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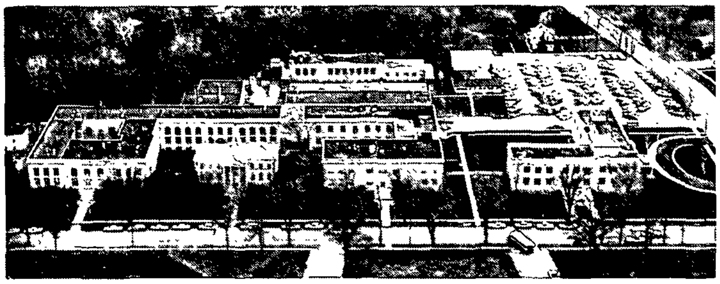

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EVALUATION OF ALTERNATIVE PULPING METHODS BY SYSTEMS MODELLING

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EVALUATION OF ALTERNATIVE PULPING METHODS BY SYSTEMS MODELLING

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Abstract

Mathematical modelling is discussed as a tool to be utilized in assessing the economic and environmental impact of alternative pulping methods. The concepts of process simulation are briefly reviewed. The simulation of a kraft pulp mill is discussed, and the economics of this mill are developed to act as a reference case for other processes. The problems encountered in developing the simulation model for new technologies are illustrated with a model of the oxygen-alkali process.

Introduction

The kraft pulping of southern pine is one reason for the increased utilization of this renewable resource. Unfortunately, the kraft process is very capital intensive. In addition, it produces effluents, both aqueous and airborne, which have adverse environmental impacts. A question that is currently being raised is, "Are there other processes that can be applied to southern pine which produce a kraft quality pulp with lower capital requirements and with less environmental side effects?" Several processes are being actively considered. Among the more promising is the oxygen/alkali (OA) process. However, before the OA process is pursued in great detail, studies need to be made to determine if the process can meet the goals of lower pollution and less capital intensity. Mathematical simulation offers one mechanism to help answer these and related questions.

This paper reviews the concepts behind system modelling, describes how these concepts are applied to a base kraft mill, and discusses the procedures for simulating a novel process, with direct reference to the OA process.

Systems Modelling

The petrochemical industry has been using systems modelling techniques for many years for process design and development work (1-3). It is only recently that these techniques have been applied in the pulp and paper industry (4-6).

The techniques used in these modelling routines are conceptually straightforward. As shown in Figure 1, a process is made up of various pieces of equipment, or units, connected together by pipes, information signals or energy transfers. Collectively, these are called streams. Thus, a process can be conceived of as a collection of process units which take information, be it a material flow, an energy flow, or control signal, and transform it into output information. The output information stream then becomes an input to some other process module.

If the material/energy/information streams pass directly through the process, the modelling process is simple, and only pencil and paper (and perhaps a hand calculator) are necessary to turn the raw material into a finished product. However, in real processes, recycle and stream branching greatly complicate the process. For example, in kraft pulping, the cooking chemicals are washed out of the pulp in the brownstock washers and recycled through the recovery system to the digester. Thus, one has a formidable problem of determining process outputs from inputs which are dependent on the outputs.

An obvious solution to this problem is to guess the input values, compute the outputs, and recompute the input values. If the computed value is sufficiently close to the initial value, all is well. Otherwise, we must cycle through the process again. Such a cyclical, repeated process is ideal for a computer. It is the control of this iterative process that is the heart of computer simulation.

Figure 2 illustrates the basic structure of a computer simulation program. The executive is the boss of the simulation. It reads the process description and thereby controls the routing of material through the process. The executive also computes necessary physical property information, such as steam temperature, given the pressure, density of liquor as a function of solids content, etc. When an

*Presently with Kimberly-Clark Corp.

entire recycle loop has been simulated, the executive compares the "guessed" values with the "computed" values and makes the decision whether to repeat the loop or continue with the simulation. Eventually, the entire process is simulated and all "guessed" values match "computed" values and the executive prints the final material and energy balance and quits. You can imagine that executives can be Volkswagens or Cadillacs with varying degrees of chrome.

