6-1980

Application of a Kraft Mill Mathematical Model of a PDP-11

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APPLICATION OF A KRAFT MILL MATHEMATICAL MODEL ON A PDP-11

by

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A Thesis submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree

Western Michigan University
Kalamazoo, Michigan
June, 1980

ABSTRACT

The need to estimate the effects of a design or operating change in kraft pulping and recovery processes has resulted in the development of a working mathematical model. This model is a series of equations which evaluate significant chemical flows and losses, cooking rates and process economics. Through careful application to a PDP-11 computer system, this model is available for economic evaluation of process changes to improve pulp quality. The information necessary to start up, run and understand the data is covered along with discussion of the history of the development of mathematical modelling.

TABLE OF CONTENTS

INTRODUCTION

The objectives of this thesis are to set up a kraft mill mathematical model on a PDP-11, document the usage of the system and program, and explain what the program can provide in the way of simulation technique. In the following section of this report is explained the history and method used to model a system after a prototype. This explaination does not include the exacting procedures required behind mathematical modelling but rather touches on the ingredients necessary.

The program explaining the kraft mill model already existed and is used by the Scott Paper Company. This is an attempt to alter the input and output of this program and describe its usage for simulation demonstration in a classroom atmosphere. Clarification is necessary to make the program easier to use than the original form. This along with a detailed documentation of machine usage should make up the bulk of the experimentation.

THEORETICAL DISCUSSION

MODELLING CONCEPT

The concept of applying the language of mathematics to explain a physical, biological, social, psychological or conceptual entity is called modelling. The theory behind using a model to explain phenomena has been utilized by the earliest philosophers and scientists. It can be a bridge between theory and observation or an exacting mathematical formula for a well-defined problem and anything in between.

When a prototype is a physical or natural object, the mathematical model represents a change on the scale of abstraction. The model presents a simplified version with certain particularities removed. Because of these alterations, some regard the model as less real than the prototype without realizing that the prototype is a model of equations and the two are reciprocal.

The formulation of the equations in a model requires expressing the physical laws or principles with appropriate symbols. The nomenclature must be clear and concise along with easily applicable to the model. Selecting variables, choosing suitable units, reducing the number of variablès wherever possible, drawing and examining particular cases, and being willing to throw out and change the equations is the basic method of designing a workable model. Care must be taken to be accurate in strategy of approach but williness to change tactics and view the problem from all angles is also extremely important. After finding the model works, all that is left is effective presentation.

The interests of the pulp and paper industry has been shifting more and more to effective computer control. Along with computer control of processes comes the need for an accurate portrayal of what is being controlled. This need has spawned the "simulation" or mathematical model to demonstrate changing operating conditions.

The very nature of kraft pulping and the recovery process has been to react to a change by bringing about a set of interrelated changes. These changes are in both process conditions and economic factors. Due to this reaction, a need exists for methods by which these interrelated changes can be estimated in advance and taken into account. Utilizing a "simulation" is the key.

GEMS DEVELOPMENT

In recent years two methods of approach to simulation have sprung up. One is the computer program this thesis is representing which is a program applied to a single kraft mill with modifications necessary for a wider application. The other utilizes a general control segment method and is called GEMS. It is a General Energy and Materials System developed by the Department of Chemical Engineering at the University of Idaho. Written in Fortran language, it coordinates the execution of the steps involved in a process flow.

To make GEMS represent a specific simulation, work has been done to research each flow. For a pulp mill, subroutines are written to trace total flow of pulp, flow of oven dry fiber as chips, flow of ovendry fiber as pulp, flow of water, and pulp consistency through each stream in the process circuit. After the process circuit and related subroutines are defined, a flowsheet comprised of blocks identifying the subroutines are strung together in series to indicate the direction of flow.

After a coherent diagram is developed, data cards are prepared. These cards contain the equipment number, the name of the process subroutine, the streams flowing in and out of the subroutine and any equipment parameters associated with it. In addition each input stream to the system must be specified.

GEMS initially checks the validity of the input data, and if necessary will correct errors where practical. From here it performs the subroutines strung together to represent a process circuit, checks to see if equilibrium state has been achieved and then prepares the output.

The greatest advantage to GEMS over other simulation programs is the high versatility offered. This is an enormous advantage for engineering use in plant design and analysis. By simulating a proposed mill design, the state of the variables in all the streams can be predetermined. And by varying selected parameters or flow rates, a series of sensitivity analyses can be performed to determine the effect of an upset introduced into a system.

The provision of accurate mass balance enables users to have better insight into the various interactions within the sections of a mill. It allows also identification of the stages with problems (excessive water requirements as in a pulp mill) and to use the simulation package to determine the effects of reducing or altering these problems into workable solutions.

OTHER SIMULATION TECHNIQUES

Simulation development of a single system, as in the program used in this thesis, is approached in much the same way. First establishment of model parameters and close evaluations of the model equations is undertaken. After determination of a base case considerations for process change improvements can be evaluated qualitatively.

Re-evaluation of the model can now be made using the new parameter values to set up a test case. Comparison between the test case and base case establish all the effects of the applied change. This change is then evaluated to establish plausibility and determine if more simulations should be run or use the results to guide a change in the real process.

The method of determining modelling equations and setting up the model is a long arduous process. Knowledge of the process involved is of course a necessity. Closely tied to this is the need to fully understand mathematical programming and all that it entails. The major areas grouped under this computational practice are 1) model formulation and data base management; 2) optimization strategies; 3) algorithmic tactics and data structures; and 4) computer systems interface. The first area embodies matrix generation and report writing. The second area and third areas cover solving linear and slightly non-linear models, optimizational strategies which involve setting effective upper and lower boundaries on variables in the model and devising efficient solution operators. The last area is tied in with basic computer science considerations including operating systems and machine configurations. All of these processes are beyond the scope of this paper.

