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RESIDUALS MANAGEMENT IN THE PULP AND PAPER INDUSTRY

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INTRODUCTION

As has been noted many times, all human activities result in the generation of various residuals—liquid, gaseous, and solid. Depending on the nature of these residuals and how they are modified after generation, if at all, they may have greater or lesser impacts on environmental quality when discharged into one or more of the environmental media. With increasing affluence per capita and increasing population, managing residuals in relation to environmental quality will become increasingly important and increasingly dependent upon knowledge of the factors which affect residuals generation in the first place. As one of the important industries in the United States and as an important residuals generator, the pulp and paper industry deserves rigorous analysis if residuals-environmental quality management policies are to be chosen which will be both efficient and equitable for society. The objective herein is to describe and to illustrate the major factors which affect residuals generation in the pulp and paper industry.

Figure 1 is a simplified flow diagram of the steps involved in producing paper products. Essentially the process involves modifying a raw material—round wood from the forest or residues from saw mills and wood products mills—by preparing the wood, producing pulp, bleaching where necessary or desired to increase the brightness,

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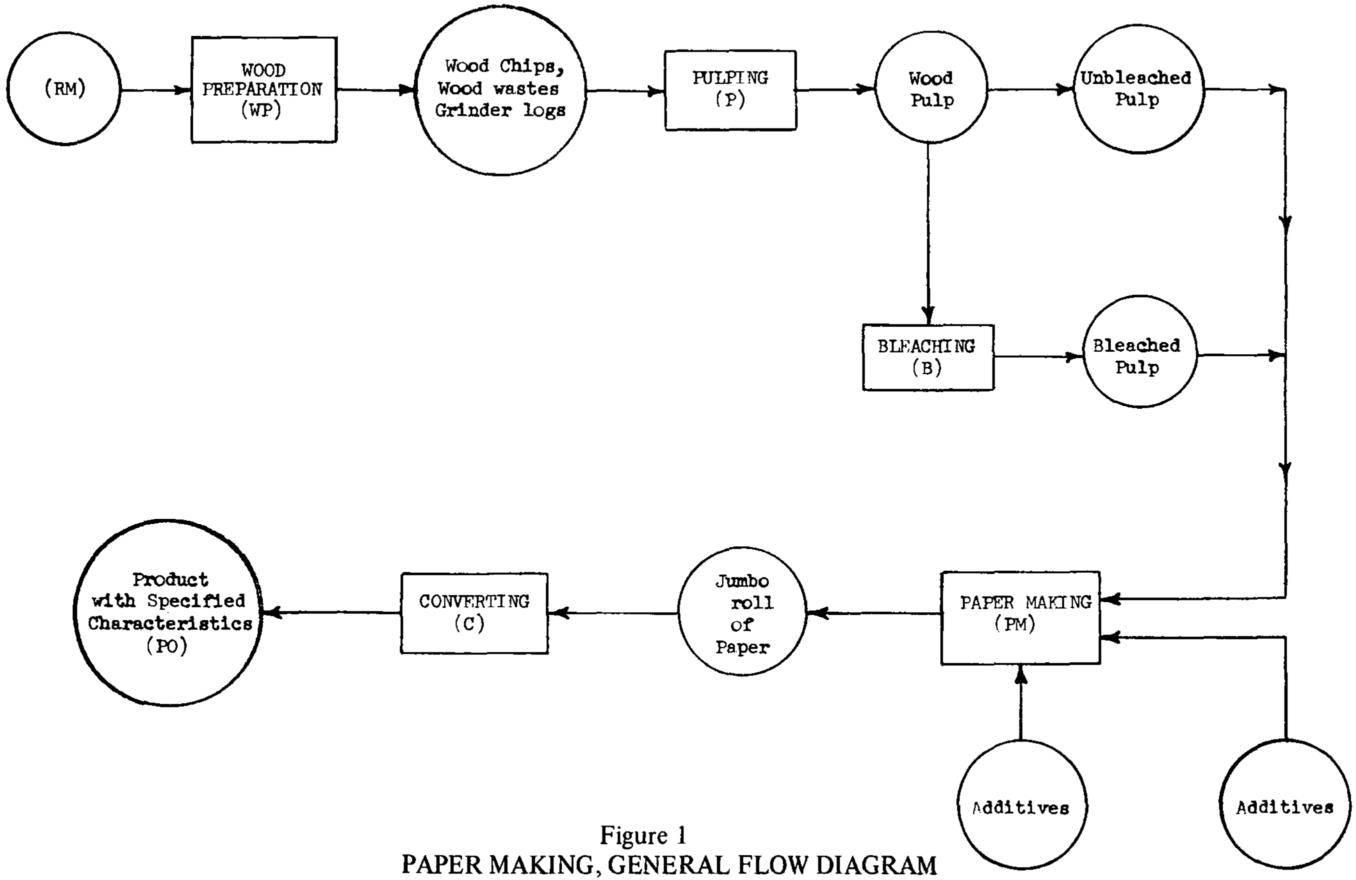

Figure 1
PAPER MAKING, GENERAL FLOW DIAGRAM

forming a paper sheet of interlaced and bonded fibers, and converting the paper into the final "user" products.[1]

Starting with logs delivered to the mill, the usual operation in wood preparation is the removal of bark from the logs and sawing the logs to the proper dimensions for the next step in the manufacturing sequence. For all pulps other than stone groundwood, the logs are then cut into small chips.