One piece of chrome that is under development for executives is an economic package. The complete material and energy balance isn't much good without some economics attached to it. The ideal situation would be to simulate the material and energy balance and then have the executive call in the cost accountants so that the final report includes capital and operating costs. This aspect of the problem is covered in more detail in the discussion of the kraft mill simulation.

In the paper industry today, there are two simulation programs currently seeing relatively high use. These are (1) GEMS (General Energy and Mass Balance Simulator) developed by Dr. Lou Edwards at the University of Idaho, and (2) GEMCS (General Engineering and Management Computation System) initially developed by A. I. Johnson at McMaster University for petrochemical industry simulation. It is continuing to be adapted to the paper industry by Dr. Tom Boyle at McGill University and by the Chemical Sciences group at The Institute of Paper Chemistry. The differences between the two (GEMS and GEMCS) are relatively minor. In terms of an earlier analogy, they are both mid-range Chevrolets, with different placement of chrome.

The Kraft Mill Simulation

A major utility of simulators is to be able to quickly and easily evaluate alternative process configurations for environmental/economic impact. The first task is to develop a model of an existing process as a base case to ensure that the simulator is working correctly and, more importantly, to provide a basis for comparison. We chose to use a 750 tpd kraft mill as the base case. The schematic for this process is shown in Figure 3.

Note that no woodyard, bleachery, or effluent treatment facilities are included. The woodyard is roughly the same for both the kraft and OA processes and serves only to supply chips. Although the bleachery and effluent treatment facilities are potentially different for the kraft and OA processes, they have no effect on the pulping process in that no streams recycle to the pulping process. Thus, while these three processes affect the capital and operating cost, they do not affect the material and energy balance within the pulp mill proper and can be deleted.

However, the full liquor recovery system, including the precipitator on the furnace, is included. The basic data for this system are given in Table 1. Table 2 lists the major process models used in this GEMCS simulation. These models are very phenomenological in nature. For example, the user specifies the desired black liquor solids out of the evaporator unit and the steam economy. The simulator then can quickly compute the amount of steam required. No elaborate heat transfer calculations are used. The other modules work in a similar manner.

Table 1. -- SPECIFICATION FOR A SIMULATED KRAFT MILL

Pulp production	750 ADT/day
Chip feed	1590 ADT/day
Moisture content	46.5%
Extractives	6.5%
Digester yield (based on bone dry pulp)	47.6
Final kappa no.	47.0
Liquor/wood ratio	3.82
Effective alkali charge	16.4%
Brownstock washer efficiency	0.895
Steam economy (6 effect)	4.77

For this particular model, the pulp plays a minor role. It flows into the digester, out through the blow tank, on to the brownstock washers, and out of the process. It is the cooking chemicals that make this process relatively difficult to simulate, as they cycle through the process, with minor losses in the recovery furnace and out with the pulp. The simulation requires about 10 minutes on the Institute's IBM 360/44 computer, but only about 20 seconds on a big IBM 370/168 machine.

Table 3 gives estimated capital costs for this process. As mentioned earlier, it would be desirable to have GEMCS compute these costs. To do so, however, requires costs as a function of throughput or size, and although these data are available for most major pieces of equipment in the petrochemical industry, these data are not available for most paper industry equipment; this is an area which needs further work in the pulp and paper industry. The cost data in Table 3 were obtained from an engineering firm and represent installed cost for a recent mill. Table 4 presents operating (chemical and material) costs for this hypothetical mill. Recall, however, that the simulated mill does not have a wood-

