood specialty papers, and wrapping papers are examples of coarse paper (228). These are manufactured on fourdrinier machines primarily from virgin pulps and the production of many of them requires little in the way of additives other than alum and starch. Because of this, the effluents from their manufacture contain relatively little dissolved BOD, this value being largely determined by the concentration of suspended fiber or pulp fines present. Frequently, clarified water from the paper machines producing these products is used in pulping or other papermaking operations at the same location. A list of coarse paper mill effluent flows and their BOD_5 and suspended solids content is presented in Table 33.

TABLE 33

LOSSES FROM COARSE PAPER MANUFACTURE

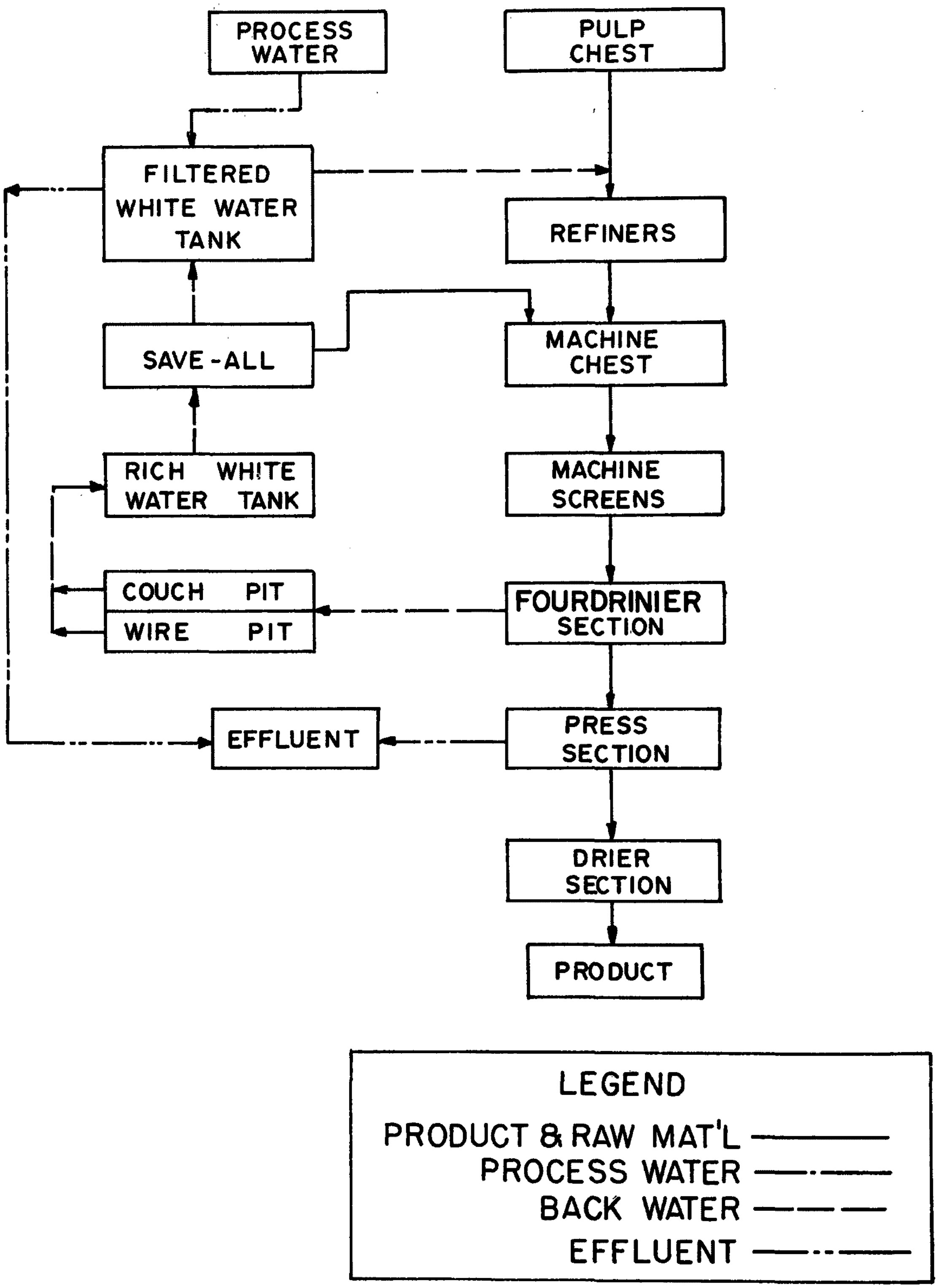
Mill #	Eff. Flow M gal/ton	BOD_5 #/ton	T.S.S. #/ton
1	2.6	14	21
2	2.2	4	42
3	3.7	19	16
4	10.3	18	11
5	5.6	10	12
6	4.1	14	10
7	1.9	8	21
8	6.1	11	17
9	11.5	20	15
10	10.3	21	14
11	14.0	26	19
12	12.5	19	13
13	15.2	24	16

Fine and Book Papers:

Most fine paper and book paper is manufactured on fourdrinier machines (228), a flow diagram for which is presented in Figure 36. The pulp employed is refined and cleaned with centrifugal cleaners and the necessary additives applied ahead of the machine. These consist of sizing materials such as alum and resins, sodium aluminate, and certain wax emulsions. Synthetics such as acrylics, isocyanates, alkene ketene dimer, fluocarbons, and others are sometimes employed to impart special characteristics to the paper produced. Fillers additives include clays, calcium carbonate and sulfate, talc, barium sulfate, alumina compounds, and titanium dioxide. When fillers are employed, retention aids, generally starches or synthetic resin-type compounds, are added to increase retention of the filler in the sheet. Fillers add opacity to the paper and improve. They are added in quantities up to 15 percent by dry weight of the materials used in the process.

FIGURE 3E

FOURDRINIER PAPER MACHINE PROCESS DIAGRAM



Some papers are machine-coated with mixtures of pigments and filler materials and adhesives such as especially prepared starches, dextrines, and gums such as mannoglactans and synthetic resins.

All modern mills recycle most of the machine waters and employ a save-all to capture materials lost through the fourdrinier wire (25). These employ sedimentation, filtration, and flotation with the separated materials being returned to the papermaking process and a portion of the clarified water returned for stock preparation and other uses in the paper machine system. Effluent volume together with the BOD_5 and total suspended solids content is shown in Table 34.

TABLE 34

LOSSES FROM FINE PAPER MANUFACTURE

Mill #	Eff. Vol. M gal/ton	BOD_5 #/ton	T.S.S. #/ton
1	70.6	50	104
2	33.3	19	66
3	24.0	17	38
4	11.4	24	56
5	57.0	16	25
6	7.2	7	26
7	38.0	14	44
8	53.7	40	187
9	7.5	45	18
10	22.7	39	100
11	36.3	23	208
12	40.0	97	442
13	18.8	37	150

White water from paper manufactured without fillers produces a machine overflow water containing from 150 to 300 ppm of suspended matter. The solids consist mainly of pulp fines and are about 90 percent organic (199). BOD_5 values are in the same range, the demand being due to the cellulose present as well as organic additives (27).

Filled and coated sheets produce effluents of much higher suspended solids content than those not containing inorganic additives. About half of the additional suspended matter consists of these substances, hence their high ash content, frequently amounting to 40 to 50 percent of the total suspended solids. BOD values are frequently higher because of the dispersants and adhesives used to retain the filler or coating in or on the paper. The inorganic materials impart a high turbidity to these effluents which is generally in proportion to the percentage of them used in the furnish. The true color of such effluents is low and the pH is in the neutral range.

These machine waters respond well to treatment by the usual processes with the exception of the fact that due to the presence of very fine, high-brightness inorganics, removal of all opalescence is very difficult.

Tissue Papers and Related Products:

Tissue and toweling papers as well as cellulose wadding are produced on fourdrinier paper machines from furnishes consisting mainly of bleached sulfite, kraft, groundwood, and deinked pulps. Resins are sometimes added to give these products special properties such as high wet strength. Because of the light weights of these sheets the volume of water employed is high and the effluents weak ranging in total suspended solids content of from 15 to 250 mg/l and BOD values of from 35 to 100 mg/l (236, 195). These run higher at a few mills which use some deinked pulp in the furnish. The pH value is substantially neutral and natural color is very low. Table 35 gives loss data for tissue paper.

Specialty Papers:

Specialty paper mills produce over a thousand kinds of paper which are made and used in small quantities (225). Some mills produce as little as two tons daily; many single mills produce as many as one-hundred different grades. A wide variety of pulps and an almost endless number of additives are used and both fourdrinier and cylinder machines are employed. Runs of a particular grade are generally short, so that changeover losses can be higher than those entailed in continuous operation. A number of these use cotton linters or textile fibers such as flax, jute, and some synthetics (237).

Because of the great variation of these operations, it is not possible to give specific numbers to their sewer losses. However, references (220, 238, 239) will give some idea of their magnitude.

TABLE 35

LOSSES FROM TISSUE PAPER MANUFACTURE

Mill #	Eff. Flow M gal/ton	BOD_5 #/ton	T.S.S. #/Ton
1	19.2	12	31
2	15.3	34	46
3	62.2	96	64
4	30.4	32	61
5	28.9	10	65
6	21.5	19	48
7	26.6	53	106
8	10.0	15	43
9	18.0	45	83
10	35.9	74	149
11	52.0	80	111
12	44.5	44	156
13	19.0	17	32
14	38.1	34	33
15	24.0	51	39
16	11.8	12	22
17	15.0	39	34
18	30.2	31	10
19	32.9	22	13
20	9.5	14	17

Waste Paperboard Mills

Waste paper is the primary furnish for most paperboard mills although a small percentage of virgin pulp and fillers are used as lining or coating on the product. Some mills also deink white paper to supply the latter requirements. The paper forming section of the board machine, or wet end, employed depends on the type of product made. Both fourdrinier and cylinder machines and some special devices as well are used (228).

Variations and exceptions occur throughout the industry, although in general, a fourdrinier is used to make a single-stock sheet and a cylinder machine a multi-ply sheet or heavy board. During recent years, cylinder machines have been replaced by variations of the so-called "dry-vat" principle in order to produce a multi-stock sheet at higher speeds.

The type of paper machine used has little apparent bearing on the raw waste load generated per ton of product. This parameter is developed in the stock preparation area and is mainly a function of the type of raw materials and additives used. In general, the higher the percentage of kraft or neutral sulfite waste paper used in the furnish, the higher the BOD value per ton of product. Conversely, the higher the percentage of waste newsprint of groundwood origin used in the furnish, the lower the BOD_5 per ton of product. Mills whose wastes have the higher BOD value generally include those that employ an asphalt dispersion system in the stock preparation process in order to melt and disperse the asphalt found in corrugated waste paper. This system subjects the fiber to a heat and pressure environment in a press and digester which contributes to the higher BOD loads. A process flow diagram of a typical waste paperboard mill is shown in Figure 37.

Numerous types of paper and board for a multitude of uses are produced in about 145 mills in the United States, ranging from crude products such as pad backing and egg crate filler through corrugated medium and testliner to coated folding and foodboards.

Effluent volume, BOD_5, and total suspended solids data for 42 mills have been collected and these data are presented in Table 36. These were compiled from data collected by the Department of Environmental Sciences at Rutgers University (240), the Michigan Water Resources Commission (241), the Wisconsin Water Resources Commission (199), the Pennsylvania State Health Department (195), and the NCASI (242). The volume of effluent ranged from 3.3 to 24.0 thousand gallons per ton of product and it is known that at three mills the effluent has been virtually eliminated through clarification and water reuse. However, these mills manufacture a small number of products of coarse grade which makes this procedure possible. Extended full-scale trials on complete water reuse after diatomite filtration of the machine water at several other mills indicated this practice to be unsatisfactory when a variety of high-quality products were made (243).

FIGURE 37

WASTE PAPER BOARD MILL PROCESS DIAGRAM

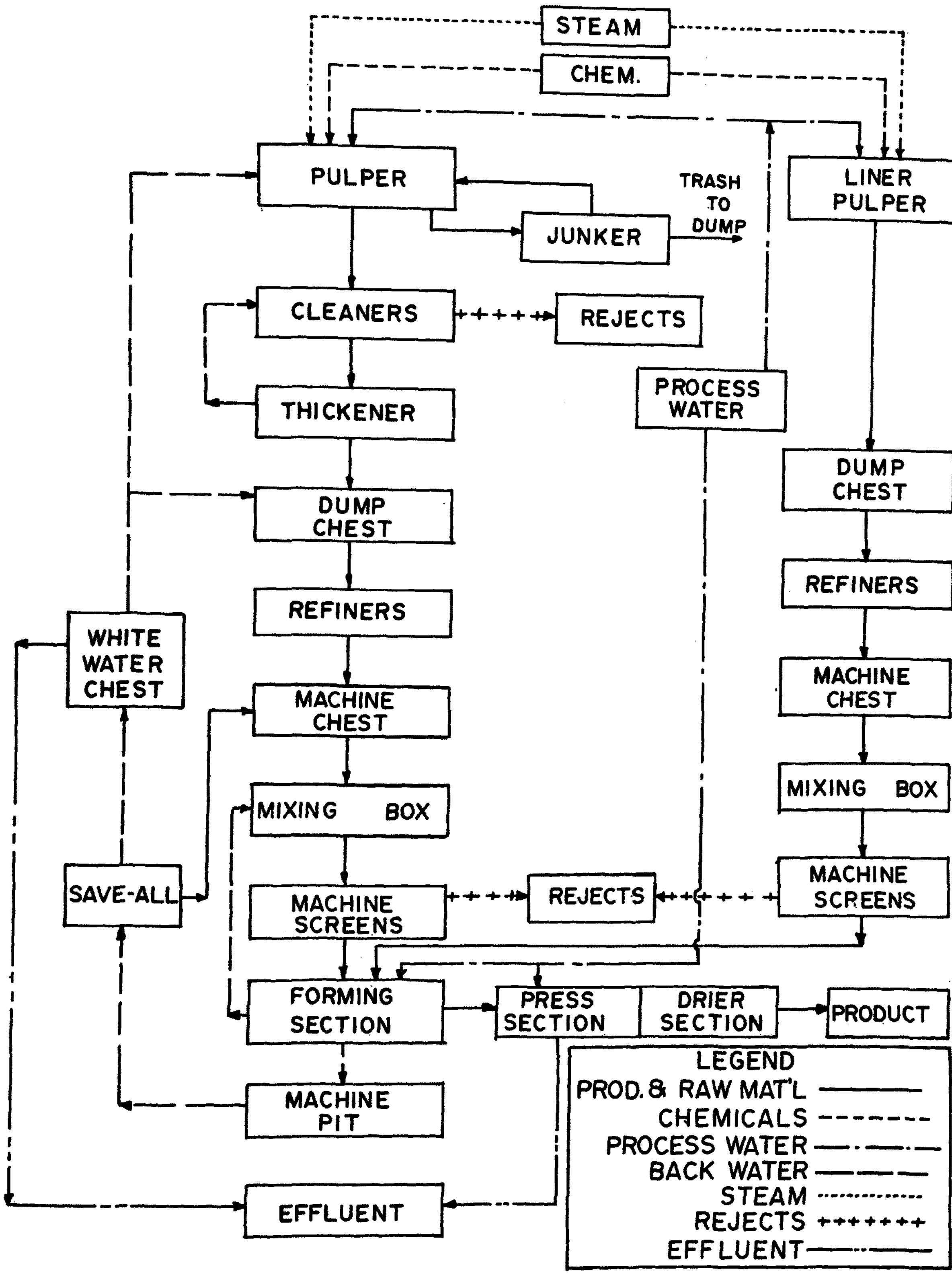


TABLE 36

WASTE PAPERBOARD MILL WASTE LOADINGS

Mill #	Eff. Vol. M gal/ton	BOD_5 #/ton	T.S.S. #/ton
1	11.0	36	122
2	16.3	42	123
3	8.5	15	87
4	14.3	22	98
5	4.0	16	8
6	10.8	13	20
7	21.6	14	40
8	10.0	16	42
9	20.0	36	28
10	9.7	20	33
11	9.5	18	28
12	10.0	19	18
13	9.5	75	67
14	6.7	12	14
15	15.0	67	106
16	12.4	23	42
17	10.3	24	59
18	3.3	32	21
19	11.5	12	21
20	5.8	18	34
21	15.8	16	27
22	12.5	42	76
23	9.3	22	30
24	5.8	16	18
25	13.4	10	21
26	12.7	24	30
27	7.5	35	33
28	19.2	29	40
29	6.6	46	29
30	16.6	16	65
31	13.0	36	40
32	11.4	22	43
33	6.0	17	68
34	9.5	14	32
35	10.0	25	16
36	10.4	20	14
37	8.6	12	14
38	24.0	25	54
39	10.0	25	70
40	10.4	20	16
41	8.6	12	14
42	12.5	26	18

The minimum quantity of water required also depends on whether or not food packaging grades of board are produced. If they are not, a reduction of discharge to the three to four thousand gallon per ton level may be achieved. If they are, reuse is somewhat restricted since taste- and odor-producing substances tend to accumulate in the system and adversely affect the product. Slimicide usage is likewise limited since some of these also impart odors. Hence, the minimum practical discharge for a mill producing foodboard is generally considered to be about seven to ten thousand gallons per ton of product. Practically all products can be produced in this effluent range.

Total suspended solids losses for the 42 mills listed range from 8 to 123 pounds per ton of product; 27 containing 40 pounds per ton or under. This value depends upon the type of save-all employed for fiber recovery and the application of the more effective types is contingent upon the kinds of waste paper used and the products manufactured. All mills of this type can employ a cylinder-type save-all and, while it is not the most effective type, it serves to separate usable from unusable fiber and ordinarily restricts losses to less than 40 pounds per ton. It also serves to protect effluent treatment systems from slugs of fiber and clarifiers from flotation problems.