KRAFT MILL PROGRAM

The program being utilized in this thesis was developed by T.J. Boyle and M.G. Tobias of Scott Paper Company at Philadelphia, Pennsylvania. It was to represent the operation of kraft pulping and recovery processes along with an economic evaluation of process changes.

The model relies on the interrelationships among chemical flows, cooking rates, chemical losses and process economics. It utilizes 74 variables within 31 equations. The model does not cover all the possible interrelationships in such a complex process. Instead an effort was made to represent the physical relationship in a simple, workable form. The model is not without deficiencies. Many plant parameters were not singled out as variables but were instead involved in the numerical coefficients. Figure 1 illustrates the process flow stream along with some of the key variables described by the model. Table 1 contains a list of the nomenclature used in the model.

There are six main groups of equations contained within the model: wood relationships, water balances in cooking and washing, chemical flow determination, cooking and production relationships, evaporation and burning, and economics. Each will be explained separately.

Wood Relationships

This model base is set up to require a wood fiber content of 1800 lb. to equal the one ton air dried pulp utilized in the material balance. The other wood relationships are diagrammed schematically in Figure 2. Pulping yield and wood moisture content are necessary ingredients in this segment to complete specifications and allow the total solids, water and solubilized organics (lignin) fractions to be calculated. The equations and nomenclature involved in this segment of the program are as follows:

$$W_F = 1800 \text{ LB}$$

$$W_S = W_F/Y$$

$$W_T = W_S/(1 - W_M)$$

$$W_W = W_T - W_S$$

$$W_L = W_S - W_F$$

W_F - Weight of wood fiber, lb/ton a.d. pulp

W_L - Weight of wood lignin, lb/ton a.d. pulp

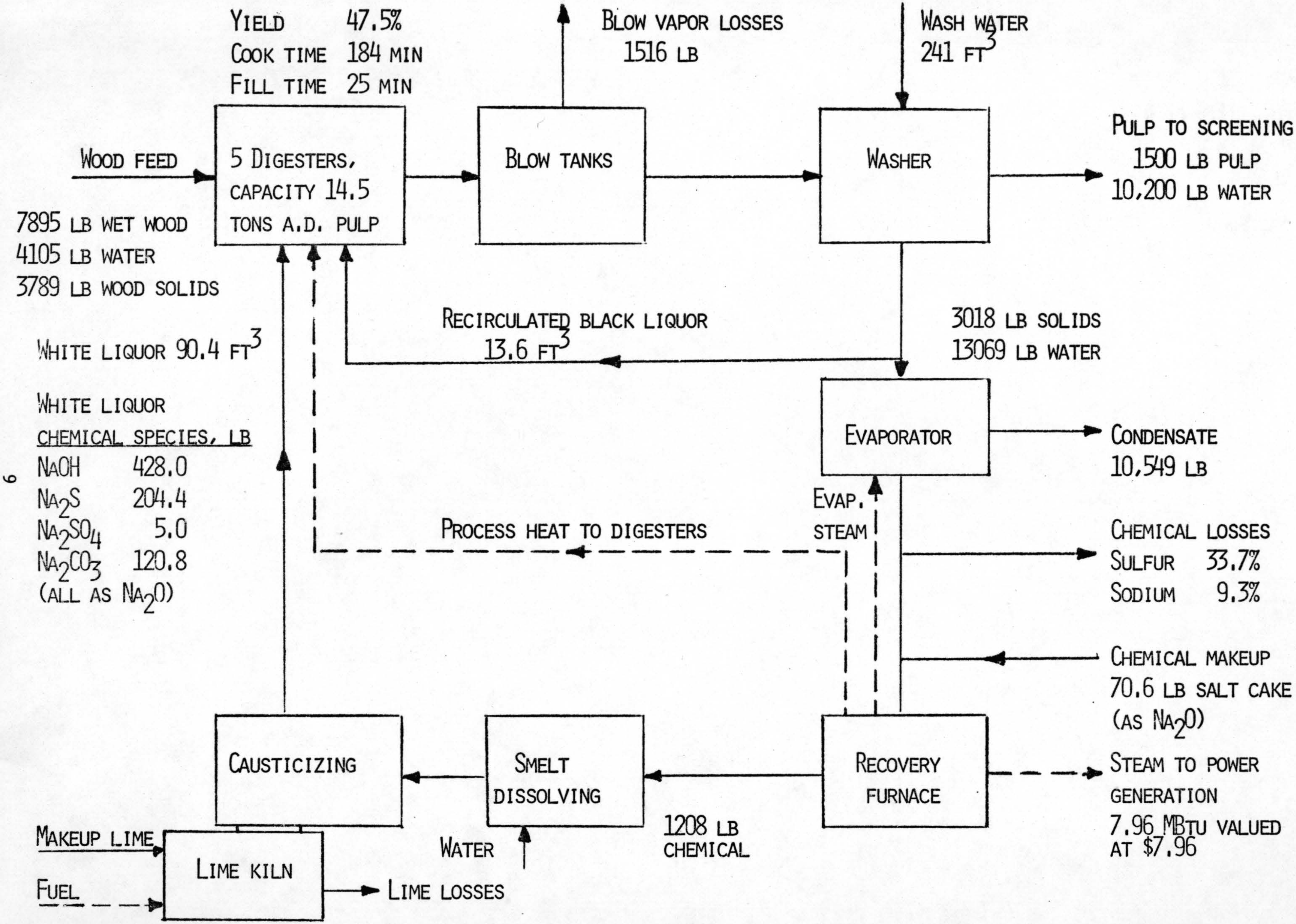
W_M - Moisture content of wood (fraction), lb/lb