Pulp is composed of cellulosic fibers and is made by a variety of processes. Mechanical pulps are produced simply by grinding the wood, usually on rotating grindstones in the presence of water, into small fibrous bundles which contain virtually all the components in the original wood.

Chemical pulps are made by a process of cooking the wood chips under pressure with various types of chemical solutions in water to effect a dissolving of most of the materials in the wood other than cellulose. Following the cooking process, in batch or continuous digesters, the slurry of softened chips and the spent cooking liquor is discharged under pressure into a blow pit where the chips disintegrate into fibers. The pulp is then washed free of the cooking solution and the dissolved wood components. Approximately half of the organic matter in the wood dissolves and enters the spent cooking solution.

The major difference between chemical pulping processes is the composition of the cooking liquor. The sulfite processes use mixtures of sulfurous acid and the acid sulfite salts of calcium, ammonium, magnesium, or sodium. The kraft or sulfate process is an alkaline treatment with solutions of sodium sulfide and sodium hydroxide. All of the processes with the exception of the calcium-sulfite pulping process can be operated, and in fact in most cases *must* be so operated for economic reasons, to recover the spent cooking liquor for reuse. Extensive chemical recovery facilities are therefore involved in most pulp mills.

If white paper is to be made, further purification and bleaching of the pulp is required. Chemical pulps are bleached usually in a sequence of steps, commonly involving chlorination, washing with caustic soda, calcium hypochlorite solution, and, in the case of kraft pulp for the whitest products, chlorine dioxide. Mechanical pulps are brightened, to a lesser degree and without appreciable extraction of components, by addition of chemicals such as zinc hydrosulfite.

Paper is made by distributing a dilute slurry of the proper grades of pulp and small quantities of certain additives on a rapidly moving

1. For a detailed description of paper making, *see* any standard reference, such as Handbook of Pulp and Paper Technology (K. Britt 2d ed. 1970).

endless wire screen or a perforated cylinder. The water is drawn through the openings leaving the cellulose fibers deposited on the surface as a wet interlaced mat. This wet sheet is run between rolls to remove part of the water and then on to heated drums which vaporize the water from the sheet to form a continuous strip of dry paper. Various types of surface finishes and coatings can be applied to the sheet as it passes through the machine to the final winding roll.

VARIABLES AFFECTING RESIDUALS GENERATION

Residuals generation in the pulp and paper industry is a function of seven major variables, i.e., R = f (RM, WP, P, B, PM, C, PO), where R = the vector of residuals generated, types and quantities; RM = type of raw material; P = pulping process; B = bleaching sequence; PM = papermaking process; C = converting operation; and PO = the specifications for the final product output. To produce a given final product, PO, there are many combinations of the other variables which are possible. Each of these combinations is termed herein, a "production combination." Before presenting examples of such combinations, a short discussion of some of the major variables is presented.

Just as final demand, the set of goods and services desired in society, is the "driving force" behind residuals generation and consequent impacts on environmental quality in society, so the desired characteristics of the paper products are the "driving force" behind residuals generation in the pulp and paper industry. The objective of combining the several variables in a production combination is to produce a paper product with specified characteristics, such as wet strength, crushing strength, absorbency, smoothness, brightness, opacity, printability, and color. These characteristics can be obtained by combining various types of raw materials with various pulping processes, bleaching sequences, and additives in the papermaking operation. However, not all product characteristics can be achieved with all types of raw material or all pulping processes. For example, to achieve the requisite strength characteristics for strength papers, *e.g.*, for use in making grocery bags, the kraft process must be used. To achieve a specified brightness in the final product some combination of brightness of the pulp stock plus additives in the form of coatings can be used. In the pulping process, *i.e.*, digestion, a longer cook will yield a softer pulp but at the cost of some strength. Table 1 shows the properties which are of most importance in five of the major types of paper products. These five products, plus linerboard

Table 1
PROPERTIES OF IMPORTANCE IN VARIOUS PAPER PRODUCTS

(1) Tissue, napkins, towels	(2) Printing Papers	(3) Strength Papers	(4) Newsprint	(5) Folding Boxboard
softness	strength to weight ratio	dry strength	strength to weight ratio	strength
wet strength	basis weight[2]	wet strength	basis weight	moisture and vapor proof
strength/softness[1]	opacity	multi-ply	runability[4]	*surface*
absorbency	gloss	resistance to internal and external environments	opacity	brightness
substance (bulk)	printability	functional coatings	printability	smoothness
brightness	(a) ink absorption	brightness[3]		printability
freedom from linting	(b) smoothness	color[3]		cleanliness
freedom from specks (cleanliness)	(c) lack of linting			color
double plying	brightness			
degree of coloring	color			
printing				
embossing				
perfuming				

Note: Readability is probably not improved by increases in brightness above a certain level.
1. Balancing strength and softness
2. *The weight of a standard number of sheets of paper of a specified size.*
3. For certain purposes only, i.e., not for all strength papers
4. Runability pertains to the freedom from sheet tearing and breaking when being printed in high speed rotary presses.

and corrugating medium, comprise about 75% of total paper and paperboard production in the United States.