BOD_5 values ranged from 10 to 75 pounds per ton of product, 30 of the 42 being less than or equal to 25 pounds per ton. Over and above that portion of the BOD imparted to the waste by fibrous organic materials, residual pulping liquor, starch, and other adhesives, such as glutens, account for most of it. Hence, there is no in-process control that can be exercised over the BOD losses other than the reduction of suspended solids. This accounts for the wide variation observed. Some hydrolysis of cellulose takes place during the process adding to the dissolved BOD.

These wastes are generally substantially neutral though for some grades of board lean toward the acid side due to the large amount of alum used as sizing. They seldom, however, contain mineral acidity and can be treated biologically without neutralization. They generally contain relatively little true color unless such is imparted by the water supply, but can be quite turbid due to the presence of clay or titanium dioxide used in the process or entering the system with the waste paper. They are not toxic, but can have a high bacteria count, these organisms being largely Enterobacter aerogenes. Concentrations of suspended solids, BOD_5, and COD are similar to that of strong sanitary sewage and they respond well to the treatment methods applied to sewage. Table 37 presents detailed analysis of the effluent from two paperboard mills surveyed over three different time periods.

Close to one-half of the newsprint and waste paperboard mills discharge to public sewerage systems and additional ones can be expected to follow this procedure. These are frequently available since many of these mills are in or close to large municipalities which serve as their source of raw materials. In this manner the wastes receive both primary and secondary treatment to which they are very responsive when mixed with sanitary

TABLE 37

ANALYSIS OF WASTE PAPERBOARD MILL EFFLUENTS

Mill 1

	Survey No. 1	Survey No. 2	Survey No. 3
Production-Tons	29.25	35.38	30.89
Flow- Million Gallons	0.735	0.729	0.820
Pounds of B.O.D. (Net)	349	344	279
Pounds of B.O.D. Per Ton Product	11.9	9.7	9.0
Pounds of Dry Solids (Net)	524	486	932
Pounds of Dry Solids Per Ton Product	17.9	13.7	30.2
Pounds of Vol. Solids (Net)	328	381	632
Pounds of Vol. Solids Per Ton Product	11.2	10.8	20.5
Gallons Waste Per Ton Product	15,200	9,830	15,300
Fiber Loss-Percent	0.59	0.57	1.08
Population Equivalent	2,090	2,060	1,670

Mill 2

	Survey No. 1	Survey No. 2	Survey No. 3
Production-Tons	43.19	43.0	43.4
Flow-Million Gallons	0.54	0.518	0.593
Pounds of B.O.D. (Net)	1,224	957	870
Pounds of B.O.D. Per Ton Product	28.3	22.3	20.1
Pounds of Dry Solids (Net)	1,857	1,080	940
Pounds of Dry Solids Per Ton Product	43.0	25.1	21.7
Pounds of Vol. Solids (Net)	1,496	880	785
Pounds of Vol. Solids Per Ton Product	34.6	20.5	18.1
Gallons Waste Per Ton Product	12,500	12,050	13,650
Fiber Loss-Percent	1.82	1.08	0.95
Population Equivalent	7,330	5,730	5,210

sewage as pointed out by Gehm (179) and Edde (80). They represent no problems for the treatment plant when normal fiber recovery is practiced at the mill and the proportion of mill waste to sewage is not excessive. However, a fall-off in efficiency in biological treatment due to insufficient nutrients can occur and difficulties in anaerobic sludge digestion can result from too high a cellulose level in the primary sludge (316). In the case of low nutrient level the condition is readily corrected but this is not true in the case of digestion problems. However, qualified sanitary engineers are aware of this latter problem and avoid recommending combined treatment under untenable circumstances.

Over 30 mills treat their wastewater by coagulation and sedimentation, flotation, or biological oxidation. Some provide only clarification of the mill effluent after coarse fiber removal. Mechanical clarifiers are employed and coagulants sometimes used to increase clarity of the overflow (317). As previously pointed out, this treatment produces little additional BOD reduction over settling alone.

Coagulation can remove substantially all the suspended solids and an additional five to ten percent of the BOD_5 over that obtained by sedimentation alone. According to Rudolfs (240) about 25 percent of the BOD is removed by settling and 30 percent by coagulation and settling. This is accompanied by total suspended solids and settleable solids removals of 75 and 95, respectively.

High-degree BOD reduction is practiced by a number of mills. Activated sludge was the first process to be used as reported by Betts and Weston (103,318) after trials with storage oxidation failed due to odor production. Klinger (319,320), Shaw (321,322) as well as Peters (323) reported on construction and operation of modern well-equipped plants of this type.

Gellman (118), Amberg (324,325), and Haynes (326,232) discuss the application of aerated stabilization basins for the treatment of waste paperboard mill effluent. Two of the most recent installations of this kind have been put into operation within the last year (327,328).

Both methods of treatment are capable of reducing the BOD_5 of this waste over 80 percent consistently. This will be noted on inspection of the performance data for such plants presented in Table 38 which follows.

Building Products

Building papers are made on fourdrinier and cylinder machines in generally the same manner as other coarse papers and paperboard from waste paper, unbleached kraft, and groundwood pulps and combinations thereof (228). Some are highly sized with alum and resins. The BOD_5 and suspended solids losses from the manufacture of these products depend upon the particular furnish employed and in-mill fiber recovery practice. BOD_5 content of effluents ranges from 5 to 25 pounds per ton of product

TABLE 38

TREATMENT OF WASTE PAPERBOARD MILL WASTE

Mill #	Pretreatment	Type Biological Oxidation	Flow	BOD_5 #/Ton		Total Suspended Solids #/Ton	
			MGD	INF.	EFF.	INF.	EFF.
1	Alternating Basins	Aerated Lagoon	0.7	45	4	46	2
2	Clarifier	Aerated Lagoon	2.0	26	3	51	4
3	Alternating Basins	Aerated Lagoon	2.7	23	2	81	0
4	Clarifier	Aerated Lagoon	2.0	30	7	87	8
5	Clarifier	Aerated Sludge	3.3	15	0.2	7	0.5
6	Clarifier	Aerated Lagoon	0.3	8	1	56	3
7	Alternating Basins	Aerated Lagoon	0.3	15	2	60	4
8	Clarifier	Activated Sludge	2.7	14	0.7	56	2
9	Clarifier	Activated Sludge	0.6	19	2	73	6
10	Clarifier	Aerated Lagoon	1.0	27	4	49	—

and total suspended solids from 10 to 60 pounds per ton (329). Reasonably good in-mill fiber retention can hold the latter value to below 20 pounds per ton. The effluent from these operations is readily treated both alone and in combination with pulping or other mill effluents by both the common suspended solids removal and biological oxidation methods (330). Effluents containing less than 1.5 pounds per ton of product and a similar quantity of suspended solids can be anticipated from biological treatment of these effluents.

Building felts are produced from single refiner groundwood pulp, waste paper, and, in some instances, other fibers. They are made on forming machines and, since the furnish is generally hot, a very high degree of white water recycle can be practiced without experiencing slime or formation difficulties. Overflow white water volume frequently runs less than 1000 gallons per ton of product. Effluent characteristics are similar to that of waste paperboard except for the fact that some of these materials are impregnated or sized with bituminous materials or contain mold proofing or fungicidal materials which can be toxic to aquatic life.

It has been demonstrated that these wastes can be treated biologically to some degree; however, much better purification is obtained after their being incorporated with sanitary sewage (315,250,331). Presently no plant is treating this waste by itself since most felt mills are connected to public sewerage systems. Where the capacity to handle the load is adequate, no difficulty has been reported by sewage plants receiving this waste in obtaining a high degree of treatment.

Insulating board is produced on fourdrinier-type mold-forming machines from single refiner groundwood or agricultural residues such as bagasse (188,185). Some of these mills also produce board products of an inorganic nature from rock wool and glass fibers interchangeably. Water recycle depends to a great degree on the specific product manufactured as does the suspended solids content of the white water. Low-grade products allow a high degree of recycle and because of the thick fiber mat formed on the wire, high fiber retention is achieved. In the case of some products, however, the retention of fines in the sheet is undesirable and in these cases fiber losses can be very high. Hence, the suspended solids concentration of these effluents can run as high as 3500 mg/l or near 300 pounds per ton of product and the BOD_5 in the same magnitude. Removal of a large percentage of the BOD_5 is accomplished on settling out the suspended solids (264) and that remaining amounts to between 20 and 30 pounds per ton of product. Most hardboards are produced by adding binders produced in much the same manner as insulating board and consolidating it on a wire surface in a hot press (228). This treatment removes all the moisture and sets the natural binders present in the wood as well as those added, which can be linseed, tung, tall oil, or pheno-formaldehyde resins. A typical effluent from such a process amounts to 5300 gallons per ton of product containing 30 pounds of BOD_5 and 39 pounds of total suspended solids. This effluent responds well to sedimentation and biological treatment both alone and in combination with sanitary sewage and to land disposal as well (332).

A process diagram of an insulting board-hardboard mill is presented in Figure 38.

A second process for producing hardboard is the "explosion" or Masonite process in which wood chips are placed in a "gun" under steam pressure of about 1000 psig then exploded against a target plate (228). The material so produced is disc refined, washed, and formed into a wet lap on a forming machine and pressed between platens of a hydraulic press having a screen on one side to allow for drainage. When the water is removed, natural binders formed by treatment of the wood allow its bonding into a solid sheet.

The losses of BOD and fines from this process are quite high because of disintegration of fibers and solubles removed on washing the fiber. This wash water has a BOD_5 ranging from 4000 to 6000 mg/l. Parsons and Woodruff (244) indicate mean losses of 170 pounds of BOD_5 and 80 pounds of total suspended solids for one Masonite hardboard operation.

One mill evaporates and burns the strong liquor (244) and at another it is disposed of on the land (137). The weaker wastes, including machine waters, are genrally disposed of on the land (137). One insulating board mill employs an elaborate land disposal system for disposal of both weak and strong waste as described by Philipp (245). This employs a holding basin for the strong waste allowing controlled seasonal discharge on a 100-acre spray irrigation area, with a hydraulic loading of up to 0.55 inches per day and over 138 pounds of BOD_5 per acre per day.

Results of treatment at four hardboard mills by biological oxidation with and without land disposal of strong wastes indicate that effluents ranging from 2 to 13 pounds of BOD_5 per ton of product can be obtained on treatment of building board mill wastes by various means as shown in Table 39.

Miscellaneous Pulps

Textile Fiber Pulps:

Small quantities of pulps having special qualities are produced from cotton and linen rags, cotton linters, jute, hemp, flax, and old cordage (223,175). These pulps are used in the furnish for fine writing papers, monetary papers, condenser blotting, bristol, tag stock, cigarette, Bible, and a variety of other speciality papers as well as in electrical fiber and impregnated products. These pulps have the ability to impart special properties such as great strength, long life, or fine appearance to papers in which they are incorporated. At one time rags were the common source of most textile fiber pulp but because of the synthetic fiber content of most cotton rags today cotton linters have largely replaced them. In some instances linters are treated to remove impurities and bleached at the mill, producing a wastewater, while in others they are purchased in a prepared form ready for use. The preparation of linters produces a waste of from 7000 to 20,000 gallons per ton of

FIGURE 38

INSULATING BOARD, BUILDING BOARD AND HARDBOARD PROCESS DIAGRAM

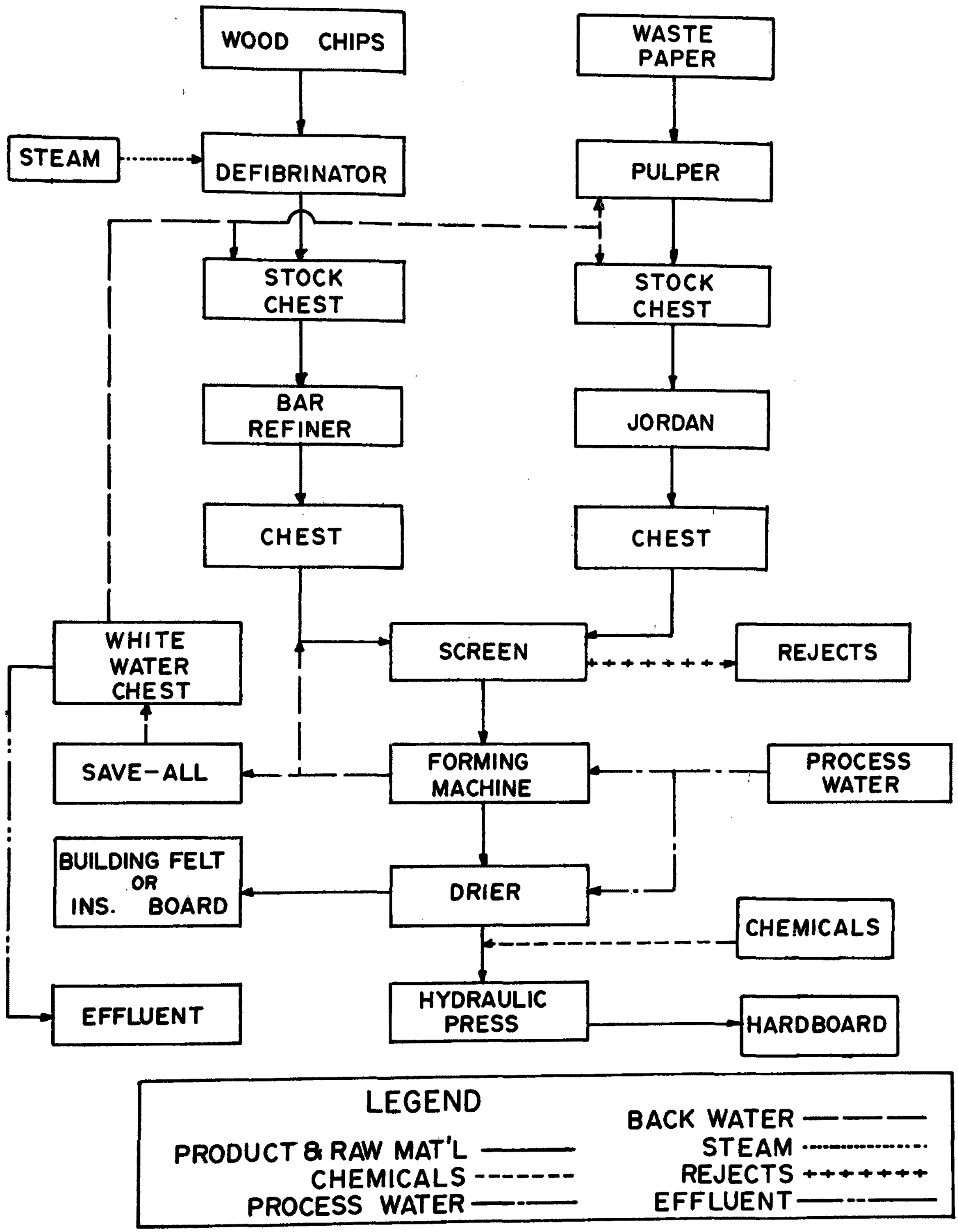


TABLE 39

RESULTS OF TREATMENT OF BUILDING BOARD MILL EFFLUENTS

Treatment	BOD #/Ton		T.S.S.#/Ton	
	Inf.	Eff.	Inf.	Eff.
Save-all, Settling Basins, Extended Aeration	120	11	45	6.0
Neutralization, Clarifier, Cooling, Activated Sludge	193	2	20	0.8
Clarifier, Storage, Activated Sludge	210	4	19	0.6
Neutralization, Settling Basins, Aerated Lagoon, Activated Sludge	61	3	14	2.8
Settling Basins, Storage Basin, Aerated Lagoon	98	13	28	4.8

product containing 250 to 500 pounds of total solids and between 35 and 100 pounds of BOD_5 depending upon the quality of the linters processed and individual mill practice. The waste is high in pH, containing both carbonate and caustic alkalinity due to the caustic soda used in treating the linters (27).

All textile fibers with the exception of flax are prepared in essentially the same manner. In many mills a number of raw materials are employed and specific pulps produced sporadically or intermittently since the equipment required for all of them is the same, but the paper products manufactured are of a wide variety, some requiring more than one type of pulp.

Cooking is conducted in rotating cylindrical or spherical pressure vessels. The vessel is charged with the raw material and in some cases this is given a pretreatment with a detergent to remove dirt. In this case, after steaming and rotating for a short time, the vessel is drained and the cooking chemicals added. These consist of caustic soda, soda ash, lime, or a combination of the latter two. Flax is cooked with either a mixture of caustic soda and sodium sulfide or draft white liquor ($NaOH$ + Na_2S). At the start of the cook, water content is generally adjusted to 2.5 to 3.5 percent of raw materials.

When cooking is completed the contents of the boiler are blown into a drained pit. At some mills the pressure is gradually relieved and wash water added to the boiler. The boiler is then rotated to aid the washing operation, drained, and the contents removed by hand.

Whether or not boiler washing is practiced, the cooked pulp is transferred to a beater where it is diluted and beaten to the desired degree. After this, the washing cylinder is lowered and a large volume of wash water introduced, washings being discharged from the cylinder. On completion of washing, if bleaching is required, calcium or sodium hypoclorite is added and the contents of the beater circulated until bleaching is complete. Most of the textile fibers require less than 0.5 percent chlorine and many as little as 0.1 percent. A final wash completes the process after which the pulp is deckered to the desired consistency and delivered to a stock chest. A process diagram is presented in Figure 39.