W_S - Weight of wood solids, lb/ton a.d. pulp

W_T - Total weight of wet wood, lb/ton a.d. pulp

W_W - Weight of wood water, lb/ton a.d. pulp

Y - Pulping yield, nondimensional



YIELD 47.5%
COOK TIME 184 MIN
FILL TIME 25 MIN
BLOW VAPOR LOSSES
1516 LB
WASH WATER
241 FT^3
WOOD FEED
7895 LB WET WOOD
4105 LB WATER
3789 LB WOOD SOLIDS
5 DIGESTERS, CAPACITY 14.5 TONS A.D. PULP
BLOW TANKS
WASHER
PULP TO SCREENING
1500 LB PULP
10,200 LB WATER
RECIRCULATED BLACK LIQUOR
13.6 FT^3
3018 LB SOLIDS
13069 LB WATER
WHITE LIQUOR 90.4 FT^3
WHITE LIQUOR
CHEMICAL SPECIES, LB
$NaOH$ 428.0
Na_2S 204.4
Na_2SO_4 5.0
Na_2CO_3 120.8
(ALL AS Na_2O)
EVAPORATOR
CONDENSATE
10,549 LB
EVAP. STEAM
PROCESS HEAT TO DIGESTERS
CHEMICAL LOSSES
SULFUR 33.7%
SODIUM 9.3%
CHEMICAL MAKEUP
70.6 LB SALT CAKE
(AS Na_2O)
CAUSTICIZING
SMELT DISSOLVING
RECOVERY FURNACE
STEAM TO POWER GENERATION
7.96 MBTU VALUED AT $7.96
1208 LB CHEMICAL
WATER
MAKEUP LIME
FUEL
LIME KILN
LIME LOSSES

FIGURE 1

TABLE 1

A_A	Active alkali on ovendry wood, lb/lb	**	0.167
A_C	Active alkali concentration, lb/ft^3	**	7.0
A_E	Effective alkali on ovendry wood, lb/lb		0.14
A_{EN}	Normalizing value of effective alkali, lb/lb	**	0.15
C	Capacity of digesters (a.d. tons), tons/batch	**	14.5
C_C	Chemicals cost, $/ton a.d. pulp		8.81
C_{NP}	Recovery system net cost, $/ton a.d. pulp		-30.99
C_{PS}	Specific heat of wood solids, Btu/(lb)(^{o}F)	**	0.33
C_W	Consistency of pulp off washer, lb water/lb pulp	**	0.15
C_{WU}	Cost of wood used, $/ton a.d. pulp	**	44.0
D_W	Density of water, lb/ft^3	**	62.4
E_C	Caustic conversion efficiency, nondimensional	**	0.78
E_{EV}	Evaporator steam economy, nondimensional	**	4.66
F	Fixed charges of pulp process, $/day	**	12000.00
F_{SE}	Solids fraction in liquor to furnace, nondimensional	**	0.545
F_{SW}	Solids fraction in liquor to evaporator, nondimensional		0.188
G_B	Blow flow rate, lb/ton a.d. pulp		1516.0
G_E	Water in liquor from evaporator, lb/ton a.d. pulp		2519.0
G_{EV}	Evaporation rate from evaporator, lb/ton a.d. pulp		10549.0
G_P	Water leaving system with pulp, lb/ton a.d. pulp		10200.0
G_W	Water in liquor to evaporator, lb/ton a.d. pulp		13069.0
H_{CD}	Heat capacity of digester contents, (Btu/^{o}F)/ton a.d. pulp		11845.0
H_{CL}	Heat of combustion of lignin, Btu/lb	**	8100.0
H_{FS}	Heat of fusion of smelt, Btu/lb	**	530.0
H_{LF}	Heat losses from furnace, Btu/ton a.d. pulp	**	480000.0
H_{LW}	Latent heat of water, Btu/lb	**	1000.0
H_P	Heat produced in recovery process, Btu/ton a.d. pulp		7.96×10^6