Over time, particularly in the last decade, specifications for some of these products have changed substantially. This appears particularly true for consumer products—tissues, napkins, towels—and printing papers, and to a somewhat lesser extent strength papers and newsprint. The changes have been in the direction of more stringent specifications, with respect to such characteristics as brightness, absorbency, softness, strength. In addition, colored paper products, primarily consumer products, appeared in the last decade. An attempt to depict the relative changes in product characteristics or specifications for these major product categories is shown in Figure 2. Two points should be emphasized. First, the changes indicated are qualitative and relative in terms of the trends among the various products. Second, to some small degree "new" products, *i.e.*, multi-ply strength papers and perfumed tissues are included. Primarily, however, the trends reflect changes in specifications relating to existing products rather than completely new products.

The importance of changes in product characteristics can be illustrated by brightness. The trend towards higher brightness means that more bleaching is necessary. This trend is indicated by the following data on the proportion of total sulfite plus sulfate production which was bleached:[2]

Year	Bleached sulphite + bleached sulfate pulp production, 10^6 tons	Bleached as proportion of total sulfite + sulfate production, %
1945	2½	20-25
1950	4	about 40
1955	6½	about 50
1960	9	about 50
1969	15½	about 50

These data underestimate the extent of the change, because they do not account for increases in the degree of bleaching.

A second major factor affecting residuals generation in the industry is the nature of the pulping process. The sulfate or kraft process results in a substantially different mix of residuals—as shown in Tables 3 and 4 below—compared to the sulfite pulping process, whether calcium base, ammonia base, or magnesium base. As with the degree of bleaching there has been a major shift in pulping processes in the last 25 years, as shown in Table 2.