It is obvious on examination of this diagram that wastewaters emanating from the preparation of these pulps can include the following individual streams:

(1) Scour and blowdown wastes
(2) Boiler wash water
(3) Blow-pit drainings
(4) Beater wash water
(5) Bleach wash water
(6) Decker water

Nemerow (246) and Rudolfs (194) evaluated these wastes in terms of total suspended solids and BOD content and typical data is shown in Table 40.

FIGURE 39
SPECIALITY PULP MILL

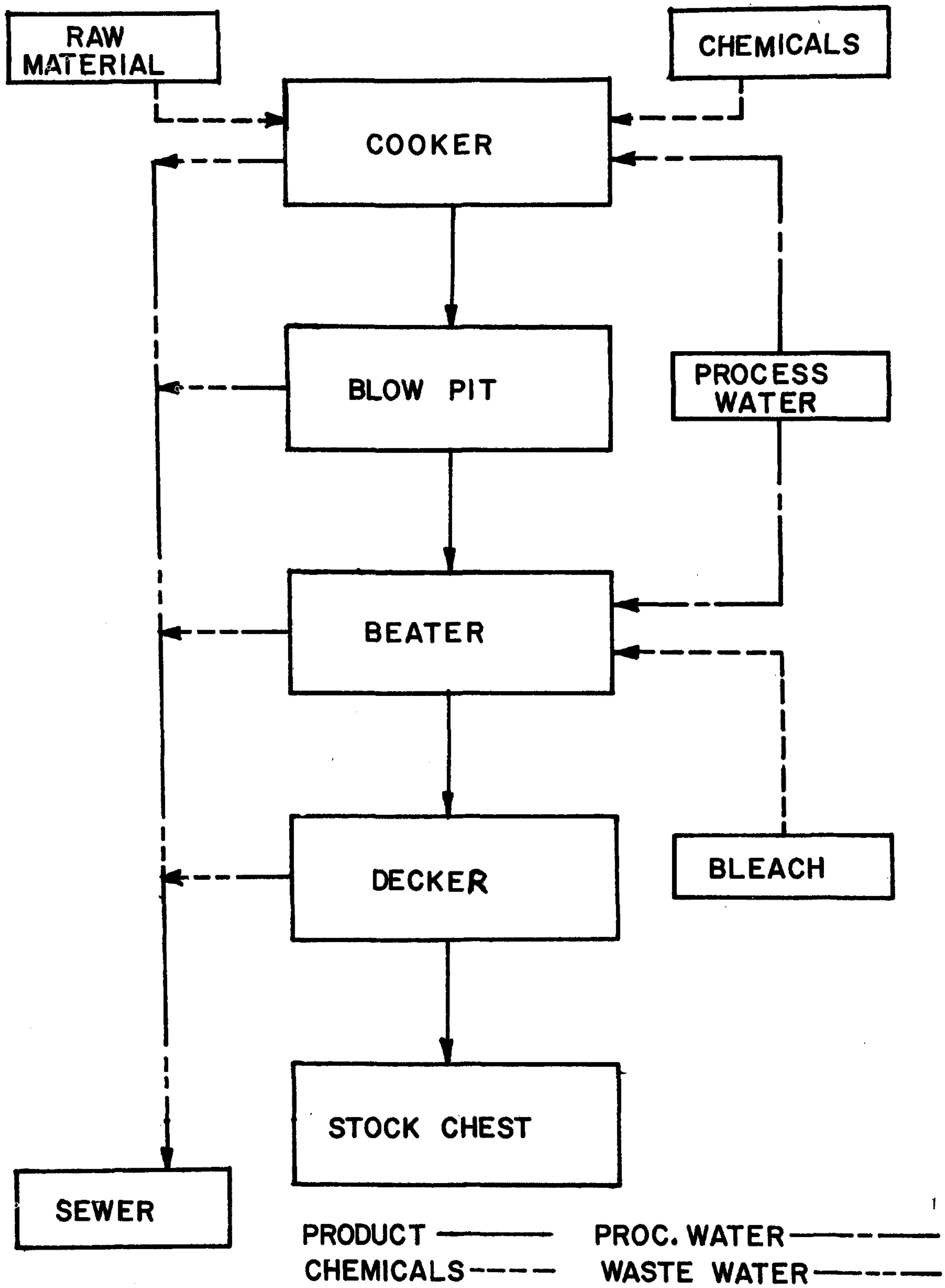


TABLE 40

POLLUTION LOAD FROM TEXTILE FIBER PULPING

TYPE PULP	WASTE VOL. THOUS. GAL/TON	TOTAL SOLIDS #/TON	TOTAL SUSP. SOLIDS #/TON	BOD_5 #/TON
Jute	65	922	281	316
Rope & Hemp	75	1,360	277	1,213
Rag	80	2,600	474	707

They (247) also determined the load distribution during the washing operation in terms of BOD_5 and total and suspended solids for rag, rope, and jute pulps as shown in Table 41. Interest has been aroused in improved washing techniques which can greatly reduce the volume of water required and contain the liquor solids in a small volume.

Textile fiber pulping and boiler wash liquors are frequently lagooned because of their small volume and high strength. Also, it is well to keep them out of the general waste stream if chemical coagulation is practiced since they interfere with this process (244). The washer and bleaching wastes are generally combined with the mill white water. The combined flow can be treated by common sewage treatment processes such as sedimentation (247), coagulation (248), or biological oxidation (223,249). Storage oxidation of the combined waste has been the most common method of treatment but one mill ran a trickling filter for many years (251). Both pilot and full-scale tests by Nemerow (57) in which a mixture of jute pulping wastes and white water were settled revealed that a 78 percent total suspended solids reduction was observed as compared with a 91 percent reduction for the white water alone. Effluent BOD_5 values doubled when the pulping waste was intermixed due to the presence of solubles as well as the lesser reduction in suspended solids.

Pulping wastes have been treated along with mixtures of alum and calcium chloride. After settling the sludge is lagooned and the supernatant discharged into the general waste stream.

Studies have revealed that liquors could be handled by anaerobic digestion after neutralization and nutrient additives (252).

Agricultural Residue Pulps:

Small quantities of bagasse, straw, cotton seed hulls, esparto grass, bamboo, and corn stalks are pulped in this country (185), some on a continuous full-scale basis and others intermittently. The latter procedure is either because of periodic shortages of the usual raw

TABLE 41

Load Distribution in Cook Liquors and Progressive Beater Wash Water Wastes

Flow(%)[1]			Washing Time (hr.)	B.O.D.(%)[1]			Total Sol.(%)[1]			Susp. Sol.(%)[1]		
Jute	Rope	Rag		Jute	Rope	Rag	Jute	Rope	Rag	Jute	Rope	Rag
7.4	2.8	1.8	0(cook)	41	47	65	34	61	52	25	4	25
16.7	10.9	8.6	1/4	74	68	77	64	76	62	56	34	33
25.9	19	14.3	1/2	85	80	83	77	83	70	71	54	42
44.5	35.2	26.9	1	93	90	92	88	90	79	88	75	50
63	51.5	39.4	1-1/2	96	94	96	93	93	85	93	84	65
81.3	67.6	51.8	2	99	96	98	97	95	89	97	87	71
100	83.9	64.3	2-1/2	100	98	99	100	98	91	100	93	77
----	100	76.8	3	----	100	99+	----	100	94	----	100	82
----	----	89.3	3-1/2	----	----	99+	----	----	96	----	----	91
----	----	100	4	----	----	100	----	----	100	----	----	100

[1]Percentage of total accumulation.

material used or is on an experimental basis. Straw once accounted for an appreciable quantity of board which was produced largely in Indiana and Illinois (198,253). However, its use is now a rarity. Straw has been replaced with wood pulp because of its low yield and bulk density as well as the serious water pollution problem accompanying the pulping of this material. Bagasse pulp is produced at one paper mill and a wallboard plant in this country. Here again, the low yields obtained limit its use.

Since strawboard mill effluent typifies the effluent obtained in pulping most agricultural residues a representative analysis as given by Bloodgood is shown in Table 42 (254,253,255).

TABLE 42

TYPICAL ANALYSIS OF STRAWBOARD WASTE

Effluent Flow	35,000 gal/ton
Total Solids	1,050 #/ton
Ash of Total Solids	70%
Total Suspended Solids	490 #/ton
BOD_5	246 #/ton

Sludges obtained from settling wastes produced from pulping agricultural residues do not dewater well and are productive of odors (due mainly to H_2S) on lagooning. Storage of either the waste or sludge results in a considerable BOD reduction because of anaerobic decomposition, but the odor problem is too severe to permit this practice. The wastes respond to both aerobic (253) and anaerobic treatment (256,257,258,259), but the plant capacity requirements were too high to permit their application. Land disposal was practiced at one mill (260) but the high organic matter content limited loadings at which the waste could be successfully applied to the soil.

It is likely that most textile and agricultural residue pulping operations, together with the attendant papermaking, will dispose of their effluents into public sanitary sewerage systems in the future. Their small size as well as their ability to reduce water consumption, and in some cases, the waste loading to a considerable degree, and the proximity of most operations to municipalities makes this course of action most reasonable since they are readily handled by the sewage treatment processes (220).

Other Mill Effluents

In addition to process effluent, many mills discharge water from their utilities. These consist of filter backwash and sedimentation tank underflow or clean-out from water treatment, boiler blowdown, and cooling water. In some instances the latter is salt or brackish water. In addition, mills burning bark and/or coal usually sluice ash to a ponding area. Frequently the grits and dregs from kraft recovery systems are combined with this flow. In addition to these effluents, some mills dispose of process clarifier underflow on landfill areas. In respect to landfill areas, good practice dictates the return of overflow water from them to the waste treatment system since it can be high in both suspended solids and BOD. The overflow water from ash sluicing ponds generally carries but a small pollution load which frequently is discharged only during periods of high precipitation. Hence, it is diluted with rain water and the receiving stream at relatively high runoff.

SECTION XI

COST OF TREATMENT

The most recent and complete statistics on pulp and paper industry expenditures for waste treatment and attendant information on this activity are contained in the reports of surveys conducted every two years by the NCASI. These detailed reports for 1968 and 1970 were published by Bolduc (342) and Blosser (370,373). The last survey was drawn upon extensively for information used in this section.

At that time, 70 percent of the mills which were responsible for 89 percent of the nation's pulp and paper production reported. These totaled 414 mills of which 326 provided some form of effluent treatment or employed specialized disposal methods or ocean outfalls. Others discharged to municipal systems as discussed in Section IX of this report. There were 242 mills reported as providing primary treatment and 112 secondary treatment in the form of storage oxidation, aerated stabilization, activated sludge, or trickling filters.

Capital Cost

Gross capital expenditures for treatment by type of mill is shown in the table below reproduced from this report:

Type of Mill	Millions of Dollars
Kraft Pulp and Paper	200
Sulfite Pulp and Paper	65
Semi-Chemical Pulp and Paper	39
Mechanical Pulp and Paper	33
Mixed Chemical Pulp and Paper	13
Non-Integrated Paper and Paperboard	30
TOTAL	380

Most of the expenditures for primary treatment ranged from $1,000 per ton of daily production capacity to in excess of $4,000, although a few ranged between $300 and $1,000 per ton. Most expenditures for secondary treatment ranged from $1,000 to greater than $6,000 per ton of daily production capacity with a limited number of mills reporting values lower than $1,000. The simplest form of secondary treatment, storage oxidation, accounted for the lower values.

The wide range in capital costs from mill to mill results from variations in plant size, local labor and materials costs, and land prices, as well as topography, foundation, and piping requirements. Costs of individual pieces of equipment are set forth in Volume III of "The Cost of Clean Water" (341) published by the Department of the Interior. This data can be adjusted to present cost levels.

Industry trends also have a decided effect on costs. Some of these are the abandonment of small, old chemical pulp mills which are no longer profitable; refurbishment and expansion of the older kraft mills; the large capacity for which the new mills are designed; improved recovery and other internal sewer loss control techniques; and increased water recycle.

Operating Costs

The operating costs of primary treatment were reported from 20 cents per ton of product for earthen settling basins to $2 to $5 per ton where mechanical clarifiers and dewatering were employed. Biological oxidation operating costs showed an even wider range running from as low as 20 cents per ton for an isolated case employing storage oxidation. For systems reducing the BOD_5 greater than 70 percent, costs ranged from $1.20 to $7 per ton. The cost for high-rate secondary treatment, including disposal of the sludge produced, exceeded $2.50 per ton.

Size naturally affects operating costs appreciably, the larger units being generally more economical to run on a unit basis. Amberg (339) presents figures showing the wide variations that can occur in operating costs from mill to mill for both primary and secondary treatment. Costs for the former at three mills amounted to $6.28, $12.29, and $35.50 per million gallons treated. Corresponding values for secondary treatment at the first two mills amounted to $32.00 and $42.60 per million gallons treated or $1.58 and $1.75 per ton of product. Costs per pound of BOD_5 removed generally run from 2 cents to 7 cents for the larger mills.

Operating costs for sulfite liquor recovery run from $1 to $10 per ton and for NSSC between $1 and $5 according to Blosser (373).

Advanced Waste Treatment Costs

Cost of treatment of linerboard mill effluent for color removal with lime, but without lime recovery, is given for Davis (177,371) as $3.19 per ton of product for a 400-ton-per-day unit. Computations presented by Herbert (40) indicate that recovery could substantially reduce this figure. These investigations included lime recovery from effluent recarbonation as well as that recovered from the precipitate containing the color bodies from the effluent.

Berger (367) and Thibodeaux (349) calculated that a water of good quality except for the presence of electrolytes could be produced from linerboard mill effluent for less than 20 cents per thousand gallons. However, substantial removal of the electrolytes would add 50 cents per thousand gallons.

Leitner (366) and Voelken (347) indicated that reclaiming reusable water and obtaining a concentrate suitable for recovery from strong pulping wastes would cost $1.17 per thousand gallons. Considerable information on water reclamation unit process costs have been presented by Hoenig (372) and in other reports covering the U.S. Public Health

Service investigation on advanced waste treatment (343). Although these studies were conducted on pretreated sanitary sewage rather than pulping effluents, costs appear reasonably comparative for the unit processes involved. Additional data of this type have been published by Critts (340) for water treatment in which the values presented appear comparable.

It remains for present and future demonstration projects to substantiate computations for reclamation of treated pulp and paper mill wastes of the various types commonly discharged. The need for more efficient, reliable, and less costly electrolyte reduction is obvious if anything approaching closed systems is to be realized. The hope for this lies in perfection of processes capable of selectively removing such undesirable ions as chlorine. Such processes are discussed by Reeve and Rapson (233).

Cost of Converting Calcium Base Sulfite Mills to Magnefite Pulping

The cost of converting large (400 to 500 tons per day) calcium base sulfite pulp mills to magnefite pulping runs in the neighborhood of $16 million, the range in cost per ton being between $30,000 to $40,000.

SECTION XII

EVALUATION OF COMMON TESTING PROCEDURES

FOR PULP AND PAPER MILL EFFLUENTS

Biochemical Oxygen Demand (BOD)

The BOD test serves to measure the biochemical oxygen-consuming capability of papermaking wastewater and is a good measure of the effect of the wastes on receiving streams (261). Since this test can be quantified in terms of quantity of oxygen required, it is one of the fundamental measurements of wastewater characteristics, and is particularly applicable to wastewaters of the pulp and papermaking process. The time required for completion of the normally employed test (five days) is a major shortcoming and unfortunately rules out the test for process control use. Attempts to shorten the time interval to less than five days have not been overly successful (262).

Suspended Solids

Because suspended solids from papermaking operations have differing properties depending upon their organic or inorganic nature, it is pertinent to distinguish between or to characterize the nature of the solids discharged. This is determined by differentiating between volatile and non-volatile fractions of the solids that are present in the wastewaters. The method for suspended solids (non-filterable solids) is specified in the EPA manual, previously cited, and requires filtration through a glass fiber filter of specified pore size, followed by drying at 103° to 105°C. "Standard Methods" and other publications (261, 263) offer alternatives in filtration media such as the "asbestos mat" and the membrane filter. Historical data based on the "Standard Methods" should be acceptable for this test. However, the "Federal" method should be specified for future testing.

Chemical Oxygen Demand (COD)

The National Council for Air and Stream Improvement reported on a study of COD/BOD relationship of raw and biologically treated mill effluents (188). In concludes:

> "Based on the results obtained it does not appear possible to develop time-automated treatment process and effluent discharge controls for rapid BOD estimation based on the COD test. Examination of BOD, COD, and lignin content relationships on 352 samples of untreated and treated pulp mill effluents showed no fixed relationship between these values. It is probable that materials other than lignin which are resistant to biological oxidation are present in the waste, as well as some lignin materials which do not decompose. Possibly these latter are functional groups of the

large lignin molecule. There is also wide variation in momentary relative concentration of the various constituents present in these wastes as discharged. Correcting COD values for oxygen equivalent of the lignin content of both untreated and treated wastes significantly lowers the COD/BOD ratio. However, it does not yield a ratio sufficiently constant for reliably estimating BOD by this technique.

In view of the large number of representative samples used and the well controlled laboratory techniques employed, it appears that final solution of this problem will depend on the separation and measurement of those constituents contributing to both chemical and biochemical oxygen demand."