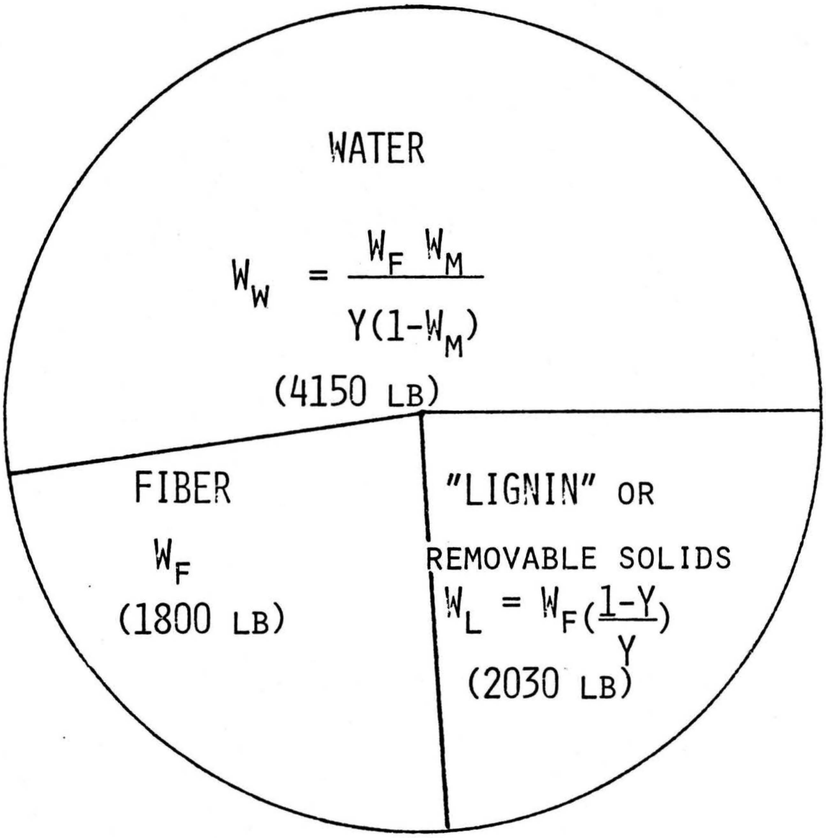
K_1	Constant in cooking model, minutes	**	222.5
K_2	Change in cook time per change in A_E, minutes	**	-200.0
K_3	Change in cook time per change in S_C, minutes	**	-100.0
K_4	Change in cook time per change in R_{LW}, minutes		100.0
L_{ST}	Total sulfur loss fraction, nondimensional	**	0.337
L_{NT}	Total sodium loss fraction, nondimensional	**	0.0931
N	Number of digesters, nondimensional	**	5
P_1	Price of salt cake, $/ton	**	50.00
P_2	Price of sodium carbonate, $/ton	**	60.00
P_3	Price of makeup lime, $/ton	**	33.00
P_4	Price of kiln fuel, $/MBtu	**	2.50
P_5	Value of process heat, $/MBtu	**	5.00
P_R	Production rate, tons a.d. pulp/day		500.0
R	Total return on process, $/day		18600.00
R_D	Furnace reduction ratio, nondimensional	**	0.976
R_{LW}	Liquor-to-wood ratio, lb/lb		2.8
R_{LWN}	Normalizing liquor-to-wood ratio, nondimensional	**	5.0
R_T	Return per ton of pulp, $/ton a.d. pulp		372.99
S	Sulfidity of cooking liquor	**	0.323
S_C	"Effective" sulfide in cooking liquor, lb/lb wood		0.0539
S_{CN}	Normalizing sulfide content, nondimensional	**	0.05
S_S	Solids in smelt, lb/ton a.d. pulp		1208.0
S_W	Black liquor solids in liquor to evaporators, lb/tons a.d. pulp		3018.0
T_L	Temperature of digester contents as loaded, ^oF	**	150.0
V_T	Top cooking temperature, ^oF	**	340.0
V_F	Usage of kiln fuel, MBtu/ton NaOH	**	8.54
U_L	Usage of makeup lime, lb/lb NaOH	**	0.0276

V	Value of slush unbleached pulp, \$/ton a.d. pulp	**	410.00
V_{BL}	Volume of black liquor to digesters, ft^3/ton a.d. pulp		13.6
V_{FW}	Volume of fresh water to washer, ft^3/ton a.d. pulp	**	241.0
V_{TL}	Volume of total cooking liquor, ft^3/ton a.d. pulp	**	104.0
V_{WL}	Volume of white liquor, ft^3/ton a.d. pulp		90.4
W_F	Weight of wood fiber, lb/ton a.d. pulp	**	1800.0
W_L	Weight of wood lignin, lb/ton a.d. pulp		1989.0
W_M	Moisture content of wood (fraction), lb/lb	**	0.52
W_S	Weight of wood solids, lb/ton a.d. pulp		3789.0
W_T	Total weight of wet wood, lb/ton a.d. pulp		7895.0
W_W	Weight of wood water, lb/ton a.d. pulp		4105.0
X_1	Weight of caustic (as Na_2O) in cook liquor, lb/ton a.d. pulp		428.4
X_2	Weight of sulfide (as Na_2O) in cook liquor, lb/ton a.d. pulp		204.4
X_3	Weight of sulfate (as Na_2O) in cook liquor, lb/ton a.d. pulp		5.0
X_4	Weight of carbonate (as Na_2O) in cook liquor, lb/ton a.d. pulp		120.8
X_5	Weight of makeup salt cake (as Na_2O), lb/ton a.d. pulp		70.58
X_6	Weight of makeup carbonate (as Na_2O), lb/ton a.d. pulp		0.06
Y	Pulping yield, nondimensional	**	0.475
Z_C	Cook time (including heatup), minutes		183.8
Z_F	Digester fill and down time per batch, minutes	**	25.0

** Indicate input data to program.

FIGURE 2

WOOD COMPONENTS REQUIRED PER TON A.D. PULP



NOTE: NUMBERICAL EXAMPLE BASED ON 47% YIELD AND 52% MOISTURE IN WOOD.

Water Balances in Cooking and Washing

The water balancing in the cooking and washing segment revolves around specified pulp consistency, blow loss and liquor control. The volume of white liquor to be used is determined from wood solids and cooking chemical specifications. The blow loss is calculated when the digester contents pressure is reduced to atmospheric by use of a heat balance. Fresh water addition is determined by the program user. A process flow diagram is shown in Figure 3 to depict the water balance in this segment. The equations and nomenclature utilized in this segment are as follows:

$$V_{WL} = W_S A_A / A_C$$

$$V_{BL} = V_{TL} - V_{WL}$$

$$G_P = W_F(1 - C_W)/C_W$$

$$H_{CD} = C_{PS}W_S + W_W + D_W(V_{WL} + V_{BL}) \qquad \text{(NOTE 1)}$$

$$G_B = H_{CD}(T_T - 212.)/H_{LW}$$

$$G_W = W_W + D_W(V_{WL} + V_{FW}) - G_B - G_P$$

V_{BL} Volume of black liquor to digesters, ft^3/ton a.d. pulp

V_{WL} Volume of white liquor, ft^3/ton a.d. pulp

A_A Active alkali on ovendry wood, lb/lb

A_C Active alkali concentration, lb/ft^3

V_{TL} Volume of total cooking liquor, ft^3/ton a.d. pulp

G_P Water leaving system with pulp, lb/ton a.d. pulp

C_W Consistency of pulp off washer, lb water/lb pulp

H_{CD} Heat capacity of digester contents, (Btu/^oF)/ton a.d. pulp

C_{PS} Specific heat of wood solids, Btu/(lb)(^oF)