Table 2. -- MAJOR MODULES FOR KRAFT SIMULATION

KDIGES	Kraft digester
FLSHTK	Flashes a stream to a specified pressure, used as a blow tank
WASHER	Washes a pulp stream with a specified displacement ratio and dilution factor
EVAPOR	Evaporates a stream to a specified total solids content, uses a specified steam economy to simulate multiple effects
TALOIL	Separates the nonvolatile extractives from the pulp
BLIQOX	Uses air to oxidize the sulfur in the black liquor
SMELTK	Forms green liquor from the smelt
CAUSTI	Causticizes the smelt to a given effective alkali ratio. Also separates off the lime mud and dregs
LIKILN	Burns the lime mud to lime
DCEVAP	Evaporates a stream by direct contact with a hot gas
RECFUR	Includes most of the functions of a kraft recovery boiler, including steam generation
FCNTRL	Regulates the material flowing in a pipe

Table 3a.-- KRAFT MILL CAPITAL COST COMPONENTS

	$ Millions
Pulping	11.8
Recovery	35.2
Power generation	12.4
Buildings	19.2
Total in Jan., 1976	78.6
Escalation (2 yr @ 8%/yr)	13.3
Fixed capital	91.9

Table 3b. -- KRAFT MILL CAPITAL REQUIRED

	$ Millions
Fixed capital	91.9
Contingency (10%)	9.2
Total fixed capital	101.1
Working capital	15.0
Total capital required	116.1

Table 4. -- VARIABLE COSTS, $/ADT

Raw materials	
Wood, 2.12 tons @ $40/ton	84.80
Limestone, 46.9 lb @ $0.0075/lb	0.35
Salt cake, 48.4 lb @ $0.023/lb	1.11
Operating supplies	3.00
Utilities	
Excess power generated, 574 kw-hr @ $0.02/kw-hr	(11.48)
Fuel oil (for lime kiln), 1.95 MM Btu @ $2.50/MM	4.88
Boiler feedwater	0.15
Process water	0.54
Total variable cost	83.35

yard, effluent treatment facility, or bleachery. These operating costs are only for the simulated section of the pulp mill.

Being satisfied that the simulation is operational and gives reasonable operating costs, we can now experiment with the process.

For example, if the efficiency of the brownstock washers were increased, how great are the savings in makeup chemical, what is the new steam production, and what other effects are realized? Similarly, if the washers are overloaded, what price do we pay? Table 5 compares two possible situations with the base case. Using the data in Table 6, we can compute the economic value of installing more or better washers or the penalty for overloading the existing system. Note that a major effect is the change in chlorine used in the bleachery due to the changes in lignin carried in with the pulp.

Table 5. -- EFFECT OF INCREASED WASHING EFFICIENCY ON THE KRAFT MILL MATERIAL AND ENERGY BALANCES

Overall displacement ratio in washers	0.850	0.898	0.920
Steam from recovery furnace, Btu/ADT	1.35×10^7	1.35×10^7	1.35×10^7
Steam to evaporators, Btu/ADT	2.57×10^6	2.57×10^6	2.57×10^6
Steam to heater, Btu/ADT	1.21×10^5	1.22×10^5	1.22×10^5
Tall oil, lb/ADT	172.53	173.21	173.52
Salt cake make-up, lb/ADT	32.87	26.06	23.02
Dissolved lignin in outgoing pulp stream, lb/ADT	10.4	7.0	5.5

Table 6. -- CHEMICAL COST SAVINGS ASSOCIATED WITH AN INCREASE IN WASHING EFFICIENCY

Overall displacement ratio in washers	0.85	0.90	0.92
Cost of saltcake make-up, $/ADT	0.758	0.600	0.529
Cost of chlorine required to oxidize dissolved lignin in chlorination stage, $/ADT	0.874	0.588	0.462
Total of saltcake and chlorine costs, $/ADT	1.632	1.188	0.991
Annual savings associated with DR increase from 0.85 in 750 ADT/day mill	($116,550)	--	$51,712

New Pulping Processes

The previous types of simulations are valuable for mill operations and mill managers. For researchers and planners, the simulation of future technologies offers some distinct advantages over traditional methods of research and planning. Let us consider the OA process as a vehicle for this discussion.