This is not surprising, nor has there yet been discovered any physical-chemical procedure that correlates well with the BOD test. However, this shortcoming--the lack of correlation--is not sufficient to rule out a test procedure that can provide meaningful information that may be translated into stream or effluent quality appraisal. The dichromate procedure for COD (with chloride correction) has been recognized as a "Standard" method. This method seems to correlate well with filtered domestic sewage and with wastewaters having characteristics similar to domestic sewage. A less favorable correlation is experienced with treated effluents, with the COD/BOD ratio increasing with greater biological stabilization. This serves to indicate that biologically stabilized effluents contain organic components that react very slowly biologically, but retain chemically oxidizable properties. The COD test is also more easily repeatable than the BOD test since its conditions are better controlled. On the other hand, there is little established usage of the COD test in which it is readily quantified. Treatment plant performance designs are predicated strictly on BOD/suspended solids criteria, especially through secondary treatment stages. Therefore, the COD test as currently practiced, provides some useful information that may be utilized to provide a general classification of the total oxidizable organic content of a wastewater or its receiving stream, but the interpretation of COD values, without other qualifying data, provides very little of value for classifying effluents or the resultant effects on stream quality.

<u>Color</u>

The need to measure color and to limit its presence in receiving waters is spelled out in the water quality criteria for aesthetic, water supply, fish, aquatic and wildlife propagation, and some industrial uses. For aesthetic purposes, the criteria specify the absence of objectionable color. For water supply uses, the criteria recommend a limit of 75 color units (cobalt-platinum standard units). This standard permits water treatment plants to produce a satisfactory finished water with moderate dosages of coagulants and chemicals. For fish, aquatic life, and wildlife propagation, the criteria specify that at least ten percent of incident light must reach the bottom of a desired photosynthetic zone in order to maintain adequate dissolved oxygen levels. The conversion of this requirement into standard color units is not possible because of associated turbidity from natural and wastewater sources. However, a value above 50 units has been significant in limiting photosynthesis and having a deleterious effect upon aquatic life, particularly phytoplankton and the benthos. Some specific industrial water users, primarily the food and beverage producers, require raw water color to be limited to five units. However, industry in general sets no specific limit because of its varied specific water uses.

The standard method for color measurement is in terms of platinum-cobalt units of color, as specified in "Standard Methods" for water. Since the color of the wastewaters from pulp, paper, and paperboard manufacture have the characteristic brown color very similar to the platinum-cobalt standard, there is little need to modify this procedure except for those special processes in which dyes are used to introduce other colors. Brown (159) suggests, however, that all mill effluent measurements be made at pH 7.6 because there is a significant pH effect on the color of pulping and bleaching wastes.

Turbidity

Turbidity and suspended solids parameters are not synonymous. Suspended solids are filterable particulates in the fluid; turbidity is the light-scattering properties of a fluid. Where suspended solids are present, turbidity is always found. However, sometimes turbidity may be observed under conditions of extremely fine particle size, which pass through the standard filters used for the measurement of suspended solids. Historical data on turbidity of mill process streams is non-existent, but methodology is well established (261), since dispersed matter has traditionally been reported as suspended solids. However, the quality effect on water uses that distinguishes turbidity from suspended solids requires that effluents be characterized using both parameters. It is therefore recommended that turbidity be a standard measurement of plant effluents only, since its usage in the operating mill process flows has no important significance.

Coliform Organisms

The use of the total coliform test as a quality criterion for natural waters is rapidly being displaced by the fecal coliform test. This differentiation is significant to the assessment of natural water quality for contact recreation purposes and for public water supply because it is being universally recognized that the protection of the public health is served better through the elimination of those organisms that are directly related to human and animal fecal matter.

It has also been amply documented that many of the wastewaters from this industry have a property of stimulating the multiplication of coliform organisms because of the presence of various carbohydrates extracted from wood during the pulping process. The resultant high coliform concentrations may appear significant, but invariably, these are classified as non-fecal types, with only a very small fraction testing out as of fecal origin (265). Where mill sanitary sewage is combined with process wastes, there is, of course, a relatively higher fecal coliform content. Based on these considerations, the total coliform tests should no longer be a requirement for effluent bacteriological quality. It should be replaced by tests that differentiate the presence of the fecal coliforms. If these are found in appreciable numbers their sanitary significance should be evaluated for the specific situation.

TL_m - Medium Tolerance Limit

This is a bioassay procedure used to establish a concentration level of the substance under test that will result in survival of (or non-injury to) 50 percent of a test population during a specified time interval (266). A static procedure has been standardized in "Standard Methods" using fish as the test organism for those instances in which the material being tested is persistent, non-volatile, and without significant oxygen demand.

It is well known that process wastewaters from various pulping processes exert varying degrees of toxic effect upon the ecology of receiving waters. It is also well known that biological treatment reduces these toxic effects significantly. Since toxicity tests are not yet recognized universally as standard tests and they are relatively expensive and tedious to perform, it would seem logical to suggest that these tests be required only under those circumstances which would constitute a sensitive relationship between the use of a body of water for wastewater disposal and its use for the propagation of valuable fish and food organisms. In these instances, the test should be performed under continuous flow-through conditions where feasible. The ultimate purpose of the test would be its use as a regulator of the discharge rate of the final effluents from the affected mill.

Alkalinity-Acidity and pH

Little in the way of acidity or alkalinity which could prove detrimental to treatment efficiency or recovery water conditions results from the discharge of papermaking effluents. While the pH of some of these may be high or low they are for the most part poorly buffered and contain little titratable alkalinity or acidity. Hence, they are readily brought within an acceptable pH range in the course of usual treatment or dilution by receiving waters containing some buffering capacity as most do. Examples of these are kraft and soda pulping effluents from balanced mills with good effluent control. Such mills normally produce an alkaline effluent which, while quite high in pH value, contains no caustic alkalinity and only a small amount of normal carbonate alkalinity, hence is readily neutralized on treatment or dilution. However, some pulping and bleaching wastes are more troublesome. Sulfite pulping effluents are acid due to the presence of sulfurous and sulfuric acids and require neutralization. Also, bleaching wastewaters from the chlorination and caustic extraction stages are respectively low and high in pH and can caustic extraction stages are respectively low and high in pH and can contain sufficient mineral acidity or caustic alkalinity to require neutralization before treatment or discharge. On combination with the pulping effluent some interaction occurs tending to neutralize the mixture. However, when a high degree of bleaching is practiced, the residual effluent is low in pH and contains sufficient mineral acidity to necessitate neutralization prior to treatment of discharge.

Since pulp and bleaching wastes contain organic acids which are poorly ionized, alkalinity and acidity are much better measures of the alkali and acid content of these wastes than is the pH value outside of the immediately neutral range (pH 5.5 to 10.5). Also these figures are required to determine the quantity of neutralizing chemicals required when this procedure must be used (50).

Alkalinity, acidity, and pH are all measured by the techniques set forth in "Standard Methods".

Heavy Metals

Low concentrations of chromium, nickel, lead, mercury, and zinc have been found in process wastewaters of the industry, particularly in the waters from pulping and bleaching operations. Mercury may be present in the caustic used in these processes; chromium and nickel could be picked up as corrosion products along with iron from the process equipment. Zinc is used in some groundwood bleaching operations in low concentrations. These metals have know toxic effects on aquatic life, and their presence in water for human consumption is limited to very low concentrations. Methods for determining mercury in pulp and paper and associated wastes are reported by the National Council for Air and Stream Improvement (267).

Nitrogen and Phosphorus

Excessive concentrations of the nutrient elements phosphorus and nitrogen, when present in a natural water body, have been implicated as the causative agents in overfertilization and overgrowth of undesirable aquatic organisms leading to eutrophication. Sources of these nutrients are the wastewaters from municipal wastes, some industrial wastes, and surface drainage. The processes in use by the pulp, paper, and paperboard industry result in wastewaters that are usually deficient in one or both of these critical nutrient elements (268). Therefore, it has been a general practice to add calculated quantities of nitrogen and phosphorus to the biological treatment processes in order to optimize treatment. It has been determined that a ratio of 1:5:100 of phosphorus: nitrogen: BOD should be maintained. However, actual requirements are frequently lower in practice. Therefore, it is concluded that there is very little likelihood of excessive nutrient concentrations being found in the process wastes or wastewaters from this industry and that no useful purpose would be served to suggest analysis for these substancees.

Toxic Components

Van Horn (269) published methods for the detection and quantitative measurement of the major toxic components of alkaline pulping effluents. Those covered by his studies were sulfides, mercaptans, and resin acids for which techniques for determination in the fractional mg/l range were set forth. An improved method for determining resin acids in a similar concentration range was developed by Carpenter (270).

Foaming Capacity

An empirical method for evaluating the foaming capacity of mill effluents was developed by Carpenter (127). The technique advocated was patterned after those employed in the soap and detergent industry and involves the persistence as well as degree of foaming.

SECTION XIII

EFFLUENT MONITORING

Biochemical oxygen demand (BOD) and total and suspended solids are the most useful parameters to be employed in monitoring the effluents of this industry. These three parameters measure the effect of the most significant components of these wastewaters on receiving waters and provide the basis for quantitative evaluation of treatment effectiveness.

It has been demonstrated (271) that a linear relationship exists between total dissolved solids and the BOD_5 of unbleached kraft pulping decker filtrate as illustrated by Figure 40. The efficiency of this relationship was corroborated by the fact that the total dissolved solids content of kraft black liquor and BOD_5 are similarly related. The same relationship was shown to exist for NSSC spent liquor. While the determination of total dissolved solids is infrequently used, it can be determined in about an hour's time as compared with the BOD_5 which requires five days. While attempts have been made to shorten the period of time required for biochemical oxygen demand determinations (261), none of the tests proposed to accomplish this have met wide acceptance. This is probably because those proposed required a day or more to complete. Hence, attention has been given to quicker tests and those lending themselves to automation which could be used for immediate control of sewer losses within a mill. These included the oxygen consumed and COD tests (272,273), neither of which showed any fixed relationship to the BOD_5 for kraft or NSSC wastes. Variations in momentary relative concentrations of biologically oxidizable and refractory organics probably account for this lack of correlation between the determinations.

However, color as measured by light absorption and conductivity exhibits a linear relationship to the BOD_5 value. The observed relationship of light absorption to BOD_5 for kraft mill decker filtrate is presented in Figure 41 and that for NSSC machine effluent in Figure 42.

A color-BOD_5 relationship also exists for evaporator jet condenser water as shown in Figure 43. This could be expected since the carryover of black liquor from the evaporators contributes color and BOD_5 in proportion to the concentration.

Control monitoring in pulp mills is accomplished largely by conductivity, a measurement which can be made continuously and reliably with a minimum of instrument attention. Multiple-point instruments can be employed to cover such streams as the decker filtrate overflow for indicating pulp washing losses and on the sewer carrying evaporator condensate to