D_W Density of water, lb/ft^3

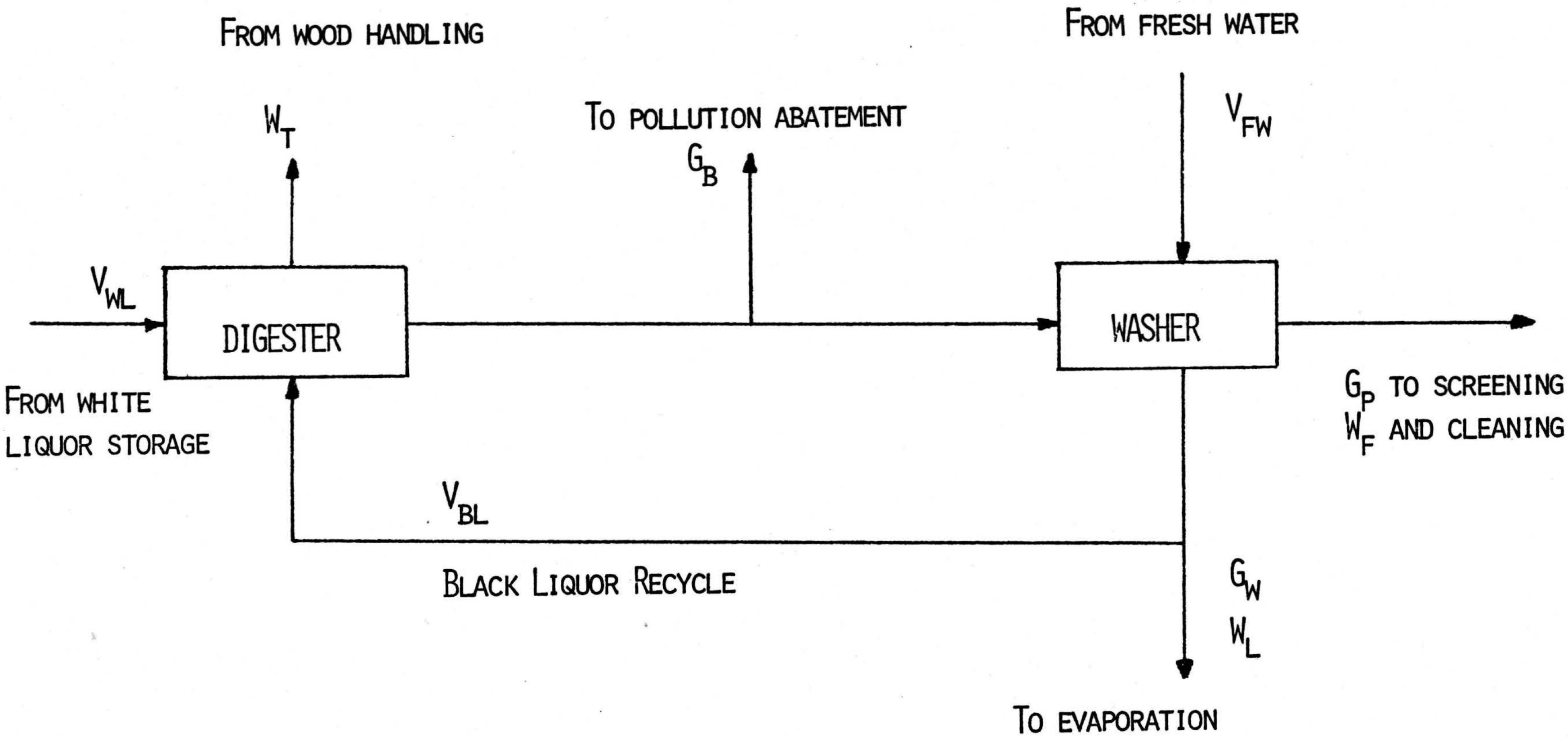


FIGURE 3

WATER BALANCES AROUND COOKING AND WASHING

G_W Water in liquor to evaporator, lb/ton a.d. pulp

G_B Blow flow rate, lb/ton a.d. pulp

H_{LW} Heat losses from furnace, Btu/ton a.d. pulp

V_{FW} Volume of fresh water to washer ft^3/ton a.d. pulp

T_T Temperature of digester contents as loaded, ^oF

NOTE 1 - Neglect digester shell heat capacity and heat capacity of cooking chemicals.

Chemical Flow Determination

The composition of chemicals and their usage is the basic motivation behind this model. The chemicals in the liquor and liquor makeup are the factors that determine the efficient pulping of the wood. Four of the main ingredients in white liquor are: sodium hydroxide (X_1), sodium sulfide (X_2), sodium sulfate (X_3), and sodium carbonate (X_4). The makeup chemicals used are sodium sulfate or salt cake (X_5) and sodium carbonate (X_6). In order to keep track of the atoms of sodium in the process, all of the above chemicals are expressed as the equivalent weight of sodium oxide per ton of air dry pulp. A table of chemical balance equations and their basis follows:

$$X_1 + X_2 = W_F A_A / Y$$ Chemical used

$$\frac{X_2}{X_1 + X_2} = S$$ Sulfidity desired

$$\frac{X_2}{X_2 + X_3} = R_D$$ Furnace reduction ratio

$$\frac{X_1}{X_1 + X_4} = E_C$$ Caustic conversion efficiency

$$L_{ST}(X_2 + X_3) = X_5 \qquad \text{Sulfur balance}$$

$$L_{NT}(X_1 + X_2 + X_3 + X_4) = X_5 + X_6 \qquad \text{Sodium makeup}$$

Notes: 1 All chemical amounts expressed as equivalent pounds of lb Na_2O/ton a.d. pulp.
2 Sodium and sulfur balances are on a 1-ton a.d. pulp basis.