2. American Paper Institute, Statistics of Paper (1964, Supp. 1970).

FIGURE 2

TRENDS IN PRODUCT CHARACTERISTICS

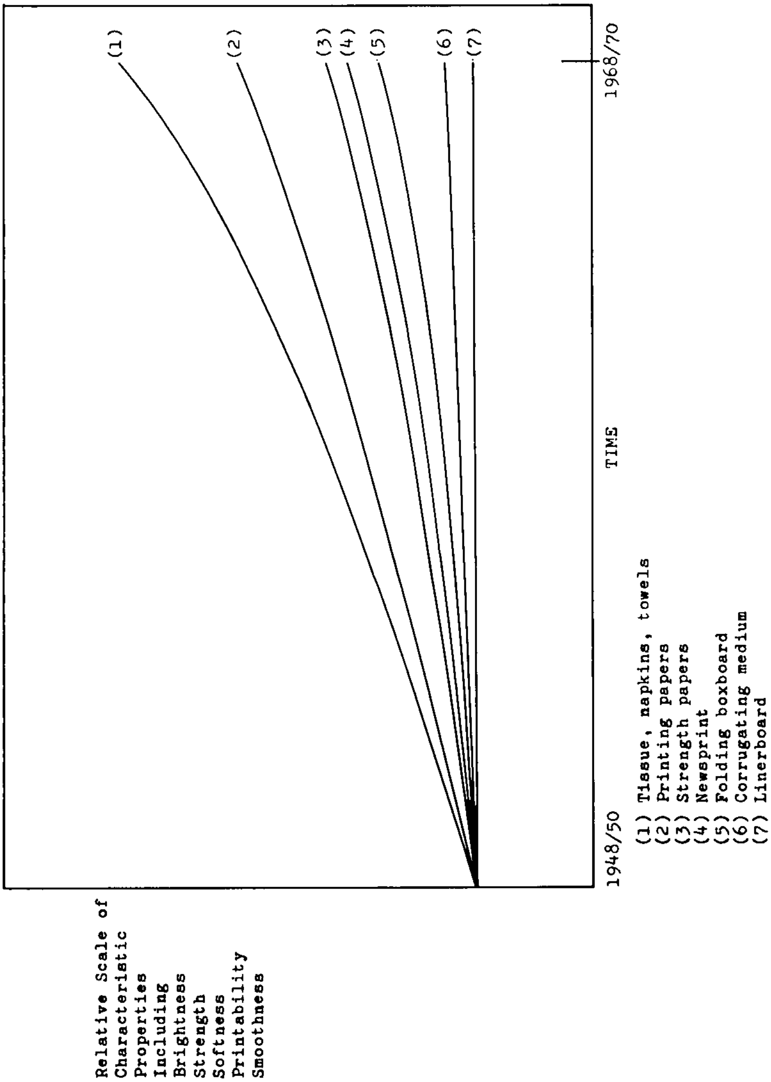

TABLE 2
WOOD PULP PRODUCTION IN THE UNITED STATES BY PROCESS

Pulping Process	Production, 10^6 tons			Proportion of total wood pulp production, %		
	1945	1965	1969	1945	1965	1969
Mechanical	1.8	3.9	4.2	18	12	10
Sulfite[1]	2.4	4.3	4.0	23	13	9.5
Semichemical	Neg[2]	2.9	3.4	–	8.5	8.5
Sulfate (kraft)	4.5	20.5	27.6	44	61.5	67.5
Other	1.5	1.7	1.8	15	5	4.5
Total	10.2	33.3	41.0	100	100	100

1. Includes alpha and dissolving grades.
2. Neg = neglible.
Source: American Paper Institute, Statistics of Paper, (1964, Supp. 1970).

RESIDUALS GENERATION

The primary residuals generated in pulp and paper production are gaseous residuals from chemical pulping (digestion)–sulfur dioxide, and, to a much lesser extent particulates from sulfite processes; hydrogen sulfide, organic sulfides (odorous compounds), and particulates from the kraft process; dissolved inorganic and organic solids from bleaching and digestion operations; bark and dirt from wood preparation; and fiber, primarily from paper machine white water. Additional residuals are generated in the modification of these residuals prior to discharge.

A definition is in order to insure clarification. The term "residual" is defined operationally. Into essentially all operations there are flows of materials and energy. Out of these operations flow equal amounts of materials and energy. For such processes as manufacturing, mining, agricultural operations, one or more of the material or energy flows will be the "product" or "products." The other material and energy outflows will be the residuals. In economic terms, these (residual) outflows will have zero prices in existing markets, or at least prices less than the variable costs of production.[3] Management's or the householder's objective is the disposal of these residuals at minimum cost.

It should be emphasized that within the "black box" of many production processes are flows of materials and energy which are recovered and reused. Broke[4] from the paper machine is an example;[5] chemical recovery systems to save input chemical costs

3. *See* Russell, *Models for Investigation of Industrial Response to Residuals Management Actions,* 73 Swedish J. Econ. 135 (1971).
4. "Broke" is the term which applies to paper scrap from trimming and slitting the sheet and from miscellaneous sources in start-up and shut-down of the machine.
5. *See* Figure 3.

and hot water recirculation to save fuel costs are other examples. Thus, a basic production process is defined to include all such internal recirculation flows of materials and energy which would be instituted in the *absence* of pollution controls, *i.e.*, are economically justified in relation to the costs of factor inputs, given present prices. The remaining materials (and energy) produced, other than the salable products, are defined here as residuals generation.

It is also important to emphasize that residuals generation is not synonymous with residuals discharge into the environment. Many residuals are modified to some degree by various means, such as additional materials recovery and "waste treatment," prior to discharge.

Tables 3 and 4 show the pounds of residuals generated in the production of one ton of newsprint and tissues, respectively, by different production combinations. In Table 3, newsprints of three different degrees of brightness are shown—present specifications, i.e., 66-70, and two lower brightnesses. All other specifications are the same. Similarly, in Table 4, three degrees of brightness are shown for tissues, all other product specifications being the same. The tables exclude residuals from converting, which will be discussed subsequently.

What are the effects of these different production combinations on residuals generation? First with respect to newsprint: comparing NP 4 with NP 1, the substitution of refiner groundwood for stone groundwood enables decreasing the proportion of kraft pulp in the fiber mix, thereby decreasing sulfur dioxide (SO_2) generation by about 40%, reduced sulfur compounds (RS) by about 40%, and particulates by about 15%. Dissolved inorganic solids (DIS) are reduced by about 30%. However, dissolved organic solids (DOS) and suspended organic solids (SS-O) are increased by about 10% and about 40%, respectively.[6] If sulfite pulp is used in place of kraft, as in NP 2, odorous sulfur compounds are eliminated but SO_2 shows a considerable increase and the dissolved organic compounds in the waste water are almost 60% higher.[7]

Reducing the brightness specification for newsprint from the 66-70 range presently used to a brightness of about 58, results in a small decrease in liquid residual primarily because of reduced bleach

6. DOS and SS-O are the primary residuals resulting in BOD, biochemical oxygen demand. The relationships between DOS and SS-O and BOD are well defined only for some of the liquid residuals streams.

7. In the magnefite process chosen here as representative of sulfite pulping, a high degree of recovery of spent cooking liquor is practiced. The figures in the table are based on recovery of 80% of the spent liquor, although higher recoveries are common. If calcium bisulfite is used, liquid residuals are roughly five times as large.