FIGURE 40

RELATION BETWEEN TOTAL DISSOLVED SOLIDS AND BOD_5 IN DECKER SEAL PIT WATER

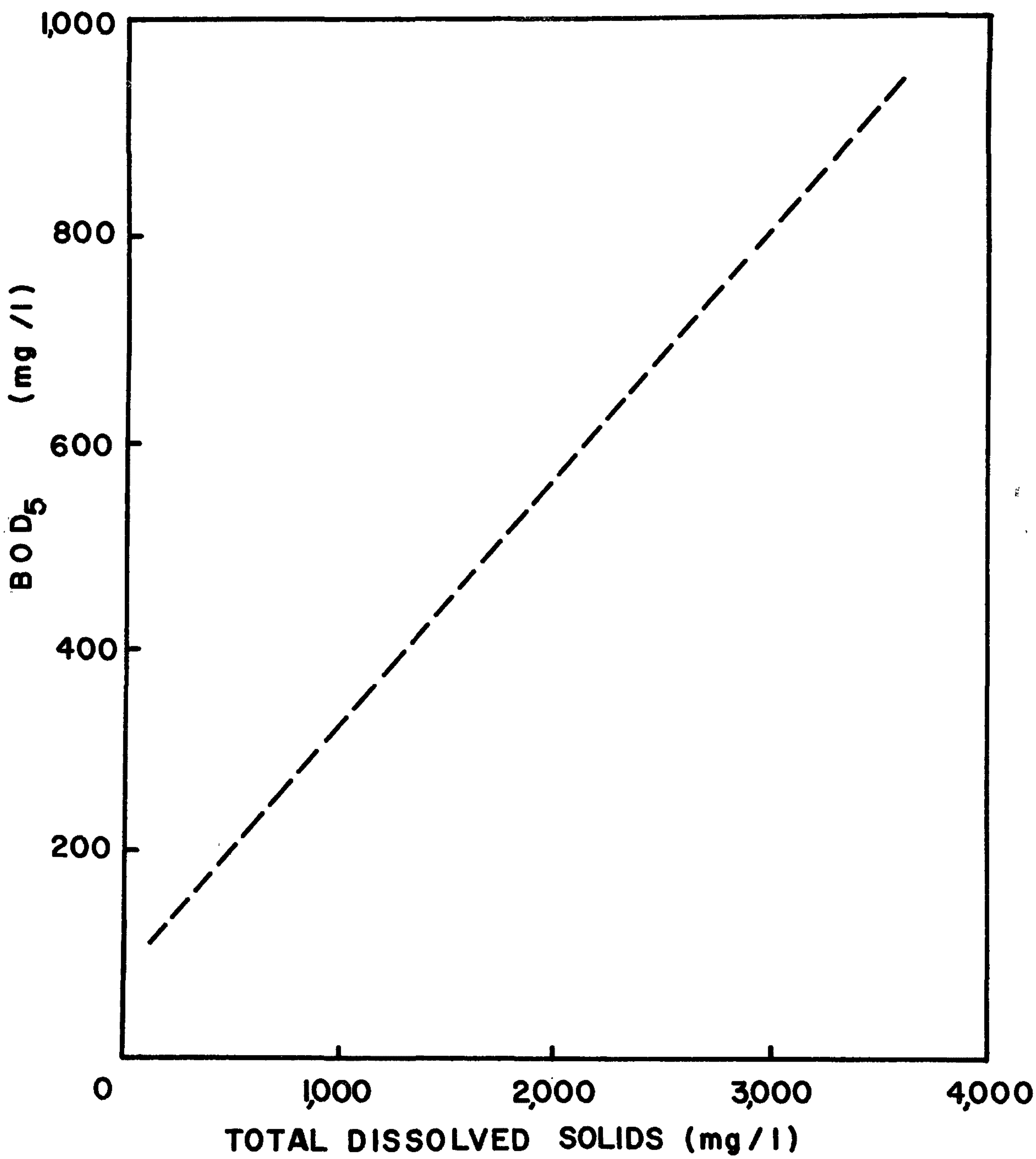


FIGURE 41

BOD$_5$ IN RELATION TO LIGHT ABSORBENCE

KRAFT MILL DECKER SEAL PIT WATER

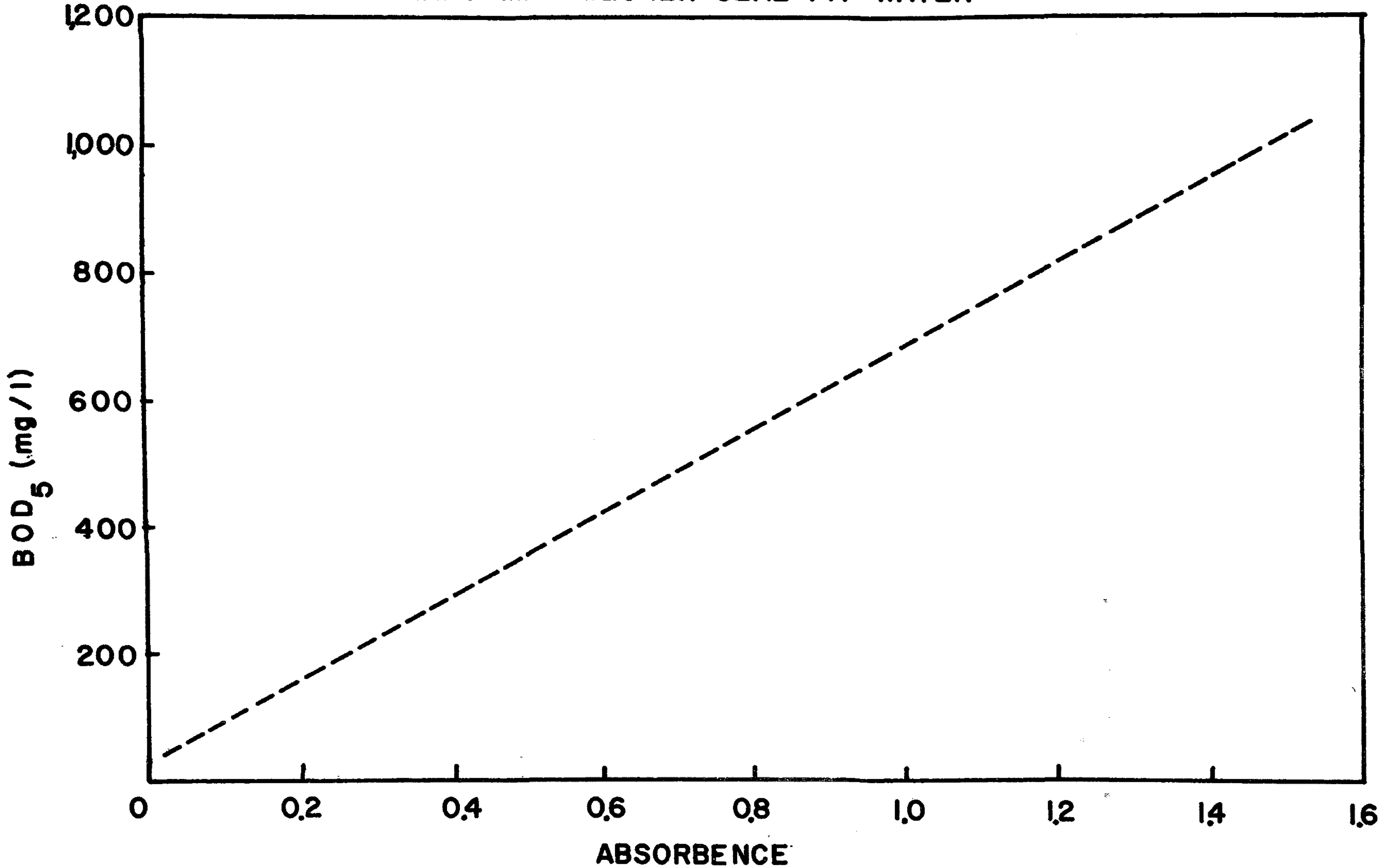


FIGURE 42
BOD_5 IN RELATION TO LIGHT ABSORPTION
OF NSSC WHITE WATER

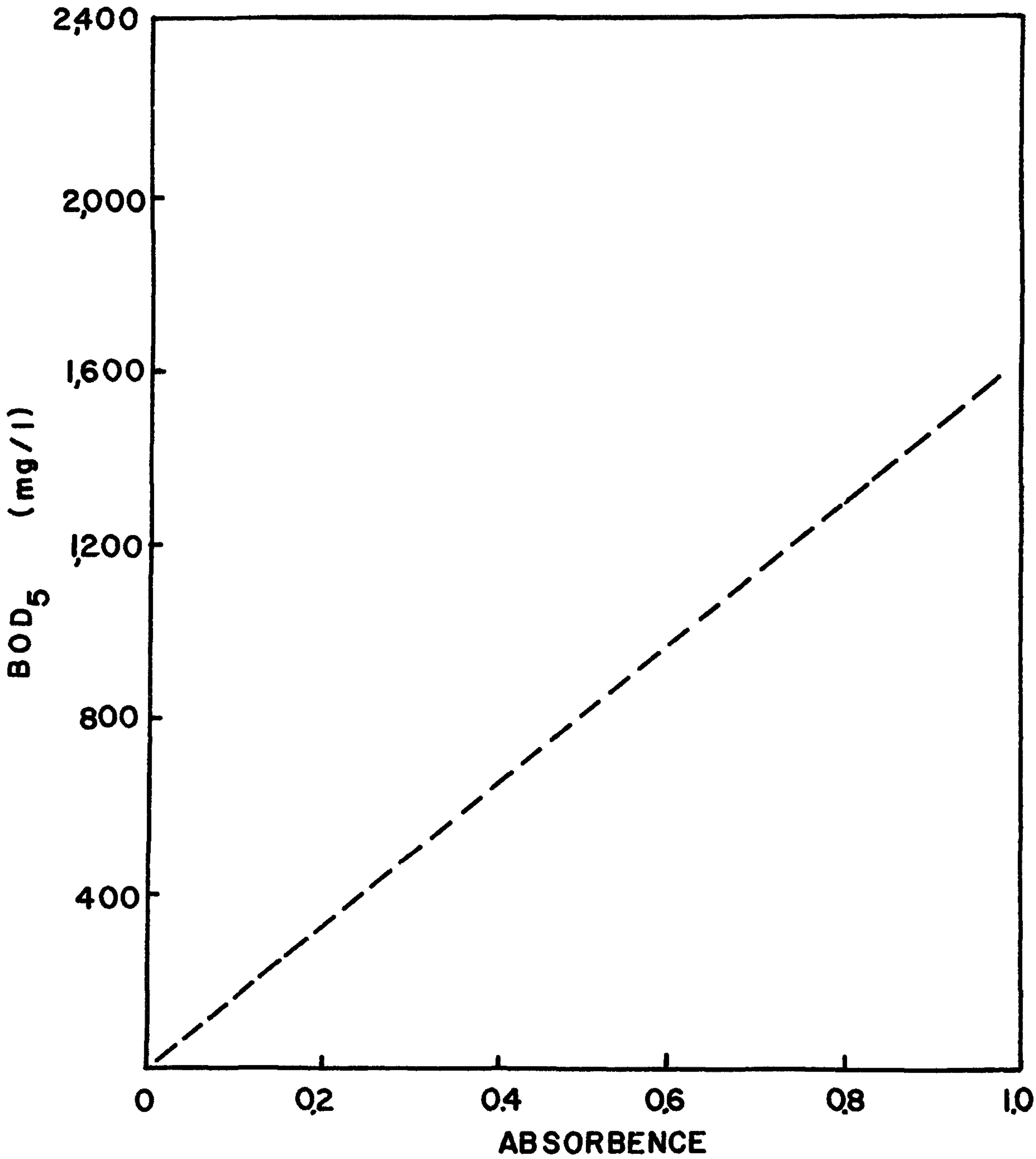
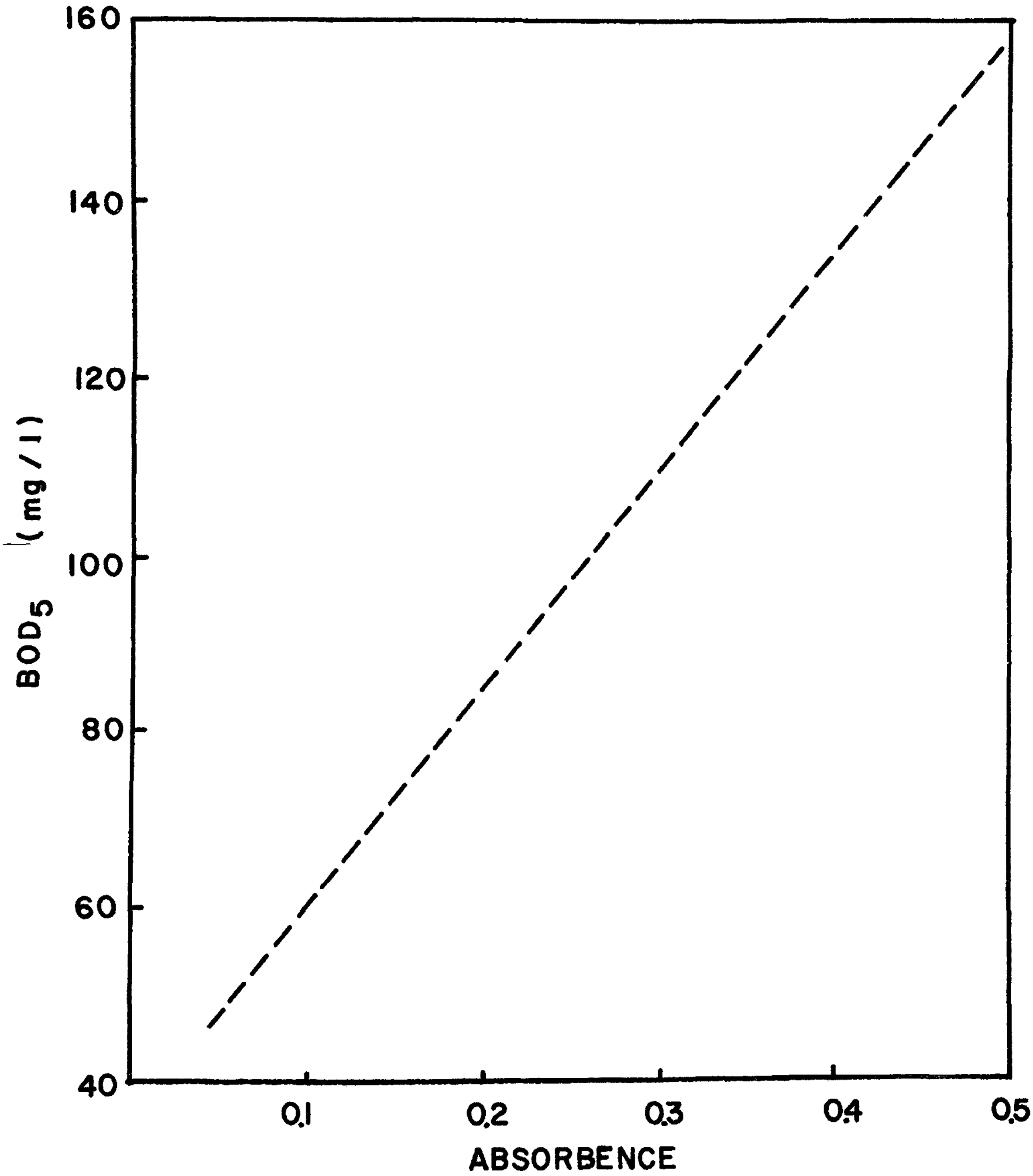


FIGURE 43

RELATIONSHIP BETWEEN BOD_5 AND LIGHT ABSORBENCE OF EVAPORATOR JET CONDENSER WATER



monitor evaporation operation. These instruments can also be equipped with audible or visual signal devices for informing the operators immediately if losses are high. Conductivity is sometimes used to activate valves diverting waste streams to holding ponds during periods of high losses resulting from operational problems, breakdowns, or accidents within the mill. The linear relationship between conductance and total dissolved solids is shown in Figure 44.

Level-indicating devices on overflow weirs are frequently used to indicate flowage from unit processes or from segments of a mill. These serve to call attention to inadvertent discharge from storage chests and tanks which can seriously affect sewer losses.

Some work has been done in respect to employing continuous turbidity and suspended solids content recording for paper mill effluents. The turbidity measurement operates satisfactorily if maintenance is good, but maintenance is more urgently needed in this application than is required in the continuous measurement of process or potable water turbidity. Color, however, can interfere with this measurement.

Ostendorf and Byrd (274) used a total carbon analyzer to estimate the BOD value of a sulfite mill effluent with satisfactory results and have since applied it to the effluent of another sulfite mill treating its waste by the activated sludge process. The same authors applied a new instrument for the continuous measurement of suspended solids in the effluent. Unlike turbidity measurement devices this instrument employs both opacity and light scattering and the readings correlate well with suspended solids content of effluent in the 100 to 200 mg/l range. The authors present correlative curves for both the organic carbon and suspended solids instruments.

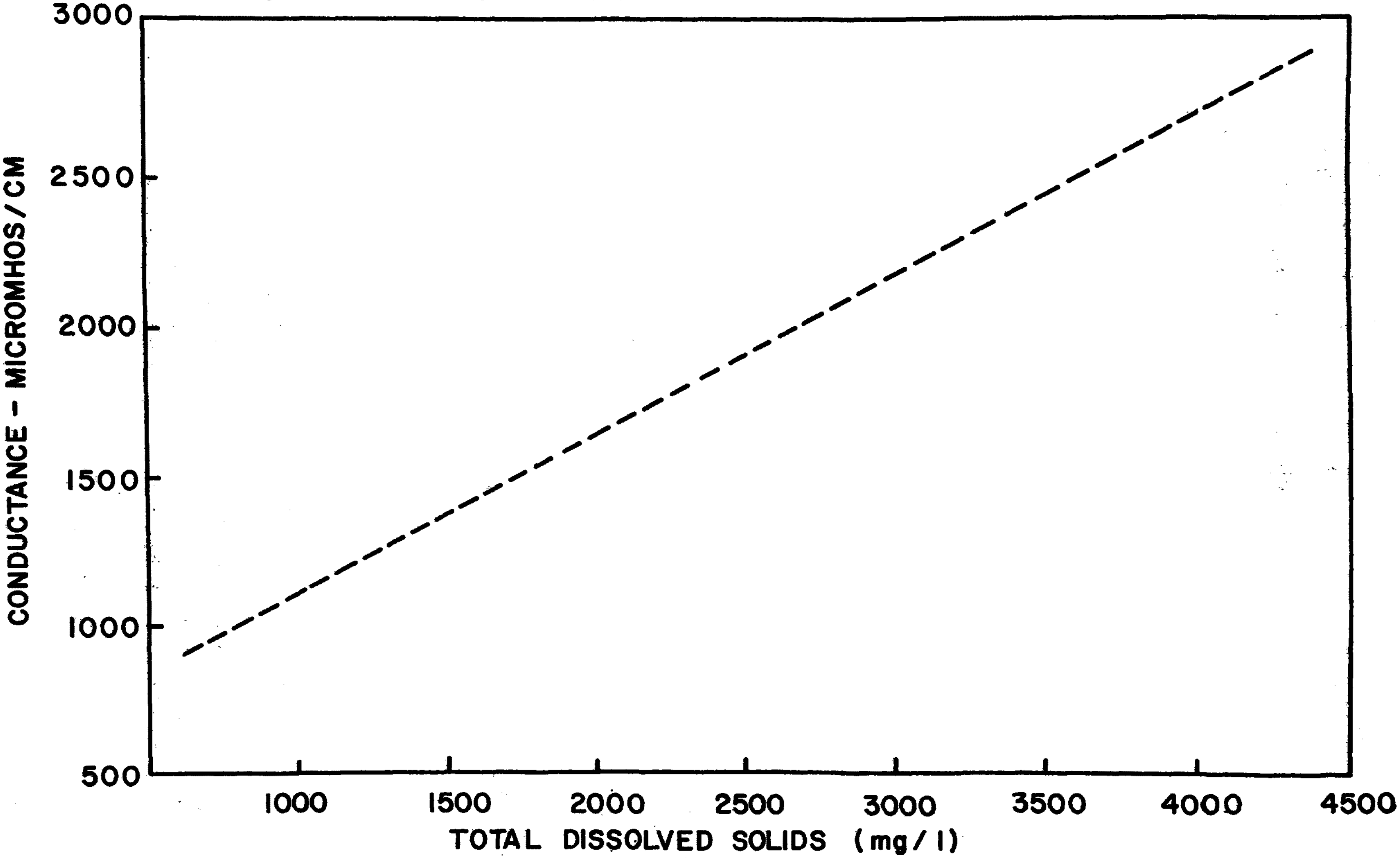
Dissolved oxygen content of wastes under treatment and on discharge is frequently recorded at pulp and paper mills employing a variety of the instruments marketed for this purpose. These require routine attention if reliable results are to be expected.

The pH value, like conductivity, has been used to indicate high pulp mill losses, but the latter is preferable since it provides a much better indication of magnitude. Since some wastes, such as sulfite pulp wash water and acid bleaching wastes, require neutralization, pH recorders are used to monitor and control automatically the dosage of neutralizing chemical required.

Interest has been shown recently in application of selective ion electrodes for monitoring pulp mill effluents. Schwartz and Light (275) report on the use of a sulfide ion electrode; others have been experimenting with a sodium ion electrode.

FIGURE 44

RELATIONSHIP OF TOTAL DISSOLVED SOLIDS TO CONDUCTANCE OF KRAFT DECKER SEAL PIT WATER



SECTION XIV

ACKNOWLEDGEMENTS

Members of the administration and staff of WAPORA, Inc. who were associated with the assembly of information and writing of this "state-of-the-art" report on the nature and treatment of pulp and paper mill effluents are appreciative for the guidance received from Mr. George R. Webster and Mr. Ralph H. Scott of EPA throughout its preparation. They are greatly indebted to individual pulp and paper manufacturers who granted access to their mills and treatment works, made operating records available, and whose technical personnel critically reviewed portions of this text.

Appreciation is extended to the National Council for Air and Stream Improvement of the paper industry whose extensive research, development, and survey information covering a period of close to 30 years formed the framework of this study. Information supplied by the American Paper Institute and the Institute of Paper Chemistry is also most appreciated.

The assistance obtained from universities and personnel of state agencies concerned with water quality is herein recognized.

