THE ROLE OF TOTAL PROCESS CONCEPTS IN EVALUATING PULPING RESEARCH

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ABSTRACT

The utility of process concepts in guiding research is reviewed. The comparison of existing technology with the developing processes under investigation is an important determinant of research direction. Although this is a generally recognized guide, it is frequently ignored because the necessary information is not readily available. The trend toward computerized process simulation, the accomplishments and needs are reviewed.

Francis Bacon's statement that "The lame in the path outstrip the swift who wander from it," aptly applies to what follows, for what follows is a discussion of the use of process concepts to orient and justify pulping research. It tacitly assumes that such research is motivated by the desire to develop a superior pulping process and in this sense differs from basic research which is often defined as noncommitted. This does not infer that basic research is of lesser importance but rather that committed or developmental research should be done with goals in mind and a set of priorities to mark the path.

The kraft process is firmly entrenched as the major chemical pulping process, and it must be assumed reached this position because of its superiority. Speaking of a "new pulping process" it is inferred that such a process will have the potential of replacing the kraft process; it is the process we plan to replace or modify, and thus we may well ask "What's wrong with the kraft process?" The objective here is to take a look at the modern mill, a fully bleached kraft mill designed using proven technology, evaluate its important facets, and try to infer what may be the impact of the lines of research now in progress. At present, such an analysis can only be done in a crude, incomplete manner with considerable difficulty. However, this seems to be changing. Thus the discussion is ended by indicating what is happening in process research, and how its techniques might be more readily available to future workers.

The process features which seem to be of most importance from an economic and social viewpoint are: resource utilization, pollution liability, energy consumption, capital investment, and production costs. Data for the kraft process are presented in the following tables, the first of which (Table I) deals with utilization of the raw material. The yield values in column 1 are the percentage ratios of product to input for each of the operations. The second column, fiber loss, indicates the actual product loss where it can be determined. Because of the relationship between quality and yield it is not possible to give a simple figure €or pulping. The loss figures given in column 4 indicate the actual loss of wood substance (including bark) based on the total input to the plant, i.e. material not available for either fuel or product. Of the total wood (including bark) brought to the mill about 39% ends up as finished product, 55% as fuel, and 5.6% is not utilized, the principal losses being in wood preparation and bleaching. It could be said that overall utilization is quite high but, of course, product yield is low.

In terms of national costs, assuming the per capita consumption of cellulose fiber is around 600 lb/capita annually, it requires a third of an acre per capita for a continuing supply via the kraft process. This compares to 3-5 acres per capita for the food supply, and order of magnitude difference.

The pulp and paper industry is often characterized as energy-intensive, and this may be but if so it certainly cannot be attributed to the kraft process. Table 11 gives the energy figures for a relatively modern mill which burns bark and generates its entire electrical needs, resulting in its being 72% self-sufficient. Today, using substantially proven technology it appears possible to build mills needing no external energy. The 25% deficit of Table II calculates to a fuel consumption of 12.6 gal/yr/capita for the 600 lb/capita consumption assumed. This is insignificant in terms of other fuel expenditures, particularly when it appears possible to reduce this to zero. Some Scandanavian mills are currently operating at 88% self-sufficiency[1] which would reduce the per capita consumption to 5.4 gal/yr.

The highly offensive odor of the mercaptans produced during the kraft cook, and the previous abuses of the water supply, has gained the industry, perhaps deservedly, the reputation of a leading polluter. This, however, is not a necessity, but a question of economics. It has been demonstrated that, for a price, the modern mill can be designed to meet all existing standards for air and water quality[2,3]. The cost is shown in Table 111. Here it has been assumed that all odor sources are enclosed, condensate stripping is used, arid all odoriferous gases are fed to the recovery boiler, the auxiliary boiler, or the lime kiln. These three stacks are thus the only air emission sources. Primary and secondary treatment of the effluents has been assumed with suitable tertiary treatment of some streams for color removal. The costs for these treatments amounts to approximately 5% of the product cost. In terms of consumer cost this is less than $3.00/yr/capita to reduce the pollution level to current requirements.