TABLE 3
RESIDUALS GENERATION IN THE PRODUCTION OF ONE TON OF NEWSPRINT, POUNDS*

Brightness →		66-70			58				50	
P. C. No. →		NP1	NP2	NP4	NP21	NP22	NP23	NP24	NP31	NP32
↓ Residual	Pulp mix →	75% SG/Zn; 25% K/CEH	72% SG/Zn; 28% Mg/0	85% RG/ZN 15% K/CEH	75% SG/0; 25% K/CEH	72% SG/0; 28% Mg/0	100% RG/0	100% WPN/ FIB	75% SG/0; 25% K/0	100% WPN/ FI
G:	Cl_2	0.3	0	0.2	0.3	0	0	0	0	0
	ClO_2	0	0	0	0	0	0	0	0	0
	SO_2	1.4	6.9	0.8	1.4	6.9	0	0	1.3	0
	RS	6.4	0	3.8	6.4	0	0	0	5.8	0
	Part.	24	16	21	24	16	13	0	23	0
L:	DIS	108	88	74	86	67	9	163	26	89
	DOS	157	247	172	157	247	163	294	111	98
	SS-I	2.5	2.5	2.5	2.5	2.5	2.1	0	2.4	0
	SS-O	89	88	126	89	88	129	214	87	147
S:	So-I	31	39	37	31	39	31	14	29	11
	So-O	0	17	0	0	17	0	13	0	11

*As air-dry paper, equivalent to 1800 pounds on bone-dry basis.

SPECIFICATIONS OTHER THAN BRIGHTNESS: 32 lb. basis weight; 40 tear strength; 89-90 opacity; 100 Sheffield smoothness.

RAW MATERIAL: Softwood, except waste paper where used.

TABLE 4
RESIDUALS GENERATION IN THE PRODUCTION OF ONE TON OF TISSUES*

Brightness →		80-82				70-72			25	
P.C. No. →		Ti3	Ti4	Ti7	Ti8	Ti21	Ti22	Ti25	Ti31	Ti34
↓ Resi-dual	Pulp mix →	100% Mg/CEH	100% K/CEHD	50% K/CEHD; 50% Mg/CEH	75% K/ CEHDED; 25% WPN/FIB	100% Mg/H	100% K/CEH	35% K/CEHD; 65% WPN/FIB	100% K/O	100% WPM/F
G:	Cl_2	1.1	1.2	1.1	0.9	0	1.2	0.4	0	0
	ClO_2	0	0.6	0.3	0.9	0	0	0.2	0	0
	SO_2	26	5.6	16	4.2	25	5.6	2.0	5.1	0
	RS	0	26	13	19	0	25	8.9	23	0
	Part.	28	62	45	46	27	61	22	56	0
L:	DIS	263	263	263	244	244	263	192	22	21
	DOS	668	244	456	261	628	227	278	41	63
	SS-I	4.1	4.5	4.3	3.4	4.1	4.4	1.6	4.1	202
	SS-O	109	114	111	139	108	113	179	107	92
S:	So-I	100	70	85	56	101	70	34	63	14
	So-O	63	0	32	3.2	62	0	8.3	0	13

*As air-dry paper, equivalent to 1800 pounds on bone-dry basis.

SPECIFICATIONS OTHER THAN BRIGHTNESS: 14 lb. basis weight (single ply); low wet strength 25%
RAW MATERIAL: Softwood, except waste paper where used.

ABBREVIATIONS FOR TABLES 3 and 4

NP	= newsprint
T_i	= tissues
P.C.	= production combination
SG	= stone groundwood pulping
RG	= refiner groundwood pulping
Mg	= magnefite (sulfite) pulping
K	= kraft (sulfate) pulping
WPN	= waste paper, No. 1 News (raw material)
WPM	= waste paper, No. 1 Mixed (raw material)
CEH, CEHD, etc.	= kraft or magnefite bleaching sequences
Zn	= zinc hydrosulfite bleaching, for groundwood
O	= no bleaching
F	= waste paper processing–defibering
FI	= waste paper processing–defibering and deinking
FIB	= waste paper processing–defibering, deinking and bleaching

RESIDUALS

Gaseous

Cl_2	= chlorine
ClO_2	= chlorine dioxide
SO_2	= sulfur dioxide
RS	= hydrogen sulfide and organic sulfides
Part.	= particulates

Liquid

DIS	= dissolved inorganic solids
DOS	= dissolved organic solids
SS-I	= suspended inorganic solids
SS-O	= suspended organic solids

Solid

So-I	= inorganic solids
So-O	= organic solids

chemical use. NP 22 compared with NP 2 shows a decrease in DIS of about 25%. The use of waste news as the raw material for production of newsprint, NP 24, results in elimination of all gaseous residuals. However, compared to NP 21, the WPN pulp results in increases in DIS, DOS, and SS-O of about 90%, 90%, and 140%, respectively.