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SECTION XVI

APPENDICES

Economics Department
September, 1971

APPENDIX I

PAPER AND PAPERBOARD PRODUCTS, IMPORTS, EXPORTS AND NEW SUPPLY

CENSUS DATA
(000 Tons)

	PAPER				PAPERBOARD				OTHER GRADES				TOTAL			
	Production	Imports	Exports	New Supply	Production	Imports	Exports	New Supply	Production	Imports	Exports	New Supply	Production	Imports	Exports	New Supply
1947	9,416	4,062	310	13,167	9,187	27	114	9,100	2,499	[illegible]	50	2,4[illegible]3	21,102	4,122	474	24,749
1948	9,797	4,506	241	14,062	9,366	45	112	9,299	2,734	31	43	2,721	21,897	4,582	397	26,083
1949	9,199	4,680	234	13,645	8,997	47	102	8,942	2,120	24	36	2,107	20,315	4,752	372	24,695
1950	10,638	4,920	225	15,333	10,926	54	111	10,868	2,811	35	36	2,810	24,375	5,008	372	29,012
1951	11,625	5,033	347	16,310	11,620	78	250	11,449	2,802	39	39	2,802	26,047	5,150	635	30,561
1952	10,848	5,104	333	15,620	10,772	56	173	10,654	2,748	31	36	2,743	24,418	5,191	592	29,017
1953	11,366	5,103	238	16,232	12,335	97	283	12,229	2,902	31	34	2,900	26,605	5,231	[illegible]	31,360
1954	11,649	5,089	378	16,360	12,191	52	272	11,970	3,037	49	38	3,050	26,876	5,190	687	31,379
1955	12,905	5,268	475	17,698	13,867	45	330	13,582	3,407	73	41	3,439	30,179	5,386	845	34,719
1956	13,990	5,715	399	19,306	14,234	31	338	13,928	3,217	69	44	3,242	31,441	5,815	782	36,496
1957	13,581	5,343	448	18,475	14,062	45	379	13,728	3,024	83	43	3,065	30,666	5,472	870	35,268
1958	13,497	5,017	411	18,103	14,150	47	406	13,790	3,176	85	35	3,226	30,823	5,149	853	35,119
1959	15,071	5,440	392	20,118	15,459	44	482	15,021	3,405	139	38	3,505	33,935	5,622	912	38,725
1960	15,399	5,574	427	20,546	15,676	37	563	15,150	3,369	111	37	3,443	34,444	5,722	1,027	39,138
1961	15,823	5,621	489	20,955	16,535	42	685	15,892	3,391	115	41	3,465	35,749	5,778	1,215	40,312
1962	16,537	5,673	439	21,770	17,484	46	715	16,816	3,519	149	39	3,629	37,541	5,888	1,193	42,216
1963	17,260	5,592	473	22,418	18,239	45	829	17,455	3,691	189	38	3,841	39,230	5,826	1,341	43,715
1964	18,152	6,139	562	23,729	19,605	15	1,098	18,522	3,946	232	44	4,133	41,703	6,386	1,705	46,384
1965	19,187	6,531	566	25,152	20,834	14	1,178	19,670	4,059	255	34	4,280	44,080	6,800	1,778	49,102
1966	20,653	7,270	618	27,305	22,574	57	1,295	21,336	3,887	193	41	4,039	47,113	7,520	1,954	52,680
1967	20,944	6,897	589	27,252	22,085	20	1,470	20,635	3,897	198	39	4,056	46,926	7,115	2,097	51,[illegible]
1968	22,398	6,765	641	28,522	24,504	28	1,957	22,575	4,343	266	42	4,568	51,245	7,041	2,640	55,647
1969	23,504	7,186	619	30,071	26,022	23	2,084	23,962	4,531	284	63	4,753	54,057	7,493	2,766	58,784
1970P	23,220	7,045	616	29,649	24,940	12	2,163	22,789	4,297	211	64	4,443	52,457	7,268	2,843	56,881
1971F	24,050	7,100	615	30,545	25,630	10	2,100	23,540	4,614	215	65	4,764	54,394	7,325	2,780	58,939
1972F	25,315	7,400	615	32,100	27,235	15	2,200	25,050	4,825	245	65	5,005	57,375	7,660	2,880	62,155
1973F																
1974F																
1975F	29,[illegible]	8,370	615	37,269	31,873	20	2,805	29,088	5,624	330	60	5,894	67,211	8,[illegible]	3,[illegible]	72,[illegible]
1980F	36,035	9,810	745	45,100	38,590	30	3,420	35,200	6,745	360	60	7,045	81,370	10,200	4,225	87,345
1985F	43,260	+11,000		54,260	46,300	-4,000		42,300	8,115	+400		8,515	97,675	+7,400		105,075
1990F	52,700	+13,000		65,700	55,700	-4,500		51,200	9,850	+450		10,300	118,250	+8,950		127,200

F - Forecast by Economics Department. American Paper Institute.
P - Preliminary and Forecast.

APPENDIX 2 .—*Apparent consumption of paper and board by grade, 1920-* 1966

Year	Total paper and board		Total paper		Newsprint		Groundwood paper		Book paper						Fine paper		Coarse and industrial paper		Sanitary and tissue paper	
	Total [1]	Annual rate of increase [2]	Total [1]	Annual rate of increase [2]	Total	Annual rate of increase [2]	Total	Annual rate of increase [2]	Total [1]	Annual rate of increase [2]	Coated	Annual rate of increase [2]	Uncoated	Annual rate of increase [2]	Total	Annual rate of increase [2]	Total	Annual rate of increase [2]	Total	Annual rate of increase [2]
	Million tons	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*
1920	7.7	--	5.4	--	2.2	--	0.2	--	0.9	--	--	--	--	--	0.4	--	1.2	--	0.2	--
1925	10.4	6.2	7.1	5.6	3.0	6.4	.2	--	1.2	5.9	--	--	--	--	.5	4.6	1.4	3.1	.3	8.4
1930	12.3	3.4	8.4	3.4	3.5	3.1	.2	--	1.4	3.1	--	--	--	--	.7	7.0	1.8	5.2	.4	5.9
1935	12.8	.8	8.2	--	3.4	--	.4	14.9	1.3	--	--	--	--	--	.6	--	1.7	--	.5	4.6
1940	16.8	5.6	10.6	5.3	3.7	1.7	.6	8.4	1.6	4.2	--	--	--	--	.7	3.1	2.6	8.9	.7	7.0
1945	19.8	3.3	11.0	.7	3.5	--	.6	--	1.5	--	0.8	--	1.1	--	.9	5.2	2.7	.8	1.0	7.4
1950	29.1	8.0	16.8	8.8	5.9	11.0	.7	3.1	2.6	11.6	1.0	27.2	1.6	7.8	1.2	5.9	3.7	6.5	1.4	7.0
1955	35.0	3.8	19.4	2.9	6.5	2.0	.9	5.2	3.0	2.9	1.3	5.4	1.8	2.4	1.4	3.1	4.2	2.6	1.8	5.2
1960	39.3	2.3	22.1	2.6	7.4	2.6	.9	--	3.8	4.8	1.8	6.7	1.9	1.1	1.7	4.0	4.7	2.3	2.2	4.1
1961	40.5	3.1	22.5	1.8	7.4	--	.9	--	3.8	--	2.1	16.7	1.7	--	1.9	11.8	4.8	2.1	2.3	4.5
1962	42.3	4.4	23.2	3.6	7.5	1.4	.9	--	4.0	5.3	2.2	4.8	1.8	5.9	2.0	5.3	5.0	4.2	2.4	4.4
1963	43.9	3.8	24.0	3.4	7.6	1.3	1.0	11.1	4.3	7.5	2.4	9.1	1.9	5.6	2.1	5.0	5.1	2.0	2.6	8.3
1964	46.6	6.1	25.4	5.8	8.1	6.6	1.0	--	4.6	7.0	2.6	8.3	2.0	5.3	2.2	4.8	5.2	2.0	2.7	3.9
1965 [3]	48.9	4.9	26.6	4.7	8.4	3.7	1.0	--	5.0	8.7	2.8	7.7	2.2	10.0	2.4	9.1	5.5	5.8	2.8	3.7
1966 [3]	52.3	7.0	28.4	6.8	9.1	8.3	1.1	10.0	5.5	10.0	3.0	7.1	2.5	13.6	2.6	8.3	5.6	1.8	3.0	7.1
									PROJECTED DEMAND											
1970	60.3	4.3	32.0	3.8	9.7	2.9	1.2	3.7	6.3	4.7	3.8	6.3	2.5	2.6	3.1	5.3	6.3	2.8	3.7	5.7
1975	72.1	3.6	37.7	3.3	11.0	2.5	1.3	1.6	7.8	4.4	5.0	5.6	2.8	2.3	3.7	3.6	7.4	3.3	4.7	4.9
1980	85.9	3.6	44.4	3.3	12.5	2.6	1.4	1.5	9.5	4.0	6.3	4.7	3.2	2.7	4.6	4.4	8.6	3.1	5.9	4.7
1985	101.5	3.4	51.7	3.1	14.3	2.7	1.5	1.4	11.4	3.7	7.8	4.4	3.6	2.4	5.6	4.0	9.8	2.6	7.1	3.8

Year	Construction paper		Total board		Container board		Bending board						Building board						Other board	
	Total	Annual rate of increase [2]	Total [1]	Annual rate of increase [2]	Total	Annual rate of increase [2]	Total [1]	Annual rate of increase [2]	Special food board	Annual rate of increase [2]	Folding box-board	Annual rate of increase [2]	Total [1]	Annual rate of increase [2]	Insulating board	Annual rate of increase [2]	Hard-board	Annual rate of increase [2]	Total	Annual rate of increase [2]
	Million tons	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*
1920	0.4	--	2.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1925	.6	8.4	3.3	7.5	--	--	--	--	--	--	--	--	0.1	--	--	--	--	--	--	--
1930	.5	--	3.9	3.4	--	--	1.0	--	--	--	--	--	.1	--	--	--	--	--	--	--
1935	.4	--	4.6	3.4	--	--	1.1	1.9	--	--	--	--	.1	--	--	--	--	--	--	--
1940	.7	11.8	6.2	6.2	3.3	--	1.4	4.9	--	--	--	--	.2	14.9	--	--	--	--	1.3	--
1945	.9	5.2	8.8	7.3	4.1	4.4	2.3	10.4	0.4	--	1.9	--	.9	35.0	0.6	--	0.3	--	1.6	4.2
1950	1.4	9.2	12.3	6.9	5.8	7.2	3.1	6.2	.7	11.8	2.5	5.6	1.2	5.9	.8	5.9	.4	5.9	2.1	5.6
1955	1.6	2.7	15.6	4.9	7.4	5.0	3.9	4.7	1.2	11.4	2.8	2.3	1.7	7.2	1.1	6.6	.6	8.4	2.6	4.4
1960	1.4	--	17.2	2.0	8.2	2.1	4.4	2.4	1.5	4.6	2.9	.7	1.9	2.2	1.1	--	.8	5.9	2.7	.8
1961	1.4	--	18.0	4.6	8.8	7.3	4.5	2.3	1.6	6.7	2.9	--	1.9	--	1.1	--	.9	12.5	2.8	3.7
1962	1.4	--	19.1	6.1	9.5	8.0	4.9	2.1	1.7	--	3.2	3.2	2.3	10.5	1.1	--	1.0	11.1	2.8	--
1963	1.4	--	19.9	4.2	9.8	3.2	4.8	6.7	1.7	6.2	3.1	6.9	2.1	9.5	1.1	--	1.1	10.0	2.9	3.6
1964	1.5	7.1	21.2	6.5	10.6	8.2	5.2	6.1	1.8	5.9	3.3	3.1	2.4	4.3	1.2	9.1	1.2	9.1	3.0	3.4
1965 [3]	1.6	6.7	22.3	5.2	11.3	6.6	5.4	3.8	2.1	16.7	3.3	--	2.5	4.2	1.3	8.3	1.2	--	3.2	6.7
1966 [3]	1.5	--	23.9	7.2	12.5	10.6	5.7	5.6	2.2	4.8	3.5	6.1	2.4	--	1.2	--	1.2	--	3.3	3.1

APPENDIX 3—*Apparent consumption of wood pulp by type, 1920–1966*

Year	Total wood pulp		Dissolving and special alpha[1]		Sulfite		Sulfate		Soda		Groundwood		Semichemical		Defibrated, exploded, and screenings	
	Total [2]	Annual rate of increase [3]	Total	Annual rate of increase [3]	Total	Annual rate of increase [3]	Total	Annual rate of increase [3]	Total	Annual rate of increase [3]	Total	Annual rate of increase [3]	Total	Annual rate of increase [3]	Total	Annual rate of increase [3]
	Million tons	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*
1920	4.7	--	--	--	--	--	0.4	--	--	--	1.8	--	--	--	--	--
1925	5.6	4.0	--	--	2.3	--	.8	14.9	0.5	--	1.9	1.1	--	--	--	--
1930	6.4	2.7	--	--	2.6	2.5	1.4	11.8	.5	--	1.9	--	(4)	--	--	--
1935	6.7	.9	--	--	2.3	--	2.1	8.4	.4	--	1.5	--	0.1	--	--	--
1940	9.7	7.7	0.3	--	2.7	3.3	3.9	13.2	.5	4.6	1.8	3.7	.2	14.9	0.3	--
1945	11.8	4.0	.5	10.8	2.8	.7	4.9	4.7	.4	--	2.0	2.1	.3	8.4	.8	22.1
1950	17.1	7.7	.7	7.0	3.2	2.7	3.4	11.4	.6	8.4	2.5	4.6	.7	18.5	1.1	6.6
1955	22.3	5.5	1.0	7.4	3.2	--	11.9	7.2	.5	--	3.0	3.7	1.4	14.9	1.3	3.4
1960	26.6	3.6	1.0	--	3.1	--	15.2	5.0	.5	--	3.6	3.7	2.0	7.4	1.3	--
1961	27.8	4.5	1.0	--	3.1	--	16.1	5.9	.5	--	3.5	--	2.4	20.1	1.3	--
1962	29.5	6.1	1.1	10.0	3.0	--	17.3	7.5	.4	--	3.7	5.7	2.5	4.2	1.4	7.7
1963	31.5	6.8	1.1	--	3.1	3.3	18.8	8.7	.4	--	3.8	2.7	2.6	4.0	1.6	14.3
1964	33.8	7.3	1.2	9.1	3.1	--	20.9	11.2	.4	--	3.9	2.6	2.7	3.8	1.6	--
1965 [5]	35.0	3.6	1.2	--	3.3	6.5	21.7	3.8	.2	--	4.3	10.3	2.9	7.4	1.5	--
1966 [5]	37.4	6.9	1.3	8.3	3.3	--	23.7	9.2	.2	--	4.3	--	3.2	10.3	1.5	--

[1] Includes a number of highly purified types of wood pulp obtained from the sulfite and sulfate pulping processes.

[2] Data prior to 1940 may not add to totals because of the inclusion in the totals of wood pulps not shown separately by type. In other years, figures in columns may not add to totals because of rounding.

[3] The average annual rate of increase for 5-year periods ending in the specified years except for the years 1961–66 when annual changes are shown.

[4] Less than 50 thousand tons.

[5] Preliminary.

NOTE: Annual data on production, trade, and consumption by type of pulp are shown in the tables in appendix E.

Sources: United States Pulp Producers Association, Inc., op. cit.; U.S. Department of Commerce, Bureau of the Census. *Pulp, paper and board;* U.S. Department of Commerce, Business and Defense Services Administration, op. cit.; and U. S. Department of Agriculture, Forest Service.

Year End Paper and Paperboard Capacity 1970–1974 Summary by Group

PRELIMINARY

PRACTICAL MAXIMUM CAPACITY — THOUSANDS OF TONS

GRADES	1970	1971	1972	1973	1974
TOTAL ALL GRADES PAPER AND PAPERBOARD	58,952	60,400	62,055	63,475	64,214
TOTAL PAPER	25,806	26,138	26,588	27,025	27,398
NEWSPRINT	3,460	3,472	3,481	3,564	3,721
PRINTING, WRITING and RELATED	12,219	12,519	12,940	13,094	13,265
Solid Bleached Bristols	1,112	1,113	1,118	1,123	1,132
PACKAGING AND INDUSTRIAL CONV.	5,940	5,886	5,828	5,875	5,916
TISSUE	4,185	4,260	4,338	4,492	4,497
TOTAL PAPERBOARD	27,619	28,468	29,523	30,376	30,699
UNBLEACHED KRAFT	12,307	12,770	13,420	13,708	13,798
Kraft Linerboard	11,516	11,964	12,594	12,845	12,904
SOLID BLEACHED	3,472	3,555	3,598	3,807	3,993
SEMI-CHEMICAL	3,756	4,058	4,329	4,594	4,616
COMBINATION	8,084	8,086	8,176	8,267	8,291
TOTAL CONSTRUCTION PAPER AND BOARD AND WET MACHINE BOARD	5,527	5,794	5,944	6,074	6,117

APPENDIX 5

THOUSANDS OF TONS

PAPER AND PAPERBOARD	ADDITIONS 1956 - 1971		CAPACITY FORECAST	ADDITIONS 1972 - 1974			
				COMMITTED		COMMITTED AND TENTATIVE	
	16 YEAR INCREASE	AVERAGE ANNUAL GROWTH	END 1971	3 YEAR INCREASE	AVERAGE ANNUAL GROWTH	3 YEAR INCREASE	AVERAGE ANNUAL GROWTH
TOTAL ALL GRADES	27,231	3.8%	60,400	3,814	2.1%	4,187	2.3%
TOTAL PAPER	12,381	4.8	26,138	1,260	1.6	1,413	1.8
NEWSPRINT	1,941	5.2	3,472	249	2.3	319	3.0
PRINTING, WRITING & RELATED	6,319	4.5	12,519	745	1.9	774	2.0
PACKAGING & IND. CONV.	1,698	2.1	5,886	30	.2	30	.2
TISSUE	2,422	5.4	4,260	237	1.8	291	2.2
TOTAL PAPERBOARD	12,856	3.8	28,468	2,231	2.5	2,451	2.8
UNBL. KRAFT	8,156	6.6	12,770	1,028	2.6	1,028	2.6
SOLID BLEACHED	2,232	6.4	3,555	439	4.0	439	4.0
SEMI-CHEMICAL	2,595	6.6	4,058	558	4.4	778	6.0
COMBINATION	(126)	(.7)	8,086	205	.8	205	.8
TOTAL CONSTRUCTION PAPER & BOARD & WET MACHINE BOARD	1,994	2.7	5,794	323	1.8	323	1.8

—GROWTH TRENDS IN PAPER, PAPERBOARD AND WOOD PULP CAPACITY

Source - Paper Trade Journal 11/22/71

APPENDIX 6

PAPER AND PAPERBOARD CAPACITY BY CENSUS DIVISIONS

CENSUS DIVISIONS	YEAR END 1969 PAPER	YEAR END 1969 PAPER-BOARD	YEAR END 1969 TOTAL PAPER & PAPER-BOARD*	YEAR END 1969 WOOD PULP	YEAR END 1972 PAPER	YEAR END 1972 PAPER-BOARD	YEAR END 1972 TOTAL PAPER & PAPER-BOARD*	YEAR END 1972 WOOD PULP
	(THOUSANDS OF TONS)							
NEW ENGLAND	3,767	1,004	4,975	2,897	4,129	1,006	5,343	3,096
MIDDLE ATLANTIC	3,331	2,424	6,637	1,510	3,713	2,521	7,194	1,746
SOUTH ATLANTIC	3,370	9,661	13,580	14,287	3,432	10,421	14,445	15,299
EAST SOUTH CENTRAL	2,714	3,182	6,677	7,155	3,009	3,535	7,330	7,822
WEST SOUTH CENTRAL	2,915	2,961	6,756	6,450	3,201	4,162	8,266	8,009
EAST NORTH CENTRAL	5,160	4,131	10,087	3,212	5,475	4,321	10,652	3,513
WEST NORTH CENTRAL	592	429	1,630	1,000	641	442	1,718	1,062
TOTAL WEST (PACIFIC PLUS MOUNTAIN)	3,407	4,046	8,030	8,744	3,648	4,400	8,680	9,224
TOTAL U.S.	25,257	27,837	58,372	45,255	27,246	30,807	63,630	49,770

Details may not add to totals due to rounding.
*Includes Construction and Wet Machine Board Grades.