The capital investment for the modern mill is very high. Table IV shows the distribution of costs for a 1,000 ton/day plant. The total price of $\$105 \times 10^6$ is equivalent to a per capita investment of around $90 assuming consumption of 600 lb/capita/annum. The cost of $300/annual ton of production puts the pulpmill in the category of chemical plants. The financial effect is reflected in Table V which shows that nearly 30% of the production cost results from depreciation and other costs directly related to the capital investment.

Returning to the original question, "What's wrong with the kraft process?" The major disadvantages are the low yield and high plant investment. The costs for wood and plant account for a total of 64% of the production cost. Pollution abatement costs, as shown in Table III, are significant but not exorbitant and the external energy consumption is low. Other well-known advantages of the process are the insensitivity to wood species, the high quality of product and ability to coordinate with other processes, in particular the NSSC process. As to societal costs, considering the position of paper in our culture, it can be said that the kraft process makes only modest demands on our resources. It uses only a tenth of the land area required to supply us with food, utilizing the resource effectively, consumes little energy and does not impair our ecosystem significantly. The production cost of $57/annum/capita and the capital investment are significant but certainly far below that expended on things of lesser importance. The predominate position assumed by the process appears to be well deserved.

The figures from the preceeding tables can be used to estimate the potential gains that could result from any particular research effort. Consider, for example, the oxygen-sodium carbonate method that has been discussed. It is conceivable that such a system might result in completely eliminating the odor problem, allow the substitution of a considerably cheaper recovery furnace, and make the recausticizing section unnecessary. The reduction in pollution control costs would amount to around 25% or $\$2.7 \times 10^6$. These savings with the additional saving in fuel to the lime kiln reduce the product cost by approximately 6%. This gain, of course, would be offset by any increased cost in chemical usage, digester size, etc. It is important to note that the largest (85%) part of this cost reduction comes not from polluti abatement but from savings in the recovery system.

Perhaps the greatest gain that could result from pulping research would be the discovery of a system that would yield a more easily bleachable pulp allowing the use of a chlorine-free system. It is not news that the bleaching operation is very costly. The figures above indicate that the bleaching cost amounts to more than two-third's of that for digestion (including chemical recovery, but excluding wood). With credit given to the recovery cycle for heat recovery, the cost of digestion and bleaching are nearly equal. Although not a contributor to the odor problem, the bleach plant is the major contributor to the total pollution load. Thus, the improved bleachability of oxygen pulps is an important property, perhaps the most important asset of the system.

Reiterating, the important point is that the pollution problems of the kraft process are not going to put it out of business and any new method will have to come up with pulp of comparable quality, in increased yields and/or decreased costs. These decreased costs will result either from changes in the recovery system, the bleaching operation, or increased yields. In other words, it still is a question of quality and price.

The decrease in production cost resulting from an increase in yield can be obtained by adding credit for reduced wood consumption and capital investment (wood room, recovery furnace, and effluent treatment) to the debit for energy and increased investment in the auxiliary boiler. The net result of a 10% increase in yield is 3.75% reduction in production cost or about $7/ton. Recognizing that this is roughly the cost of the digestion operation is is apparent that the introduction of a two-stage operation must result in a substantial yield increase to be economical.

It seems to be of value, certainly of interest, to consider developmental research efforts in the framework of the entire process and to appraise a project as to its effect on various things such as energy consumption and pollution load. The type of information given in the preceeding tables can be used, fairly effectively, to make such appraisals but it has serious shortcomings. Since it is assembled piece-meal from all types and sizes of plants in various locations, the resulting figures are only crude approximations. Rut, more important, the interaction of the various process components cannot be inferred from this data. For instance, if one assumes a yield increase it is not possible to obtain directly the resulting change in capital investment for the recovery and auxiliary furnaces. This is a serious shortcoming and certainly a formidable one for a chemist with only a passing knowledge of the engineering details of the process. However, the time seems to be coming when the process engineering data will be more readily available and I'd like to close this discussion with a brief description of what Seems to be evolving in the process engineering area.