The first two equations illustrate the relationship between sodium hydroxide and sodium sulfide on active alkali on the wood and sulfidity. The amount of sodium sulfide and sodium sulfade described in the third equations embodies the reduction furnace behavior. Caustic conversion efficiency is determined by the concentrations of sodium hydroxide and sodium carbonate in equation four. These four equations are constructed so that they can be solved simultaneously.

After the determination of white liquor makeup, the sulfur balance in equation five determines the amount of salt cake required by the system. There is a certain amount of sulfur-bearing compounds lost from handling expressed as the fraction (L_{st}). The final equation in this series is the sodium makeup balance. This is achieved through balancing the sodium terms and expressing the additional makeup sodium in terms of sodium carbonate.

The set of equations shown above demonstrate the dependence each of the processes has to the amounts of chemicals provided. The program utilizes these equations to develop individually each of the components involved. These changes in equations and necessary nomenclature follows:

$$X_1 = W_F(1 - S)A_A/Y$$

$$X_2 = \frac{S}{1 - S} X_1$$

$$X_3 = \frac{1 - R_D}{R_D} X_2$$

$$X_4 = \frac{1 - E_C}{E_C} X_1$$

$$X_5 = L_{ST}(X_2 + X_3)$$

$$X_6 = L_{NT}(X_1 + X_2 + X_3 + X_4) - X_5$$

L_{ST} Total sulfur loss fraction, nondimensional

L_{NT} Total sodium loss fraction, nondimensional

Cooking and Production Relationships

This modelling program does not rely on cooking temperature to play a major role in cook time. Instead, it focuses more on process changes which are not as affected by some of the unmentioned factors in cook time. Much more emphasis is placed on chemicals and their changes than anything else. Production rate in the plant is obtainable from number and capacity of digesters and total time required per cook; this includes dumping and filling.

The choice of variables in this segment was suggested by Hinrichs work, with his results used to obtain the numerical coefficients used in this program. The relationships described rely on effective alkali on the wood, sodium sulfide on the wood and the liquor-to-wood ratio. The equations and nomenclature used in this segment are as follows:

$$A_E = (X_1 + 0.5X_2)/W_S$$

$$S_C = X_2/W_S$$

$$R_{LW} = (D_W(V_{WL} + V_{BL}) + W_W)/W_S$$

$$Z_C = K_1 + K_2\left(\frac{A_E - A_{EN}}{A_{EN}}\right) + K_3\left(\frac{S_E - S_{EN}}{S_{EN}}\right) + K_4\left(\frac{R_{LW} - R_{LWN}}{R_{LWN}}\right)$$

$$P_R = 1440NC/(Z_C + Z_F)$$

A_E Effective alkali on ovendry wood, lb/lb

A_{EN} Normalizing value of effective alkali, lb/lb

S_C "Effective" sulfide in cooking liquor, lb/lb wood

S_{CN} Normalizing sulfide content, nondimensional

R_{LW} Liquor-to-wood ratio, lb/lb

R_{LWN} Normalizing liquor-to-wood ratio, nodimensional

Z_C Cook time (including heatup), minutes

Z_F Digester fill and down time per batch, minutes

K_1 Constant in cooking model, minutes

K_2 Change in cook time per change in A_e, minutes

K_3 Change in cook time per change in S_c, minutes

K_4 Change in cook time per change in R_{1w}, minutes

P_R Production rate, tons a.d. pulp/day

N Number of digesters, nodimensional

C Capacity of digester (a.d. tons), tons/batch

Evaporation and Burning

Spent cooking liquor is evaporated and burned to recover chemicals and produce process heat to assist in cooking and evaporating. This process of evaporation incorporates the black liquor leaving the washer section which consists of solubilized solids fraction in the liquor, water and inorganic chemicals. The chemicals must be redefined to actual weight rather than equivalents of sodium oxide. These conversion factors are determined from both the molecular weights and total atoms of sodium per molecule. The determination of smelt is done by assuming all non-sulfur sodium compounds are converted to carbonate.

The heat produced by the recovery process is derived from a heat balance diagrammed in Figure 4. The furnace is handling the heat of fusion of the smelt, latent heat to evaporate the water left in the black liquor coming from the evaporators, and inherent heat losses. The other elements in the heat balance are ignored for simplification and are compensated for by selecting a suitable heat of combustion of the organics in the black liquor. The heat used by the evaporator and digester are handled very straightforwardly. The equations and nomenclature for this segment are as follows:

$$S_W = W_L + 1.29X_1 + 1.26\ X_2 + 2.29X_3 + 1.71X_4 \qquad \text{(NOTE 1)}$$

$$F_{SW} = S_W/(S_W + G_W)$$

$$G_E = S_W(1 - F_{SE})/F_{SE}$$

$$G_{EV} = G_W - G_E$$

$$S_S = 1.71X_1 + 1.26X_2 + 2.29X_3 + 1.71X_4$$

$$H_P = H_{CL}W_L - H_{FX}S_S - H_{LW}G_E - H_{LF} - H_{LW}G_{EV}/E_V - H_{CD}(T_T - T_L) \qquad \text{(NOTE 2)}$$

S_S Solids in smelt, lb/ton a.d. pulp

S_W Black liquor solids in liquor to evaporators, lb/tons a.d. pulp

F_{SW} Solids fraction in liquor to evaporator, nondimensional

G_E Water in liquor from evaporator, lb/ton a.d. pulp

G_{EV} Evaporation rate from evaporator, lb/ton a.d. pulp

F_{SE} Solids fraction in liquor to furnace, nondimensional

H_P Heat produced in recovery process, Btu/ton a.d. pulp

H_{CL} Heat of combustion of lignin, Btu/lb

H_{FS} Heat of fusion of smelt, Btu/lb

H_{LW} Latent heat of water, Btu/lb

H_{LF} Heat losses from furnace, Btu/ton a.d. pulp

H_{CD} Heat capacity of digester contents, (Btu/^{o}F)/ton a.d. pulp

T_L Temperature of digester contents as loaded, ^{o}F

E_V Evaporator steam economy, nondimensional

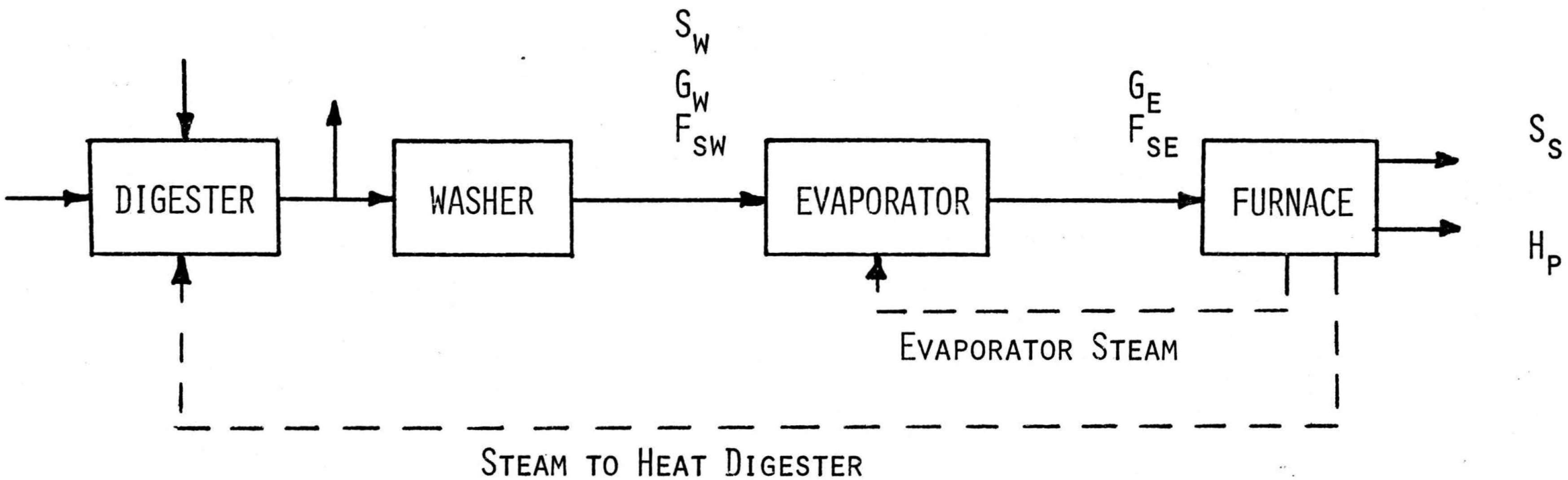


FIGURE 4
EVAPORATION AND BURNING

NOTE 1 Numerical values (1.29, 1.26, 2.29, 1.71) are ratios of pounds of chemical per pound of Na_2O equivalent.

2 Heat balance (H_p) neglects several terms. These are to be compensated by suitable adjustment of H_{cl}.

Economics

The economics of a process determines the feasibility of utilization. This segment determines the chemical costs, recovery system net cost, return per ton of pulp, and total return on the process. These are determined through manipulations of factors calculated earlier in the program and reflect some of the lack of detail due to the need to estimate the coefficients rather than accurate process imitation. These equations and nomenclature are as follows:

$$C_C = P_1(2.29)X_5 = P_2(1.71)X_6 + (P_3U_L + P_4V_F)X_1$$

$$C_{NP} = C_C - P_5H_P$$

$$R_T = V - C_{NP} - C_{WU} - F/P_R$$

$$R = P_R R_T$$

C_C Chemicals cost, \$/ton a.d. pulp

C_{NP} Recovery system net cost, \$/ton a.d. pulp

C_{WU} Cost of wood used, \$/ton a.d. pulp

P_1 Price of salt cake, \$/ton

P_2 Price of sodium carbonate, \$/5on

P_3 Price of makeup lime, \$/ton

P_4 Price of kiln fuel, \$/MBtu

U_L Usage of makeup lime, lb/lb NaOH

V_F Usage of kiln fuel, MBtu/ton NaOH

R Total return on process, \$/day

R_T Return per ton of pulp, \$/ton a.d. pulp

F Fixed charges of pulp process, \$/day

V Value of slush unbleached pulp, \$/ton a.d. pulp

PDP-11 USAGE

INTRODUCTION

This program is prepared for application and usage on a PDP-11. This computer system contains a memory core of 12K works and utilizes a BASIC/CAPS system. Because of the memory available, this version of the PDP-11 system allows string variables and the PRINT USING statement. The BASIC/CAPS is run using the CAPS-11 Cassette Monitor System. This permits sequential file capabilities and allows the user to save and retrieve files from cassettes. This system also allows user-defined functions, user-written assembly language routines, and chaining between BASIC programs with data utilizing memory and/or cassettes.