The OA process is projected to be a rival for the kraft process because it has much lower environmental impact, as sulfurous malodors are greatly reduced or eliminated, and the liquid effluents have greatly reduced color. Figure 4 is a rough schematic of one possible process. Several variations of the process are postulated. (Note, however, that the computers cannot predict changes in pulp quality. This must be done by laboratory experimentation until a more complete understanding of the pulping process is available.) The precook stage can be eliminated with increased oxygen consumption in the digester. The digester can use oxygen or air. The recovery system can be a fluid bed or a wet air oxidation unit. The cooking chemical can be sodium hydroxide, sodium carbonate, sodium bicarbonate, or a mixture of all three, depending upon the pH (7-9). The obvious question is which scheme is most economical. A more important question is, "Is the entire concept economical?" If the process is of only marginal economic feasibility, then which piece of the process should receive the most attention. That is, it is wasteful to invest many research dollars in determining the worth of the precook stage if it is measured in cents per ton when the worth of the optimal pH is measured in dollars per ton.

Simulation offers a way to hopefully discriminate between the alternative uses of research dollars. Some preliminary work is needed to define the basic phenomenological behavior of the major process units. From this elementary research, a first pass model can be constructed. Table 7 lists the units currently being developed for the GEMCS simulation of Figure 4. Note that we are using a precooker, which is modeled as a kraft type digester, with no sulfur and a high yield (90+%). Air is used in the oxygen/alkali digester, and the sodium carbonate cooking chemical is recovered in a fluidized bed combustion unit.

Table 7. -- UNITS FOR OXYGEN ALKALI SYSTEM

DFIBER	Refines the pulp after precooking
HIPPMP	Pumps the stock to desired high pressure
OXYPLP	Pulps the fiber to a given pH. Assumes carbonate - bicarbonate - hydroxide cooking liquor. Can use either air or oxygen
COMP	Compresses an ideal gas to a desired outlet temperature, computes horsepower, number of stages, and amount of interstage cooling required
DISOLV	Dissolves a mixture of Na_2CO_3-NaOH in water and computes the amount of make-up carbonate required for a given carbonate-water ratio. The amount of required liquor is determined by the digester and precooker
TURBIN	Expands an ideal gas to a fixed pressure and computes the available work
FBCOM	Burns organic material to CO_2 and water. Unit also transforms $NaHCO_3$-NaOH mixtures into mixtures of Na_2CO_3-NaOH

The simulation people must interact with the design group, or infeasible combinations may result. For example, the pulp leaves the refiner at 20-30% consistency, is pumped to

2000 psi and diluted to at least 10% consistency for the digester. The simulation group quickly runs the thick stock through a high pressure pump and then dilutes it with recirculating liquor, which is also used for temperature control. The design group quickly spotted a major flaw — where do you get a pump that can take pulp at 30% consistency to 2000 psi? The best thing they can do is one that may be able to operate at 2% consistency. Thus, the flow diagram must be changed to recirculate liquor to the suction side of the pump and dilute the stock before pressurizing. Now, do you pulp at 2% consistency with a huge digester, or do you find (develop?) a high pressure separator to increase the consistency to 10% before pulping? With a slightly different perspective, the cost differential between a large digester to pulp at 2% consistency and one to pulp at much higher consistencies is approximately the worth of developing a high pressure, high consistency pump. These types of interactions are important if a simulation is going to offer reasonable economic comparisons in the end.

We are currently wrestling with these decisions and hope to have an economic comparison done in a few months. Our major concern in this oxygen/alkali simulation work will be the overall feasibility of the process. Delineation of potential equipment selection problems will be a side benefit of the process feasibility studies. Once we have the kraft-oxygen/alkali comparison, we will know where to put our research dollars and what benefit will be obtained. Hopefully, such simulation work will prevent wasted time and effort on unprofitable avenues of work and will delineate those paths with the highest return.