The pulping process can be viewed abstractly as a group of subprocesses or subsections as shown in fig. 1. The performance of each subsection can be simulated by a mathematical model which establishes the relation between input and output, energy consumption, equipment size, and so forth. Each subsection can be conceived as an independent cell receiving inputs either from other unit cells or from an external stream, i.e. a plant feed stream. Similarly, its output is connected to other cells or is a product stream. Each subsection is modeled to be removable and replaceable and input and output streams can be readily connected so that many variations in plant operation can be simulated.

To illustrate, fig. 2 shows the possible construction of a unit process for wood preparation. Modeled as shown in the figure, it is possible to make connections to supply the digester with bark-free washed chips from roundwood, debarked washed logs to groundwood pulping, a washed bark-chip mixture from roundwood, or chips as received.

The input data required would include:

1. Species
2. Form - log or chips
3. Quality - size, extent of decay, dirt content, and sodium chloride content
4. Quantity

The output data that should be available:

1. Power
2. Steam - quantity, quality
3. Water - quantity, quality, temperature
4. Bark - quantity, moisture content, ash (including Si and NaCl), heating value
5. Chips - quantity, quality (bark, dirt, NaCl, Si, carbohydrate, and lignin)
6. Effluent - quantity, temperature, TSS, TDS, and fiber content
7. Cost data - maintenance and capital cost, labor requirements

Data stored permanently in the program would relate yield, composition, power requirements, etc. to species.

The degree of sophistication in modeling each subsection can range from simple tabulations of performance data with material and energy balances up to introducing the physical and chemical principles describing the dynamics of the process. Sophisticated simulation studies reported in the literature include the continuous digester[4], washings, recovery furnace[6], and the evaporators[7]. Bringing these together into a program to simulate the entire process will be a major task but it does seem a logical extension. Model design must be such as to allow modification and improvement as data become available. Development of the simulated plant can be viewed as a sequence of the operations indicated in fig. 1.

1. Available data from laboratory, plant, and market are collected.

2. A preliminary mathematical model is constructed using this information.

3. Results from model manipulation are compared with the real world to suggest areas of critical experimentation or data gathering.

4. Data from No. 3 is used to improve model; Nos. 3 and 4 are repeated as necessary.

5. The model can be used to optimize existing plants, which operate in changing situations, to design new plants, and to suggest the areas of greatest research interest. It would allow the future pulping chemist to readily obtain a realistic evaluation of where his research is leading and help to keep him on the path.

References

1. Asantila, R., Heikkinen, P., Nygardas, Y. and Strandell, O. Paper presented at the Annual Meeting of the Technical Association of the Pulp and Paper Industry, Miami Beach, Fla., Jan. 14-16, 1974.

2. Anonymous, Paper Trade J. 158(14):26 (1974).

3. Anonymous, Paper Age 10(4):32 (1974).

4. Johnsson, L., Acta Polytechnicia Scand., Mathematics and Computing Machines Series, 22, 115 (1971).

5. Gullichsen, J., Pulp & Paper Mag. Can. 74 (8):T266 (1973).

6. Lange, H. B., Jr., Pierce, D. P. and Kisner, J. W., Tappi 57(7):105 (1974).

7. Bolmstedt, U. and Gudmundson, C., Svensk Papperstidn. 77(1):27 (1974).

In: 1974 Non-sulfur pulping symposium, October 16-18 Sheraton Inn, Madison, WI Atlanta, GA : Technical Association of the Pulp and Paper Industry, 1974

Table I. Resource utilization

	Yield, %[a]	Fiber loss, %[a]	Wood loss (product and fuel) %[a]	%[b]
Wood preparation	88	2	1	1.0
Pulping	48	--	1	.9
Washing; screening	99	1	2	.8
Bleaching	94	0.5	6	2.5
Drying; baling	99	1	1	.4
				5.6

[a]Based on charge to operation.
[b]Based on total wood (including bark) to plant.