At a still lower brightness level of about 50, bleaching of both groundwood and kraft would not be necessary. Comparing NP 31 with NP 1 shows reductions in DIS and DOS of about 75% and about 30% respectively. Similarly, waste news would require no bleaching, so NP 32 compared with NP 24 shows a reduction in DIS of about 45%, DOS of about 70%, and SS-O of about 30%.

Second, with respect to the production of tissues: Ti 3 and Ti 4 provide a direct comparison between the sulfite[8] and sulfate pulping processes, respectively, for the present level of brightness. The former results in about 4.5 times the quantity of SO_2 and about 2.5 times the quantity of DOS per ton, as for the kraft process.[9] On the other hand, kraft pulp production generates hydrogen sulfide and organic sulfides (RS) whereas none of these odorous gases is generated in the sulfite process. About 2.2 times as much particulates are formed in the kraft as in the sulfite process. Sulfite pulping produces about 2.3 times as much solid residual as does kraft.

Reducing the desired level of brightness from the present specification of 80-82 to 70-72 results in little change in residuals generation, using either the magnefite or the kraft process. The reduction in degree of bleaching required results in only a small decrease in either case in DIS and DOS, as shown by comparing Ti 21 and Ti 22 with Ti 3 and Ti 4, respectively. On the other hand, by shifting to a brightness of about 25, representing a brown colored tissue or "Ecotissue," the kraft process can be used without bleaching, as represented by Ti 31. Comparing this with Ti 4, the residuals generated are reduced very substantially with respect to DIS and DOS, by about 90% and about 85%, respectively. The level of brightness for the Ecotissues, remembering that all other specifications remain the same, would permit the use of 100% waste paper, such as No. 1 Mixed, as the raw material.[10] This is represented by Ti 34. Utilizing this production combination would eliminate all the gaseous residuals and, compared with any of the other production combina-

8. The magnesium base sulfite or magnefite process is used wherever sulfite pulp is used in a production combination in these tables.

9. But *see* note 7 *supra,* on spent liquor recovery in magnefite pulping process.

10. No. 1 Mixed Waste Paper is assumed here to contain approximately 50% publication grade (50% chemical–50% groundwood) magazine, 25% waste newspapers, and 25% used corrugated materials, resulting in a fiber composition of about 55% kraft and 45% groundwood.

tions except Ti 31, would decrease substantially the DIS and DOS. However, compared with all other production combinations a much larger quantity of SS-I would be generated.

Several points should be emphasized in considering these comparisons. First, the brightness of unbleached sulfite pulp is much higher than that of unbleached kraft pulp, the former being around 56-58 and the latter about 25.[11] Because the bleaching process is a substantial generator of residuals, there are marked advantages from the residuals standpoint to the extent that unbleached or only lightly bleached pulp can be used. Brightness as a product characteristic should be distinguished from other product characteristics such as strength, absorbency, softness, smoothness. The latter comprise what essentially might be termed "performance" characteristics; brightness on the other hand is predominantly an "aesthetic" characteristic. That is, a brown paper towel or tissue or napkin will perform its intended function, *i.e.*, drying, just as well as a white product. To the extent then that the consumer demands, or has his demand stimulated for, a brighter product, more residuals will be generated and increased residuals management costs will be incurred.

Second, even though the sulfite process has advantages over the kraft process with respect to brightness of the unbleached pulp produced and with respect to being somewhat lower in production cost per ton of product,[12] it has the decided disadvantage of being capable of pulping only a relatively small range of wood species. The kraft process on the other hand is an "universal" pulping process, being able to handle all types of wood.

Third, the data shown in the residuals generation tables represent combinations of the production variables for any given set of which the residuals generated may vary up and down among plants utilizing the same set of variables, or for a given plant from day to day, weekly, and seasonally. These variations in residuals generation for a given production combination are a function of a number of parameters. Examples include the age of the tree when harvested, the method of storage of round wood or chips, the extent to which the digester in the pulping operation is "pushed," the quantity of excess air used in oxidation or combustion, the tradeoff from plant to plant between strength and yield as a result of length of cook, machine efficiency, the effectiveness of the white water reclamation system,

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11. For either pulping process there is substantial variation in the brightness of unbleached pulp depending on the species of wood used.

12. *See* Keller and Fahey, *Now, Sulfite Pulping of Southern Pine?*, Pulp and Paper, at 29, 30 (Oct. 23, 1967).

and "housekeeping," *i.e.*, whether or not plant management runs a "tight" operation.

Thus, the actual numbers shown based on materials balances for each of the production combinations should not be considered as "absolute." The types of parameters mentioned above result in slightly higher or lower quantities. The importance of the figures is in terms of relative quantities and different mixes of residuals generated, stemming from changes in major variables among production combinations. The variation in residuals generation stemming from the above mentioned production parameters is much less than the variation resulting from changes in production combination variables, *i.e.*, pulping process, degree of bleaching, product output specifications. With respect to the use of waste paper in particular, typical random variations in quality of the raw product input, especially for No. 1 Mixed and Mixed Book and Magazine waste papers, will result in wide variations in residuals generation for a given production combination.