Source - Monthly Statistical Summary
XLVIII, No. 12, December 1970
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APPENDIX 7

U. S. PAPER AND BOARD PER CAPITA CONSUMPTION

CENSUS DATA

Year	Lbs./Capita
1899	57.9
1904	73.7
1909	90.8
1914	108.8
1919	119.6
1924	162.6
1929	220.3
*1934	178.6
1939	243.7
1944	281.6
1947	343.4
1948	355.9
*1949	331.0
1950	381.1
1951	394.6
*1952	368.3
1953	391.6
*1954	385.0
1955	418.5
1956	432.2
*1957	410.1
*1958	401.6
1959	435.5
*1960	433.3
1961	439.0
1962	452.7
1963	462.1
1964	483.6
1965	505.6
1966	536.2
*1967	523.0
1968R	554.9
1969R	580.3
*1970P	555.6

P - Preliminary
R - Revised

*   Years of economic recession (added by author).

SOURCE: American Paper Institute

APPENDIX 8

PAPER AND ALLIED PRODUCTS INDUSTRY, PROFIT & LOSS DATA
CASH INFLOW AND SELECTED BALANCE SHEET DATA - YEARS - 1947 - 1970

Year	Net Sales	Net Profit Before Taxes	Federal Taxes	Net Profit After Taxes	Net Profit After Taxes To Net Sales	Depreci- ation	Cash Inflow	Gross Cash Flow
	- - - - - - - - (Millions of Dollars			- - - - -	(Per Cent) - - -	(Millions of Dollars- - -		
1947	5,368	932	359	573	10.7	92	N.A.	N.A.
1948	5,833	818	314	494	8.5	112	N.A.	N.A.
1949	5,177	547	210	338	6.5	153	491	701
1950	6,377	982	424	558	8.8	162	720	1,144
1951	8,022	1,417	858	559	6.9	183	742	1,600
1952	7,688	1,000	563	437	5.7	222	659	1,222
1953	8,371	1,005	554	450	5.4	242	692	1,246
1954	8,492	970	493	479	5.6	268	718	1,211
1955	9,847	1,206	601	604	6.1	310	914	1,515
1956	10,686	1,283	626	657	6.1	360	1,017	1,643
1957	10,420	1,020	497	521	5.0	376	897	1,394
1958	10,256	899	440	460	4.5	406	866	1,306
			FTC - SEC - AS PUBLISHED					
1958	10,658	987	481	506	4.7	423	929	1,410
1959	11,824	1,204	585	619	5.2	459	1,078	1,663
1960	11,764	1,135	546	587	5.0	480	1,067	1,613
1961	12,525	1,120	535	583	4.7	531	1,114	1,649
1962	13,698	1,212	584	628	4.6	583	1,211	1,795
1963	14,050	1,215	581	634	4.5	615	1,249	1,830
1964	14,771	1,312	557	754	5.1	641	1,395	1,952
1965*	16,224	1,488	619	869	5.4	671	1,540	2,159
		DATA ADJUSTED BY API FOR CONSISTENCY WITH PRE - 1959 DATA						
1959	11,323	1,075	520	555	4.9	440	995	1,515
1960	11,214	997	479	516	4.6	459	975	1,454
1961	11,911	974	464	508	4.3	506	1,014	1,478
1962	12,998	1,042	498	544	4.2	555	1,099	1,597
1963	13,288	1,033	490	543	4.1	586	1,129	1,619
1964	13,861	1,115	463	652	4.7	602	1,254	1,717
			FTC - SEC - AS PUBLISHED					
1965	15,217	1,271	517	753	4.9	632	1,385	1,902
1966	17,016	1,544	633	911	5.4	676	1,587	2,220
		DATA ADJUSTED FOR CONSISTENCY WITH 1967 DATA						
1965R	14,789	- - - -N.A.- - - -		735	5.0	- - - - -N.A.- - - - - -		
1966R	16,541	- - - -N.A.- - - -		889	5.4	- - - - -N.A.- - - - - -		
			FTC - SEC - AS PUBLISHED					
1967	16,900	1,316	523	796	4.7	723	1,519	2,039
1968	18,738	1,534	645	889	4.7	780	1,669	2,314
1969	20,607	1,675	688	987	4.8	821	1,808	2,496
1970	21,069	1,211	492	719	3.4	869	1,588	2,080

SOURCE: Yearly data calculated by API based on Federal Trade Commission-Securities & Exchange Commission, Quarterly Financial Report for Manufacturing Corporations, 1947 1970

* Estimated by API in terms of 1958-1964 definitions.

R. - 1965 and 1966 data revised by API for consistency with 1967 data.

N.A. Not available.

PAPER AND ALLIED PRODUCTS INDUSTRY, PROFIT & LOSS DATA

CASH INFLOW AND SELECTED BALANCE SHEET DATA - YEARS - 1947 - 1970

Cash Dividend	Retained Earnings	Total Assets	Property Plant & Equipment Gross	Property Plant & Equipment Net	Net Worth	Long Term Debt	Total Capital	Net Profit After Taxes To Net Worth
(Millions of Dollars)								(Per Cent)
146	427	3,907	N.A.	1,660	2,755	404	3,159	20.8
166	328	4,316	N.A.	1,990	3,048	491	3,539	16.2
146	192	4,384	N.A.	2,074	3,228	500	3,728	10.5
178	380	5,055	N.A.	2,285	3,585	490	4,075	15.6
200	359	6,005	N.A.	2,600	3,963	625	4,588	14.1
196	241	6,301	4,643	2,777	4,298	784	5,082	10.1
203	247	6,825	5,349	3,273	4,559	803	5,362	9.9
227	252	7,085	5,694	3,367	4,963	908	5,871	9.7
259	345	7,785	6,171	3,623	5,403	1,010	6,413	11.2
273	384	8,492	7,028	4,213	5,772	1,286	7,058	11.4
270	251	8,407	7,502	4,509	5,809	1,309	7,118	8.9
265	195	8,829	7,941	4,652	6,089	1,472	7,561	7.6
FTC - SEC - AS PUBLISHED								
286	220	9,170	8,200	4,818	6,341	1,500	7,841	8.0
290	329	9,721	8,740	5,062	6,642	1,512	8,154	9.3
312	275	10,087	9,432	5,385	6,956	1,622	8,578	8.4
328	255	11,051	10,447	5,857	7,612	1,719	9,331	7.6
340	288	11,670	11,058	6,062	7,766	1,953	9,719	8.1
348	286	11,859	11,420	6,079	7,886	1,964	9,850	8.0
376	378	12,560	12,380	6,585	8,304	1,967	10,271	9.1
409	461	13,850	13,378	7,321	8,672	2,439	11,111	10.0
DATA ADJUSTED BY API FOR CONSISTENCY WITH PRE - 1959 DATA								
265	290	9,342	8,627	4,965	6,367	1,492	7,859	8.7
282	234	9,640	9,246	5,272	6,624	1,491	8,115	7.8
295	212	10,537	10,240	5,724	7,225	1,662	8,887	7.0
299	245	11,089	10,838	5,907	7,327	1,745	9,071	7.4
301	242	11,206	11,160	5,899	7,398	1,894	9,299	7.3
323	329	11,791	11,848	6,280	7,731	1,959	9,690	8.4
FTC - SEC - AS PUBLISHED								
350	403	13,017	13,047	7,053	8,165	2,447	10,612	9.2
372	539	14,621	14,662	8,131	8,710	3,104	11,814	10.5
DATA ADJUSTED FOR CONSISTENCY WITH 1967 DATA								
N.A.								
N.A.					8,510	N.A.		10.4
FTC - SEC - AS PUBLISHED								
391	405	15,645	15,403	8,579	9,011	3,736	12,747	8.8
396	493	16,809	16,059	8,964	9,303	4,199	13,502	9.6
418	569	18,794	17,169	9,529	10,212	4,267	14,479	9.7
430	289	19,679	18,160	9,969	10,305	4,822	15,127	7.0

N.A. Not Available.

APPENDIX 9

GROUNDWOOD PULP MILLS IN THE UNITED STATES

Alabama	Kimberly-Clark Corp., Coosa Pines International Paper Co., Mobile National Gypsum Co., Mobile
Arizona	Ponderosa Paper Products Inc., Flagstaff Southwest Forest Industries Inc., Snowflake
Arkansas	International Paper Co., Pine Bluff
California	Kimberly-Clark Corp., Anderson
Georgia	Cox Newsprint, Inc., Augusta
Louisiana	Boise Southern Co., DeRidder St. Francisville Paper Co., St. Francisville
Maine	Statler Tissue Corp., Augusta Hearst Corp., Brunswick St. Regis Paper Co., Bucksport Great Northern Paper Co., East Millinocket International Paper Co., Jay International Paper Co., Livermore Falls Kennebec River Pulp & Paper Co., Madison Great Northern Paper Co., Millinocket Oxford Paper Co., Rumford Keyes Fibre Co., Shawmut
Michigan	Escanaba Paper Co., Escanaba Manistique Pulp & Paper Co., Manistique Scott Paper Co., Menominee
Minnesota	Blandin Paper Co., Grand Rapids Boise Cascade Corp., International Falls Henepin Paper Co., Little Falls St. Regis Paper Co., Sartell
Missouri	Packaging Corp. of America, North Kansas City

New York	J. P. Lewis Co., Beaver Falls International Paper Co., Corinth St. Regis Paper Co., Deferiet Stevens & Thompson Paper Co., Greenwich Kimberly-Clark Corp., Niagara Falls
Oregon	Publisher's Paper Co., Newberg Publisher's Paper Co., Oregon City Crown Zellerbach Corp., Wanna Crown Zellerbach Corp., West Linn
South Carolina	Bowaters Carolina Corp., Catawba Bowaters Carolina Corp., Catawba
Tennessee	Bowaters Southern Paper Corp., Calhoun
Texas	Southland Paper Inc., Houston Southland Paper Inc., Lufkin United States Plywood-Champion Papers Inc., Pasadena
Vermont	Standard Packaging Corp., Sheldon Springs
Washington	Crown Zellerbach Corp., Camas Scott Paper Co., Everett Inland Empire Paper Co., Millwood Crown Zellerbach Corp., Port Angeles Boise Cascade Corp., Steilacoom Keyes Fibre Co., Wenatchee
Wisconsin	Combined Paper Mills Inc., Combined Locks St. Regis Paper Co., Cornell American Can Co., Green Bay Charmin Paper Products Co., Green Bay Kimberly-Clark Corp., Kimberly Kimberly-Clark Corp., Niagara Consolidated Papers, Inc., Stevens Point Consolidated Papers, Inc., Wisconsin Rapids

KRAFT PULP MILLS IN THE UNITED STATES

Alabama	Container Corp. of America, Brewton Kimberly-Clark Corp., Coosa Pines U. S. Plywood-Champion Papers, Inc., Courtland Gulf States Paper Corp., Demopolis Allied Paper Inc., Jackson Georgia Kraft Co., Mahrt International Paper Co., Mobile Scott Paper Co., Mobile American Can Co., Naheola MacMillan Bloedel-United Inc., Pine Hill Union Camp Corp., Prattville Hammermill Paper Co., Selma Gulf States Paper Corp., Tuscaloosa
Arizona	Southwest Forest Industries, Inc., Snowflake
Arkansas	Nekoosa-Edwards Paper Co., Ashdown International Paper Co., Camden Georgia Pacific Corp., Crossett Arkansas Kraft Corp., Morrilton International Paper Co., Pine Bluff Weyerhaeuser Co., Pine Bluff
California	Kimberly-Clark Corp., Anderson Fibreboard Corp., Antioch Crown Simpson Paper Co., Fairhaven Georgia Pacific Corp., Samoa
Florida	Container Corp. of America, Fernandina Beach Buckeye Cellulose Corp., Foley Alton Box Board Co., Jacksonville St. Regis Paper Co., Jacksonville Hudson Pulp & Paper Corp., Palatka International Paper Co., Panama City St. Regis Paper Co., Pensacola

Georgia	Continental Can Co., Inc., Augusta Brunswick Pulp & Paper Co., Cedar Springs ITT Rayonier Inc., Jesup Georgia Kraft Co., Macon Continental Can Co., Inc., Port Wentworth Interstate Paper Corp., Riceboro Georgia Kraft Co., Rome Gilman Paper Co., St. Mary's
Idaho	Potlatch Forests Inc., Lewiston
Kentucky	Western Kraft & Corrugated Container Co., Hawesville Westvaco Corp., Wickliffe
Louisiana	International Paper Co., Bastrop Crown Zellerbach Corp., Bogalusa Boise-Southern Co., DeRidder Calcasieu Paper Inc., Elizabeth Continental Can Co., Hodge Pineville Kraft Corp., Pineville Georgia Pacific Corp., Port Hudson Crown Zellerbach Corp., St. Francisville International Paper Co., Springhill
Maine	International Paper Co., Jay Premoid Corp., Lincoln Penobscot Co., Old Town Oxford Paper Co., Rumford Georgia Pacific Corp., Woodland
Maryland	Westvaco Corp., Luke
Michigan	Mead Corp., Escanaba Packaging Corp. of America, Filer City Scott Paper Co., Muskegon
Minnesota	The Northwest Paper Co., Cloquet Boise Cascade Corp., International Falls
Mississippi	St. Regis Paper Co., Monticello International Paper Co., Moss Point International Paper Co., Natchez International Paper Co., Vicksburg
Montana	Hoerner Waldorf Corp., Missoula

New Hampshire	Brown Co., Berlin
New York	International Paper Co., Ticonderoga
North Carolina	U. S. Plywood-Champion Papers, Inc., Canton Weyerhaeuser Co., New Bern Weyerhaeuser Co., Plymouth Southwest Industries Corp., Riegelwood Hoerner Waldorf Corp., Roanoke Rapids
Oklahoma	Weyerhaeuser Co., Craig
Oregon	Western Kraft Corp., Albany International Paper Co., Gardiner American Can Co., Halsey Boise Cascade Corp., St. Helens Weyerhaeuser Co., Springfield Georgia Pacific Corp., Toledo Crown Zellerbach Corp., Wanna
Pennsylvania	Penntech Papers, Inc., Johnsonburg Combined Paper Mills, Inc., Roaring Springs P. H. Glatfelter Co., Spring Grove
South Carolina	Bowaters Carolina Corp., Catawba Westvaco Corp., Charleston South Carolina Industries, Florence International Paper Co., Georgetown
Tennessee	Bowaters Southern Paper Corp., Calhoun U. S. Plywood-Champion Papers, Inc., Cortland Packaging Corp. of America, Counce
Texas	Southland Paper Mills, Inc., Houston Southland Paper Mills, Inc., Lufkin Owens-Illinois, Inc., Orange U. S. Plywood-Champion, Pasadena Eastex Corp., Silsby International Paper Co., Texarkana
Virginia	Westvaco Corp., Covington Union Camp Corp., Franklin Continental Can Co., Hopewell Chesapeake Corp. of Virginia, West Point

Washington	Crown Zellerbach Corp., Camas
	Simpson Lee Paper Co., Everett
	Weyerhaeuser Co., Everett
	Longview Fibre Co., Longview
	Weyerhaeuser Co., Longview
	Crown Zellerbach Corp., Port Townsend
	St. Regis Paper Co., Tacoma
	Boise Cascade Corp., Wallula
Wisconsin	Thilmany Pulp & Paper Co., Kaukauna
	Mosinee Paper Mills, Mosinee
	Nekoosa-Edwards Paper Co., Nekoosa
	Consolidated Papers Inc., Wisconsin Rapids

SODA PULP MILLS IN THE UNITED STATES

Massachusetts	Oxford Paper Co., Lawrence *
New York	International Paper Co., North Tonawanda Hammermill Paper Co., Oswego

* Future uncertain.