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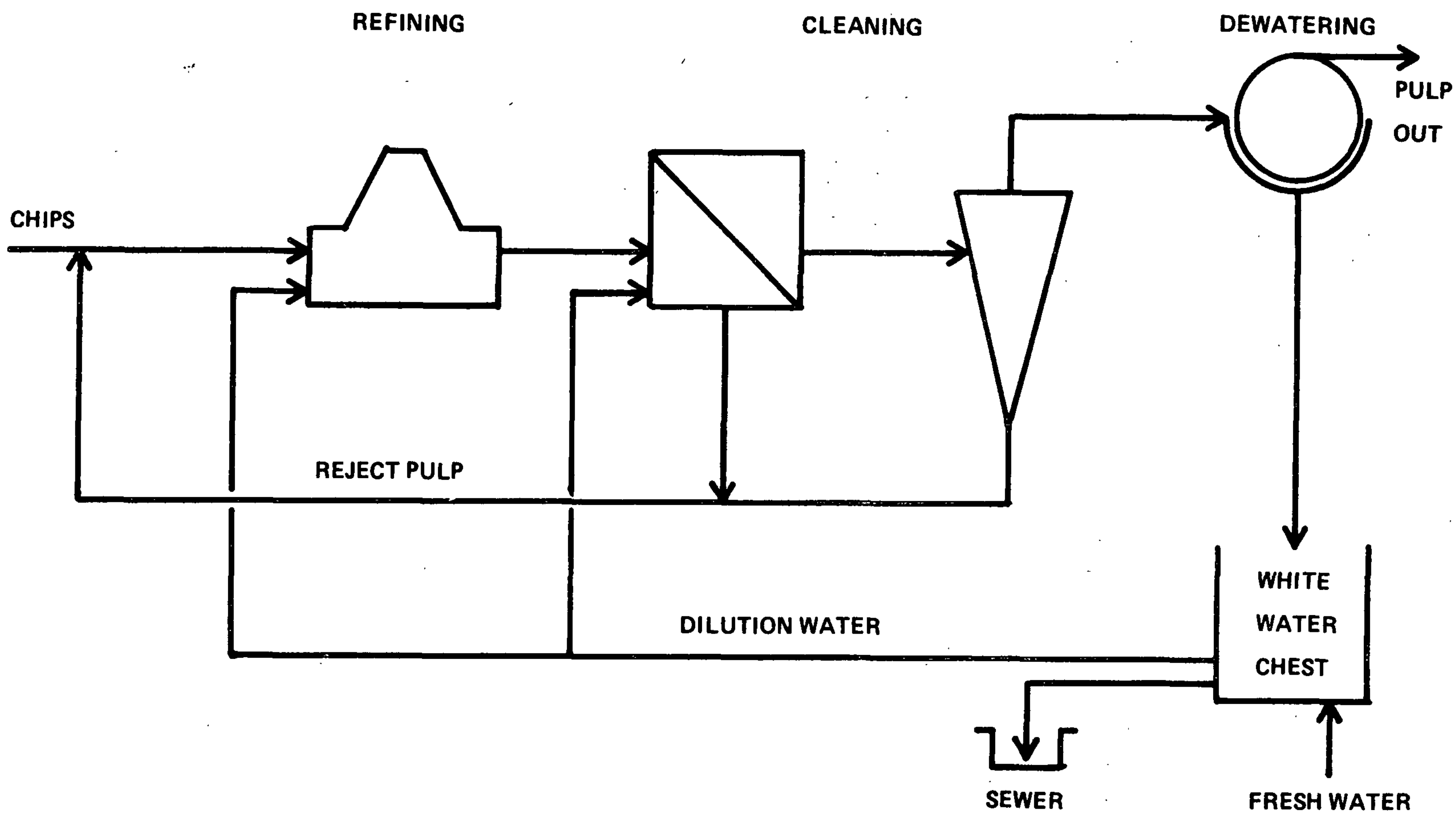