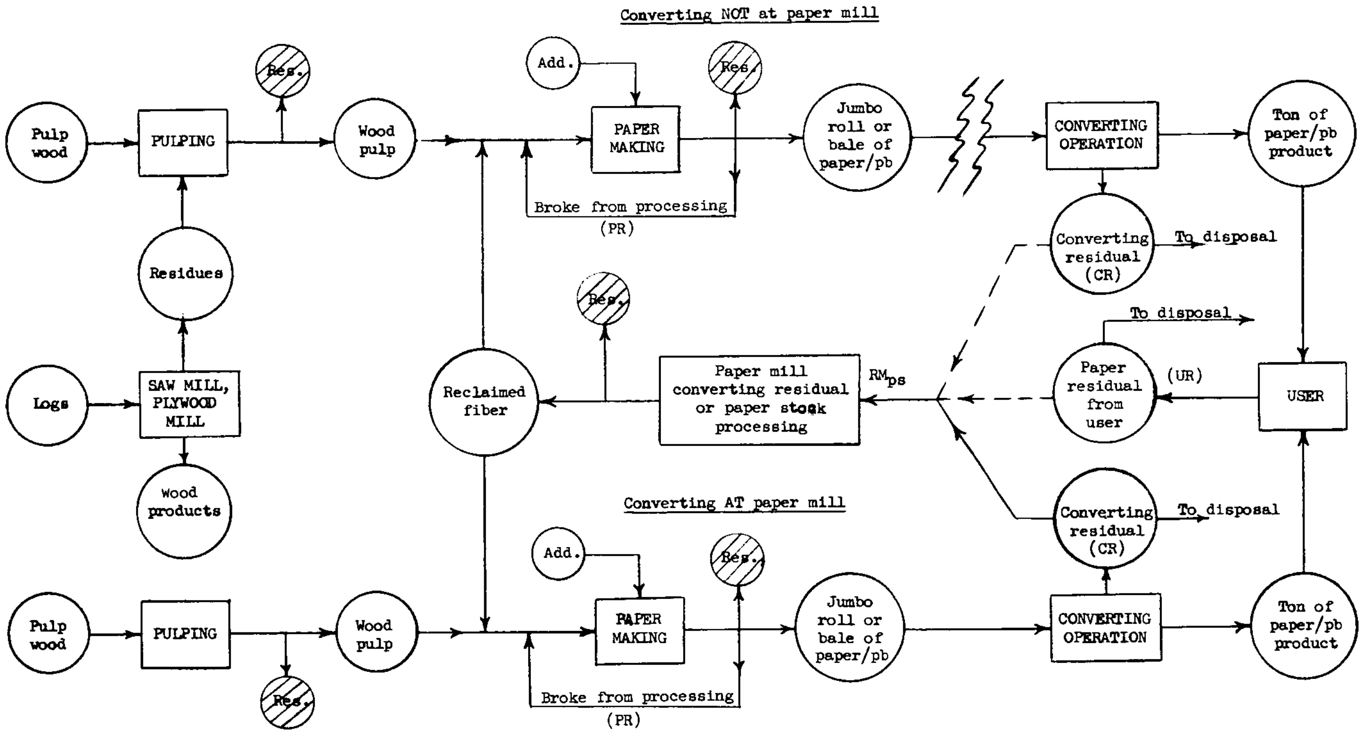
CONVERTING OPERATIONS AND PAPER RESIDUALS

The output from the papermaking operation is a "jumbo roll." This bulk output is then cut, formed, or packaged to yield the final paper product for use—package of paper towels, corrugated containers, grocery bags, reams of typing paper, etc. The various operations involved are subsumed under the term "converting." Except for consumer products, cores for paper rolls, and sometimes bags, converting operations to produce paper products for use are not generally done at the paper mill. Rather, they are located close to the markets.

The converting operation itself results in the generation of solid residuals, in the form of paper. The quantities vary from product to product, ranging from 2-3% in producing paper rolls for high speed printing to almost 20% in converting folding boxboard into boxes. In addition, the losses in converting add to the overall residuals problem in the industry, because some additional amount of raw material must be processed into pulp for each ton of final product. The additional residuals generated are a function of the magnitude of converting residuals and of their disposition, *i.e.*, whether or not they are reused as raw material. The alternative materials flow paths are illustrated in Figure 3.

Where the converting operation is at the paper mill, the converting residuals are likely to be directly reused. Significant exceptions occur, particularly with respect to colored consumer products.

FIGURE 3
CONVERTING AND PAPER RESIDUALS



Add. = Additives
Res. = Residuals for disposal
pb = Paperboard

RM_{ps} = paper stock raw material = UR + CR ; PR is virtually always directly recycled as an integral part of the production process.
The material flows shown are not meant to imply that CR from non-paper mill converting operations and UR return to the same mill in which the paper product was originally produced.
But when converting is at the paper mill, CR usually returns directly to the same paper mill involved.