NEUTRAL SULFITE SEMI-CHEMICAL PULP MILLS IN THE UNITED STATES

California	Fibreboard Corp., Antioch
Georgia	Great Northern Paper Co., Cedar Springs Union Camp Corp., Savannah
Indiana	Weston Paper & Manufacturing Co., Terre Haute
Kentucky	Wescor Corp., Hawesville
Louisiana	International Paper Co., Bastrop Crown Zellerbach Corp., Bogalusa Continental Can Co., Inc., Hodge Olinkraft, Inc., West Monroe
Maine	Georgia Pacific Corp., Woodland
Michigan	Packaging Corp. of America, Filer City Hoerner Waldorf Corp., Ontonogon Menasha Corp., Otsego
Minnesota	Hoerner Waldorf Corp., St. Paul
New Hampshire	Brown Co., Berlin Groveton Papers Co., Groveton
New York	Georgia Pacific Corp., Lyons Falls
North Carolina	Weyerhaeuser Co., Plymouth Mead Corp., Silva
Ohio	Container Corp. of America, Circleville
Oregon	Menasha Corp., North Bend
South Carolina	Sonoco Products Co., Hartsville
Tennessee	Mead Corp., Harriman Mead Corp., Knoxville Inland Container Corp., New Johnsonville

Virginia	Owens-Illinois, Inc., Big Island Westvaco Corp., Covington Continental Can Co., Inc., Hopewell Mead Corp., Lynchburg
Washington	Longview Fibre Co., Longview Weyerhaeuser Co., Longview Boise Cascade Corp., Wallula
Wisconsin	Green Bay Packaging Inc., Green Bay Owens-Illinois Inc., Tomahawk

Key

MgO - Magnesium
CaO - Calcium
NA - Sodium
NH_3 - Ammonia

ACID SULFITE PULP MILLS IN THE UNITED STATES

		Base
Alaska	Ketchikan Pulp Co., Ketchikan	MgO
	Alaska Lumber & Pulp Co., Inc., Sitka	MgO
Florida	ITT Rayonier, Inc., Fernandina	CaO
Maine	Statler Tissue Co., Augusta	NH_3
	Great Northern Paper Co., Millinocket	MgO
	Penobscot Co., Old Town	CaO
	Scott Paper Co., Winslow	CaO
New Hampshire	Groveton Papers Co., Groveton	NH_3
New York	Finch, Pruyn & Co., Inc., Glen Falls	NH_3
Oregon	Coos Head Timber Co., Coos Bay	CaO
	Crown Zellerbach Corp., Lebanon	NH_3
	Publisher's Paper Co., Newberg	MgO
	Publisher's Paper Co., Oregon City	MgO
	Boise Cascade Corp., Salem	NH_3
Washington	Scott Paper Co., Anacortes	NH_3
	Georgia Pacific Corp., Bellingham	CaO
	Crown Zellerbach Corp., Camas	MgO
	Weyerhaeuser Co., Cosmopolis	MgO
	Scott Paper Co., Everett	NH_3
	Weyerhaeuser Co., Everett	CaO
	ITT Rayonier, Inc., Hoquiam	Na
	Weyerhaeuser Co., Longview	MgO
	Inland Empire Paper Co., Millwood	CaO
	ITT Rayonier, Inc., Port Angeles	CaO
Wisconsin	Consolidated Papers Inc., Appleton	CaO
	Wausau Paper Mills Co., Brokaw	MgO
	American Can Co., Green Bay	CaO
	Charmin Paper Products Co., Green Bay	NH_3
	Scott Paper Co., Marinette	CaO
	Scott Paper Co., Oconto Falls	NH_3
	Flambeau Paper Co., Park Falls	CaO
	Badger Paper Mills, Inc., Peshtigo	CaO
	Nekoosa-Edwards Paper Co., Port Edward	CaO
	American Can Co., Rothschild	CaO

DEINKING MILLS IN THE UNITED STATES

New York	Crown Zellerbach Corp., Carthage Newton Falls Paper Mill, Inc., Newton Falls
Ohio	Mead Corp., Chillicothe U. S. Plywood-Champion Papers, Inc., Hamilton Kimberly-Clark Corp., West Carrellton Oxford Paper Co., West Carrellton
Wisconsin	Bergstrom Paper Co., Neenah Riverside Paper Corp., Appleton

Newsprint Deinking Mills

California	Garden State Paper Co., Inc., Pomona
Illinois	F.S.C. Paper Co., Alsip
New Jersey	Garden State Paper Co., Inc., Garfield

WASTE PAPERBOARD MILLS IN THE UNITED STATES

Alabama	National Gypsum Co., Anniston Stone Container Corp., Mobile
California	Sonoco Products Co., Los Angeles Continental Can Co., Los Angeles Los Angeles Paper Box & Board Mills, Los Angeles Kaiser Gypsum Corp., San Leandro Container Corp. of America, Santa Clara Georgia-Pacific Corp., Santa Clara U. S. Gypsum Co., South Gate Fibreboard Corp., Stockton Fibreboard Corp., Vernon
Colorado	Packaging Corp. of America, Denver
Connecticut	Colonial Board Co., Manchester Robertson Paper Box Co., Inc., Montville Federal Paper Board Co., New Haven Simkins Industries, Inc., New Haven Federal Paper Board Co., Inc., Sprague Federal Paper Board Co., Inc., Versailles * United Paper Products Corp., Windsor Locks
Delaware	Container Corp. of America, Wilmington
Florida	Simkins Industries, Inc., Miami
Georgia	Sonoco Products Co., Atlanta Austell Box Board Corp., Austell
Illinois	Alton Box Board Co., Alton Alton Box Board Co., Carlyle Container Corp. of America, Chicago Container Corp. of America, Chicago Prairie State Paper Mills, Joliet National Biscuit Co., Marselles

* Future uncertain.

Illinois, contd.	The Quaker Oats Co., Pekin Packaging Corp. of America, Quincy Sonoco Products Co., Rockton
Indiana	Alton Box Board Co., Lafayette Weston Paper & Manufacturing Co., Terre Haute Packaging Corp. of America, Vincennes Container Corp. of America, Wabash
Iowa	Packaging Corp. of America, Tama
Kansas	Packaging Corp. of America, Hutchinson Lawrence Paper Co., Lawrence
Maine	Yorktowne Paper Mills of Maine, Inc., Gardiner
Maryland	Chesapeake Paperboard Co., Baltimore Simkins Industries, Inc., Ilchester Federal Paper Board Co., Inc., Whitehall
Massachusetts	Continental Can Co., Inc., Haverhill Sonoco Products Co., Holyoke Union Box Board Co., Hyde Park Mead Corp., Lawrence Continental Can Co., Natick
Michigan	Michigan Carton Co., Battle Creek Packaging Corp. of America, Grand Rapids National Gypsum Co., Kalamazoo Brown Co., Kalamazoo Consolidated Packaging Corp., Monroe Time Container Corp., Monroe Union Camp Corp., Monroe Hoerner Waldorf Corp., Otsego
Minnesota	B. F. Nelson Manufacturing Co., Minneapolis Hoerner Waldorf Corp., St. Paul
Missouri	U. S. Gypsum Co., North Kansas City
New Hampshire	Hoague-Sprague Div. of USM Corp., West Hopkinton

New Jersey	Macandrews & Forbes Co., Camden U. S. Gypsum Co., Clark Township Whippany Paper Board Co., Inc., Clifton Georgia Pacific Corp., Delair National Gypsum Co., Garwood J. F. Boyle Co., Jersey City Newark Box Board Co., Newark Simkins Industries Inc., Ridgefield Park * Whippany Paper Board Co., Inc., Whippany
New York	Sonoco Products Co., Amsterdam J. P. Lewis Co., Brownville Climax Manufacturing Co., Carthage Brown Co., Castleton-on-Hudson Columbia Corp., Chatham Upson Co., Lockport Upson Co., Lockport National Gypsum Co., Newburgh Columbia Corp., Walloomsic U. S. Gypsum Co., Oakfield Continental Can Co., Inc., Piermont Warrensburg Board & Paper Corp., Warrensburg Ravenswood Paper Board Co., Long Island City Ft. Schyler Paper Board Corp., Utica
North Carolina	Carolina Paper Board Corp., Charlotte Federal Paper Board Co., Inc., Roanoke Rapids
Ohio	Crown Zellerbach Corp., Baltimore Tecumseh Corregated Box Co., Brecksville Mead Corp., Cincinnati Stone Container Corp., Coshocton Stone Container Corp., Franklin U. S. Gypsum Co., Gypsum Loroco Industries, Inc., Lancaster Chipboard, Inc., Massillon Massillon Paper Co., Massillon Diamond-International Corp., Massillon Sonoco Products Co., Munroe Falls Packaging Corp. of America, Rittman Federal Paper Board Co., Inc., Steubenville Toronto Paperboard Co., Toronto

* Future uncertain.

Oklahoma	Georgia Pacific Corp., Pryor National Gypsum Co., Pryor
Pennsylvania	Packaging Corp. of America, Delaware Water Gap Brandywine Paper Corp., Downingtown Sonoco Products Co., Downingtown American Paper Products Co., Lancaster Container Corp. of America, Philadelphia Crown Paper Board Co., Philadelphia Newman & Co., Philadelphia Federal Paper Board Co., Inc., Reading Interstate Intercorr Corp., Reading Whippany Paper Board Co., Inc., Riegelsville St. Regis Paper Co., York Yorktowne Paper Mills, Inc., York
South Carolina	Sonoco Products Co., Hartsville Carotell Paper Board Corp., Taylors
Tennessee	Container Corp. of America, Chattanooga Tennessee Paper Mills, Inc., Chattanooga
Texas	U. S. Gypsum Co., Galena Park
Vermont	Mountain Paper Products Corp., Bellows Falls
Virginia	Mead Corp., Lynchburg Federal Paper Board Co., Inc., Richmond Federal Paper Board Co., Inc., Richmond
West Virginia	Halltown Paperboard Co., Halltown Banner Fibreboard Co., Wellsburg
Wisconsin	Beloit Box Board Co., Beloit U. S. Paper Mills Corp., De Pere John Strange Paper Co., Menasha St. Regis Paper Co., Milwaukee

BUILDING BOARDS AND RELATED PRODUCTS

Wet Machine Board

Connecticut	Colonial Board Co., Manchester Rogers Corp., Manchester Rogers Corp., Rogers
Illinois	The Davey Co., Aurora
Maine	Colonial Board Co. (Rogers Fibre Div.), Bar Mills Sherman & Co., Belfast Colonial Board Co. (Rogers Fibre Div.), E. Portland
Massachusetts	Amesbury Fibre Corp., Amesbury George O. Jenkins, Co., Bridgewater George O. Jenkins, Co., Bridgewater Texon, Inc., Russell
Michigan	Simplex Industries, Inc., Palmyra
Mississippi	Atlas Roofing Manufacturing Co., Inc., Meridian
New Hampshire	Milton Leather Board Co., Milton Spaulding Fibre Co., Inc., Milton Spaulding Fibre Co., Inc., Milton Spaulding Fibre Co., Inc., N. Rochester Penacook Fibre Co., Penacook
New Jersey	The Davey Co., Jersey City
New York	Wood Flong Corp., Hoosick Falls Endicott-Johnson Corp., Johnson City
Oklahoma	Big Chief Roofing Co., Ardmore
Pennsylvania	The Davey Co., Downingtown Shyrock Bros., Downingtown Nicolet Industries, Inc., Norristown
Tennessee	Colonial Board (Shufibre Div.), Covington
Washington	Fibers, Inc., Vancouver

Building Paper

Alabama	GAF Corp., Mobile
Arkansas	Bear Brand Roofing, Inc., Bearden Celotex Corp. (Jim Walter Corp.), Camden A-R Felt Mills, Inc., Little Rock Elk Roofing Co., Stephens
California	Volney Felt Mills (Lloyd A. Fry Roofing Co.), Compton Celotex Corp. (Jim Walter Corp.), Los Angeles Johns-Manville Products Corp., Pittsburg Certain-Teed Products Corp., Richmond Anchor Paper Mills, Inc., South Gate
Connecticut	Tilo Co., Inc., Stratford
Florida	Volney Felt Mills (Lloyd A. Fry Roofing Co.), Jacksonville National Felt and Paper Corp., Miami Volney Felt Mills (Lloyd A. Fry Roofing Co.), Miami
Georgia	Great Northern Paper Co., Cedar Springs Certain-Teed Products Corp., Savannah GAF Corp., Savannah
Illinois	Certain-Teed Products Corp., East St. Louis GAF Corp., Joliet Flintkote Co., Mount Carmel Celotex Corp. (Jim Walter Corp.), Peoria Volney Felt Mills (Lloyd A. Fry Roofing Co.), Summitt Johns-Manville Products Corp., Waukegan Philip Carey Corp., Wilmington
Indiana	Volney Felt Mills (Lloyd A. Fry Roofing Co.), Brookville Volney Felt Mills (Lloyd A. Fry Roofing Co.), Mishawaka
Louisiana	Southern Johns-Manville Products Corp., New Orleans Bird & Son Inc., Shreveport Slidell Felt Mills, Inc., Slidell

Maryland	Congoleum Industries, Inc., North Finksburg
Missouri	Tamko Asphalt Products, Inc., Joplin GAF Corp., Kansas City Volney Felt Mills (Lloyd A. Fry Roofing Co.), North Kansas City
New Jersey	Armstrong Cork Co., Fulton U. S. Gypsum Co., Jersey City Philip Carey Corp., Linden Johns-Manville Products Corp., Manville Philip Carey Corp., Perth Amboy Trepaco Chem Fibre, Trenton
New York	GAF Corp., Gloucester Flintkote Co., Lockport Penn Yan Paper Products Co., Penn Yan Atlantic Asbestos Corp., Red Hook
Ohio	Certain-Teed Products Corp., Avery Philip Carey Corp., Cincinnati Logan-Long Co., Franklin Nicolet Industries, Inc., Hamilton
Oklahoma	Georgia Pacific Corp., Pryor Allied Materials Corp., Stroud
Oregon	Bird & Son Inc., Portland Herbert Malarkey Paper Co., Portland Volney Felt Mills (Lloyd A. Fry Roofing Co.), Portland
Pennsylvania	Volney Felt Mills (Lloyd A. Fry Roofing Co.), Emmaus GAF Corp., Erie Nicolet Industries, Inc., Norristown Celotex Corp. (Jim Walter Corp.), Philadelphia Certain-Teed Products Corp., York
Rhode Island	Bird & Son Inc., Phillipsdale
Tennessee	Philip Carey Corp., Memphis Volney Felt Mills (Lloyd A. Fry Roofing Co.), Memphis

Texas	GAF Corp., Dallas Southern Johns-Manville Products Corp., Fort Worth Philip Carey Corp., Houston Volney Felt Mills (Lloyd A. Fry Roofing Co.), Houston Volney Felt Mills (Lloyd A. Fry Roofing Co.), Irving
Wisconsin	Beloit Box Board Co., Beloit

Hardboard

Arkansas	Superwood Corp., Little Rock
California	Masonite Corp., Ukiah
Florida	Abitibi Corp., Blountstown
Georgia	Armstrong Cork Co., Macon
Michigan	Abitibi Corp., Alpena
Minnesota	Nu-Ply Corp., Bemidji Superwood Corp., Duluth
Mississippi	U. S. Gypsum Co., Greenville
Missouri	National Gypsum Co., St. Louis
New Jersey	National Gypsum Co., Millington
New York	Celotex Corp., Deposit
Oklahoma	Weyerhaeuser Co., Craig
Oregon	Evans Products Co., Corvallis U. S. Plywood-Champion Papers, Inc., Dee Forest Fiber Products Co., Forest Grove Weyerhaeuser Co., Klamath Falls U. S. Gypsum Co., Pilot Rock

Insulating Board

Alabama	National Gypsum Co., Mobile
Georgia	Armstrong Cork Co., Macon
Iowa	Celotex Corp., Dubuque
Louisiana	Celotex Corp., Marrero National Gypsum Co., New Orleans
Maine	U. S. Gypsum Co., Libson Falls
Michigan	Abitibi Corp., Alpena Celotex Corp., L'Anse Simpson Lee Paper Co., Vicksburg
Minnesota	Conwed Corp., Cloquet Boise Cascade Corp., International Falls
Mississippi	U. S. Gypsum Co., Greenville Flintkote Co., Meridian
Missouri	Huebert Fiberboard Co., Boonville, Mo.
New Jersey	Homasote Co., Trenton
Oklahoma	Weyerhaeuser Co., Craig
Oregon	U. S. Gypsum Co., Pilot Rock Kaiser-Gypsum Co., Inc., St. Helens
Pennsylvania	Nicolet Industries Inc., Ambler
Rhode Island	Bird & Son Inc., Phillipsdale
Texas	Temple Industries, Inc., Diboll
Virginia	U. S. Gypsum, Danville Southern Johns-Manville Products Corp., Jarratt

☆U.S. GOVERNMENT PRINTING OFFICE: 1973 514-154/253 1-3

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No.

2.

3. Accession No.

W

4. Title

STATE-OF-THE-ART REVIEW OF PULP AND PAPER WASTE TREATMENT

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s)

Dr. Harry Gehm

10. Project No.

68-01-0012

9. Organization

WAPORA, Inc.
6900 Wisconsin Ave. NW
Washington, D.C. 20015

11. Contract/Grant No.

68-01-0012

13. Type of Report and Period Covered

12. Sponsoring Organization

15. Supplementary Notes

Environmental Protection Agency report number, EPA-R2-73-184, April 1973.

16. Abstract

This report sets forth the state of the art in the treatment of pulp and paper mill wastewater as it stands in 1971. In order to lay a background for the sections on treatment, a review of both the general economic position of the industry as a whole and the major production processes is included. Such a background is needed since a considerable degree of loss control is practiced within the processes and water recycling is an almost universal practice in this industry. Included also is a review of the water quality problems which the applied treatment processes are designed to rectify. Performance data for treatment processes and systems are presented together with a review of the applicability of common analytical methods to the measurement of waste characteristics and treatment effectiveness. The techniques used to monitor waste flowages for control purposes and as means of recording treatment efficiency are included. Finally, the remaining problems relative to control and treatment of pulp and paper mill spent process waters are pointed out. Research and development needs directed toward solving these problems are defined in the light of such programs which are currently underway.

17a. Descriptors

*Paper Industry, *Pulp Wastes, *Pulp and Paper Industry, Sulfite liquors, Kraft mill wastes, Waste Treatment, Sludge Treatment.

17b. Identifiers

*Pulp and Paper Waste Treatment, *Waste Characteristics, Wood wastes, Sludge disposal, Oxidation, Suspended solids sedimentation, Treatment costs.

17c. COWRR Field & Group 05D

18. Availability

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

Send To:

WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

Abstractor Harry Gehm

Institution WAPORA, Inc.

WRSIC 102 (REV JUNE 1971)

GPO 913.261