Wood charge (including bark) - 2.570 tons
Product - 1.000 tons (38.91%)
Fuel - 1.425 tons (55.45%)
Loss - .145 ton (5.64%)

Table II. Energy consumption

	Steam 10^3 BTU's/ADT* Debit	Credit	Electricity KWH/ADT Debit	Credit	Fuel 10^3 BTU's/ADT Debit	Credit
Wood preparation	--		74			1,600
Pulping	2,650		52			11,440
Washing; screening	--		112			
Bleaching	2,310		105			
Drying; baling	3,210		145			
Recovery boiler	440	11,000	30		11,440	
Auxiliary boiler	180	4,450	30		4,630	
Power generation	2,800		15	700		
Recausticizing	400		35		1,900	
Evaporation	3,780		32			
Effluent treatment	300		70			
	16,070	15,450	700	700	17,970	13,040

*Air-dry ton

$$\% \text{ external energy} - \frac{17,970 - 13,040}{17,970} = 27.4\%$$

Table 111. Pollution abatement costs for a modern mill

	Capital investments* - $ x 10^-6			Distribution, %
	Water	Air	Total	
Wood preparation	0.205	--	0.205	1.8
Pulping	.530	0.780	1.310	11.9
Washing; screening	2.199	.205	2.404	21.6
Bleaching	2.534	.195	2.729	24.6
Recovery boiler	.308	1.200	1.508	13.6
Auxiliary boiler	--	.720	.720	6.5
Recausticizing	--	.580	.580	5.2
Evaporation	.720	.920	1.640	14.8
	6.496	4.600	11.096	100.0
Annual operating costs - $ x 10^{-6}/yr	1.350	.313	1.663	

Total costs - $9.50/ton

*January 1972 costs

Table IV. Capital investment for a 1000 ton/day mill

	Cost* - $ x 10^{-6}	Distribution, %
Direct cost		
Installed equipment		
Wood preparation	4.8	6.2
Pulping	6.5	8.4
Washing; screening	6.1	7.9
Bleaching	9.2	11.8
Drying; baling	12.1	15.6
Recovery boiler	11.3	14.5
Auxiliary boiler	8.8	11.3
Power generation	4.3	5.5
Recausticizing	5.3	6.8
Evaporation	4.8	6.2
Effluent treatment	4.5	5.8
	77.7	100.0
Services		
Water supply	2.8	
General services	4.6	
Nonprocess buildings	3.0	
Site preparation	.5	
Total direct cost	88.6	
Indirect cost	15.8	
Total plant cost	104.4	

*January 1974 costs

Table V. Production costs

		$/ADT*	Distribution, %
Wood ($35/cord)		65.10	34.2
Chemicals			
Pulping	1.18		
Bleaching	13.35		
		14.53	7.6
Labor			
Operating	18.90		
Repairs & maintenance	9.10		
Salaries	3.78		
Overhead	15.89		
		47.67	25.0
Fuel		6.43	3.4
Plant costs			
Repair & maintenance materials	9.56		
Depreciation	44.75		
Property taxes & insurance	2.39		
		56.70	29.8
		190.43	100.0