FIGURE 1. SCHEMATIC OF A REFINER MILL

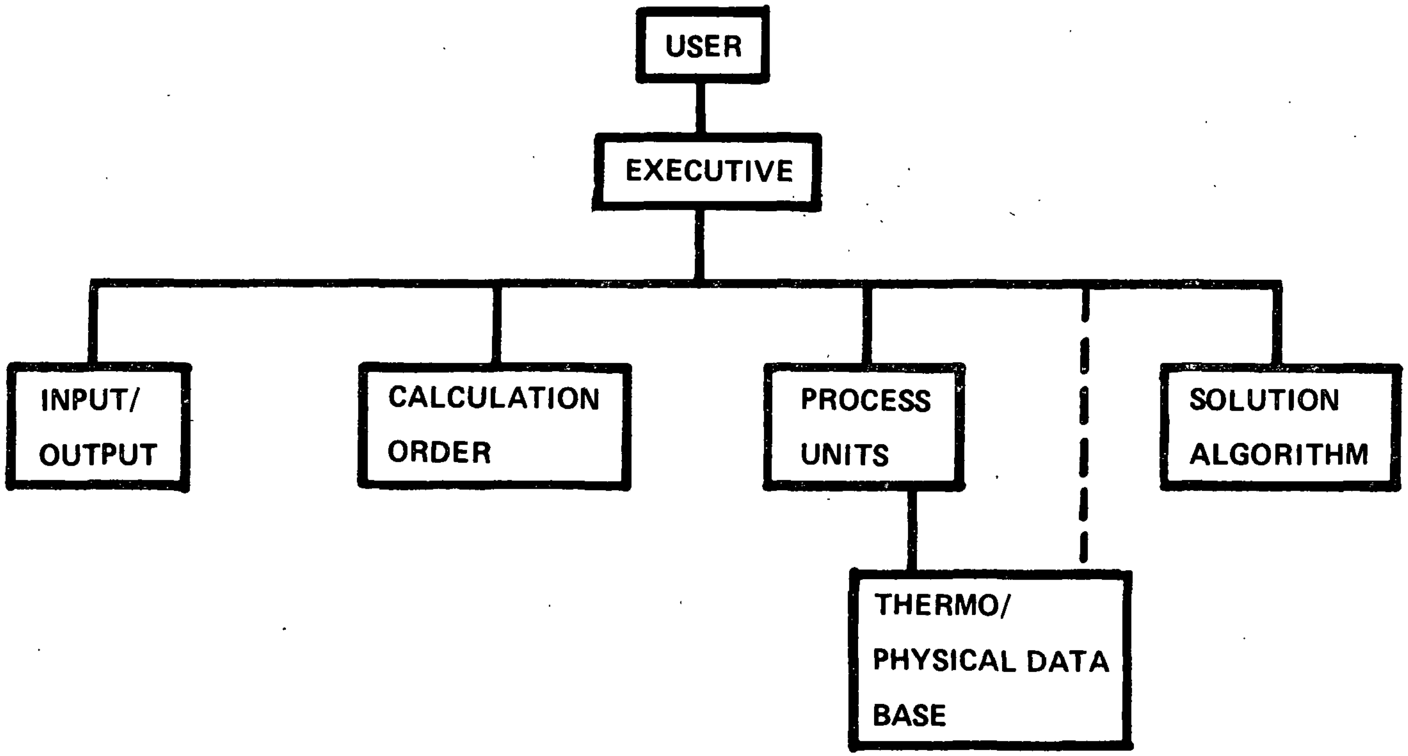

FIGURE 2. SCHEMATIC OF