Because colored paper residuals from the production of colored paper products cannot be directly reused in producing white products or products of colors different from the colors of the paper residuals, these residuals must either be disposed of by incineration or landfill, or else reprocessed–that is, defiberized and bleached–before reuse.[13] The reprocessing of course generates residuals, in a manner directly analogous to the processing of user paper residuals, such as waste news.

Figure 3 also provides a basis for clarification of much existent confusion concerning reuse of paper residuals. As indicated therein, there are two major types of such residuals–converting residuals and user residuals. Broke, generated in the paper making process from the paper machine and from the rewinding operation, is not a residual because it is directly recycled as a normal part of the production process. Converting residuals and user residuals comprise paper stock or waste paper. Both of these latter terms are applied to all types of paper residuals, regardless of source.[14]

The current interest in the environment has spawned increased interest in reusing paper residuals. Often overlooked in this interest is the fact that substantial quantities of paper residuals have long been reused, particularly those from converting operations, whenever this was economical. The degree of reuse is a function of economics, *i.e.*, the relative costs–transport, processing, residuals modification–of the three types of raw materials, round wood, mill residues, and waste paper, in conjunction with the costs of other factor inputs. Converting residuals have the desirable characteristics in contrast to most user residuals, of being generated in large quantities with homogeneous characteristics, relatively uncontaminated, at a single site. Because most of the converting residuals generated have long been utilized, usually without any attendant publicity, some current claims regarding products from "recycled" material do not involve any diversion from the solid waste stream. Only where converting residuals are now disposed of via incineration or landfill, will their increased reuse result in *net* increases of reclaimed fiber as raw material input into the production of paper products.

CONCLUSION

In the context of residuals-environmental quality management, the focus herein has been on the major variables affecting residuals gen-

13. Of course, where the same color is being produced, the converting residuals can be directly reused.

14. *See* Paper Stock Institute, *Paper Stock Standards and Practices* (Circular No. PS-69, 1969).

eration in production of paper in the pulp-paper mill and in converting to paper products. Emphasis has been given to the effects of: brightness as a product specification; processes for preparing pulp—groundwood, sulfite, sulfate, and repulped waste paper; and nature of raw material—wood types and waste paper. Different combinations of these variables result in substantially different mixes of residuals generation—types and quantities. What are some of the implications which can be drawn from the foregoing analysis?

One, simply knowing that different mixes of residuals are generated by different production combinations is insufficient for policy-making with respect to residuals management. Generating a much larger quantity of sulfur dioxide than of hydrogen sulfide and organic sulfides, or the reverse, or a much larger quantity of suspended inorganic solids than either, tells nothing about the impacts on environmental quality and on the receptors, if they were discharged. Because the generation of residuals is inevitable in production, the critical need is for damage functions which enable assessing the relative external costs resulting from discharge into the environment of, for example, sulfur dioxide versus organic sulfur compounds versus suspended solids in waste water. This is particularly important because the costs of residuals modification to reduce discharges varies greatly among the different residuals.

Two, the importance of product specifications in relation to residuals generation is clear. Higher brightness, requiring more bleaching, adds to residuals generation and hence to residuals management costs. It also limits the use of waste paper, which may or may not increase residuals management costs for the plant, but will limit the quantity of paper residuals which can be diverted from the solid waste stream and hence limit the reduction of those public costs. The increased use of color in consumer products, by inhibiting the reuse of converting residuals—either diverting them to solid waste or requiring additional reprocessing before reuse, in contrast to white products or Ecoproducts—has similar impacts. In contrast, the use of lower basis weight products, such as for newsprint, requires less pulp per area of newsprint, thereby decreasing residuals generation and residuals management costs. Inadequate reflection of external costs—stemming from the generation, and the discharge of residuals to the environment—in the prices of products has resulted in a failure to consider the impacts of product specifications on environmental quality. The analysis herein is an attempt to redress this overlooked facet.

Three, reuse of paper residuals is not a panacea with respect to managing environmental quality. Whatever the product specifications may be, the reuse of paper residuals requires processing which in itself results in the generation of substantial quantities of residuals. The efficient degree of reuse hinges on the costs of such processing—including costs of the waste paper raw material, the cost of modifying the residuals generated in that processing, and the savings in solid wastes management costs enabled by such reuse.

Finally, the analysis of residuals-environmental quality herein could be extended to encompass a larger system, beyond the confines of the paper mill, converting operations, and waste paper processing. This larger system would compare environmental quality impacts of alternative systems which would include those stemming from the production of round wood in the forest—forest management practices such as herbicide use, harvesting methods including slash disposal,—and round wood or chip transport—in addition to those associated directly with paper production. Although complex and difficult, the analysis of such systems might provide very useful insights for policy making with respect to residuals management in the pulp and paper industry and be suggestive for other industries and sectors as well.