*Air-dry tons

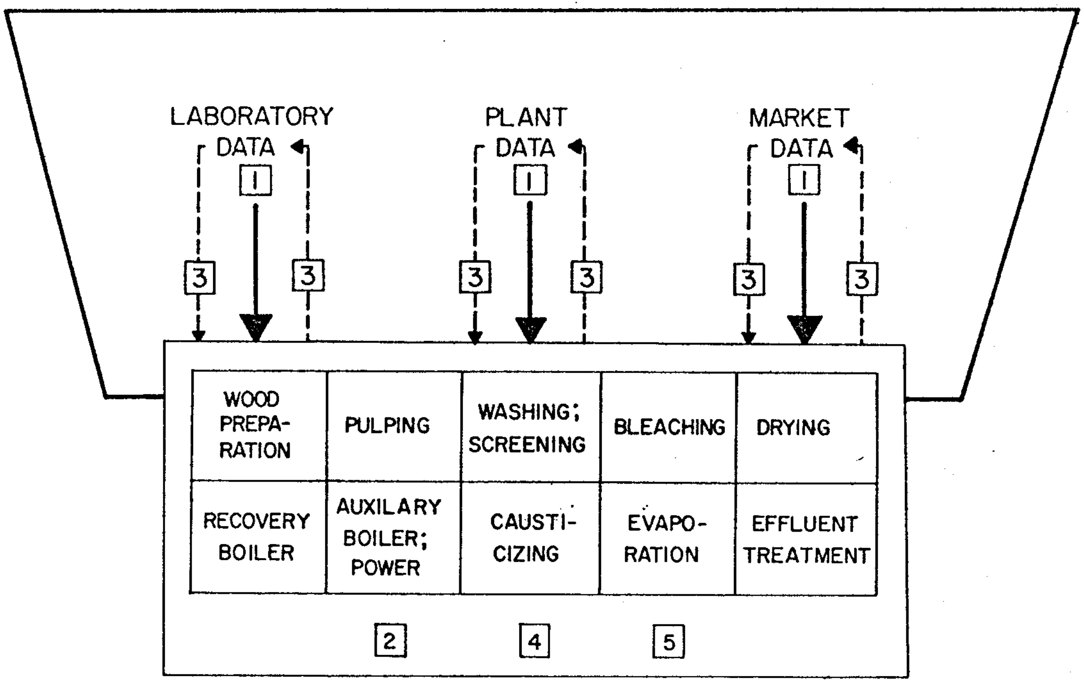
LABORATORY
DATA
PLANT
DATA
MARKET
DATA
1
3
WOOD PREPA-RATION
PULPING
WASHING; SCREENING
BLEACHING
DRYING
RECOVERY BOILER
AUXILARY BOILER; POWER
CAUSTI-CIZING
EVAPO-RATION
EFFLUENT TREATMENT
2
4
5

Fig. 1

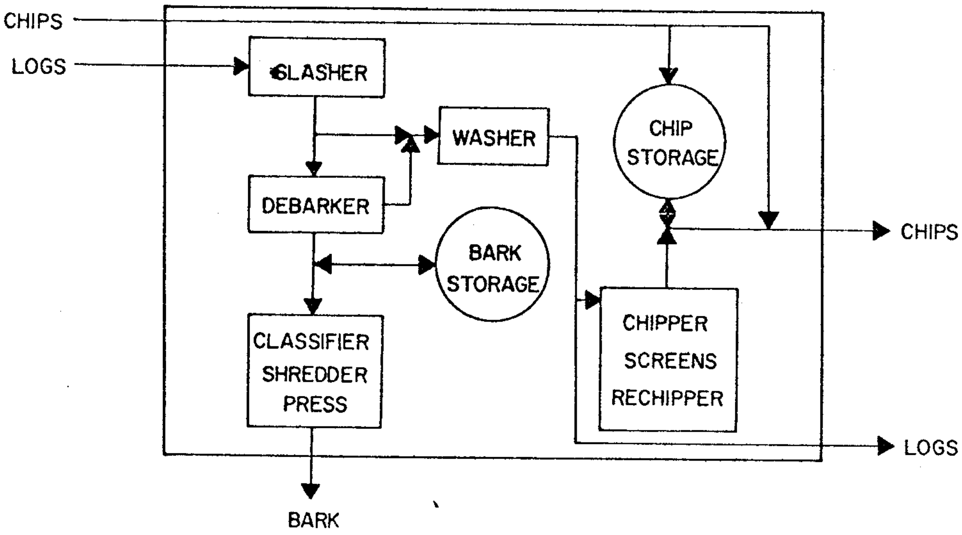
CHIPS
LOGS
SLASHER
WASHER
CHIP STORAGE
DEBARKER
BARK STORAGE
CHIPS
CLASSIFIER
SHREDDER
PRESS
CHIPPER
SCREENS
RECHIPPER
LOGS
BARK

Fig. 2