SIMULATION PROGRAM STRUCTURE

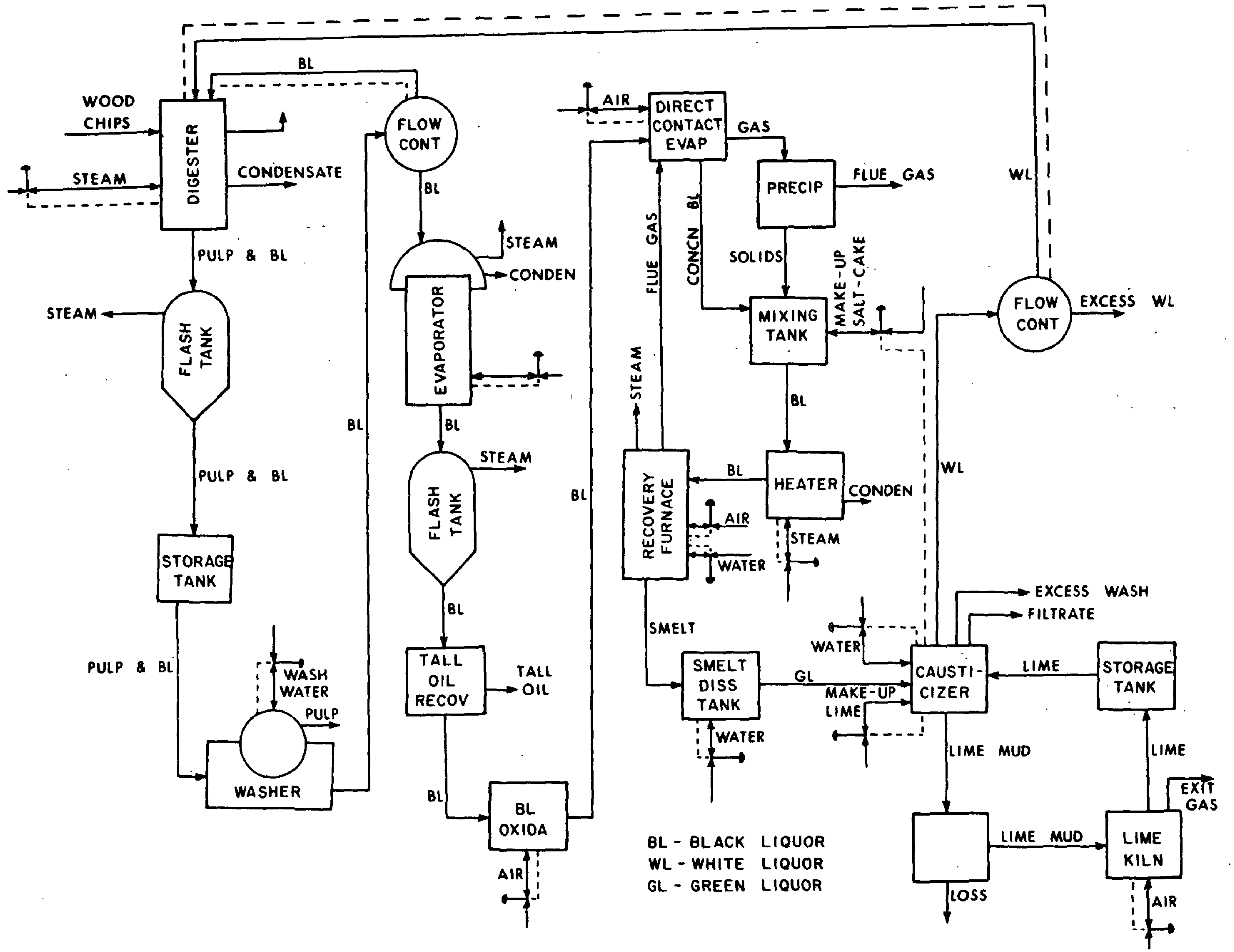

FIGURE 3. FLOW DIAGRAM OF KRAFT MILL

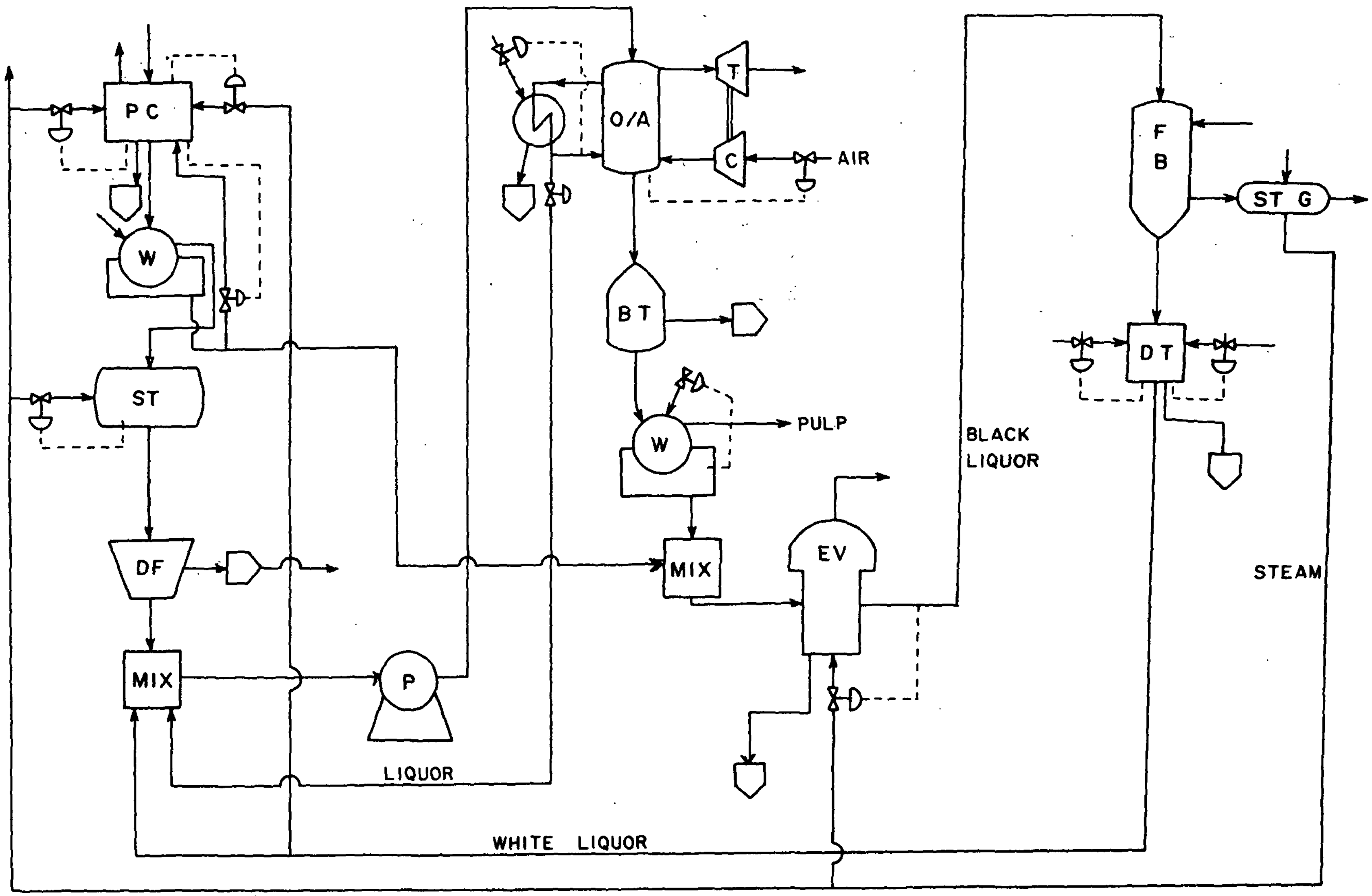

FIGURE 4. FLOW DIAGRAM OF PROPOSED OXYGEN/ALKALI MILL