SYSTEM START-UP

BASIC/CAPS is a single-user BASIC running under the CAPS-11 Cassette Monitor System. To start the system up and running, follow this procedure:

1. Turn key on PDP-11 system to Power.

2. Turn teletype on to LINE.

3. Wait a moment to see if a ?PWF (power failure) error message appears. If it does, the system will return with a READY indicating that BASIC is being run and is available for commands, program entry or retrieval.

4. If the system does not respond as above, then first press and release the HALT/ENABLE switch.

5. Mount BASIC cassette on unit 0 cassette drive.

6. Set address switches to octal 57710 (binary 0101111111001000) with down being 0 and up being 1.

7. Press and release the LOAD/ADDRESS switch.

8. Reset the address switches to octal 00011 (binary 0000000000001001).

9. Press and release the START switch. The cassette will run for a while and then stop.

10. Reset the address switches by switching the zero bit to zero, octal 00010 (binary 0000000000001000).

11. Press and release the CONTINUE switch.

The BASIC program has now been entered into the system and the initial dialogue will begin. This dialogue occurs only once and is in the form

```
BASIC/CAPS V01-01
OPT FNS?
```

where it waits for specification of optional functions. Refer to BASIC-11 Language Manual, Chapter 3 for information on these functions. Select either a carriage return, A, N, or I. A carriage return and A will cause all the functions to be added, an N none and an I causes the functions to be listed so individual functions may be selected. When running the system for usage with the Kraft Mill Model program, select I and wait for the individual functions to be listed, select the TAB function out of the listed options. The list will appear like this:

```
BASIC/CAPS V01-01
OPT FNS? I

 Y-YES  N-NO
RND  :
ABS  :
SGN  :
BIN  :
OCT  :
TAB  :
LEN  :
ASC  :
CHR$ :
POS  :
SEG$ :
VAL  :
TRM$ :
STR$ :
```

After the options are selected, the BASIC requests the terminal type by printing:

```
TERM?
```

for the system available, a carriage return is appropriate.

BASIC then requests the date in the form of

DATE:dd-mmm-yy

with dd the day of the month (may be one or two digits), mmm is the first three letters of the month and yy is the last two digits of the year. If the date is not in this form, BASIC prints

BAD DATE
DATE:

requesting the data again. After correct entry the system comes back with

READY

which indicates successful initialization and that a command or program line may be typed.

If the computer is turned off while BASIC is operating the ?PWF (power failure) error message is printed when the power is turned on again. The user program is not destroyed and BASIC returns with a READY message with all files closed.

PROGRAM USAGE

To start up the Kraft Mill modelling program, locate and mount the cassette named "KRAFT MILL MODEL" into the cassette drive 0. At this point the command

RUN BEGIN

can be made. The system will begin searching through the cassette files to locate the program BEGIN. This segment of the Kraft Mill modelling program requests information pertaining to the style of input and output desired. Two different forms of each are available. The long form input requests data input entry by entry with a complete description of the variables and appropriate labelling. If the user is familiar with the input data and variables then requesting the short form method of input is more time conserving. This method of input requests a group of variables be entered separated by commas. The variables are identified by the shortened method of WF rather than weight of wood fiber. Due to this, careful preparation of data is a must. After both methods, the program asks the user if the numbers entered are correct so that if an error is detected by the user they may correct it but in doing so must also reenter all the variables again.

After receiving the data the system is instructed internally to locate the calculation segment of the program, run it and then locate the proper output segment. This requires that the cassette is searched through for each segment to be run. This is a time consuming search and cannot be avoided.

The output selection requested in the earlier part of the program is based on the long and short method also. The short output assumes the user is familiar with output variables in the shortened form (i.e., WS instead of weight of wood solids). This format is in table form with group headings. The long form is more complete in format. It includes both the WS and the description of the variable along with correct labelling. Due to the size of the long output program, it was broken into two separate segments. When requesting this form of output the teletype will stop half way through the output and go back and search for the rest of the segment.

At the end of the output the program asks the user if they would like to rerun the program. Answering YES sends the program back to the beginning with the requests of input/output formatting selection.

PROGRAM DEMONSTRATION

To provide the user with a base example for examination of the model, a table is included showing plausible working data. Example cases are also shown to illustrate the examination process.

Example 1

In the base case, which will serve to establish the basic process parameters (see Table 1), the description is of a 500 tons per day Kraft pulp mill. The process economics are the source of comparison between the other examples which follow. The key factors involved are as follows: pulp is valued at $410 per ton as unbleached slush; wood cost is $44 per ton; a credit is given for process heat produced in excess of that consumed internally; makeup chemicals are at typical commercial rates; fixed charges of $12,000 per day are applied to all pulp produced (this figure is low but a more appropriate estimate was not available). The economic performance of the base case example is then:

Production rate, tons/day	500.
Gross profit, $/day	18,600.
Profit, $/ton	372.99
Makeup chemical costs (includes kiln fuel costs), $/ton	8.81

This base case involves observations which are to be examined in the subsequent examples. They are:

1. The liquor-to-wood ratio (2.8) is quite low and could result in high screening losses and poor pulp quality.

2. Sulfur losses from the process are high (34%).

Example 2

To improve the pulp quality, the liquor-to-wood ratio is increased to at least 3.5 from 2.8. In order to do this, the total liquor feed to the reactor is increased from 104 ft^3/ton a.d. pulp to 150 ft^3/ton a.d. pulp. This change will increase the liquor-to-wood ratio and result in higher usage of weak black liquor as a diluent, if the cooking chemical requirements are not changed. The major results of this alteration were:

1. Black liquor recirculation was raised from 13.6 to 59.6 ft^3/ton of pulp. Liquor-to-wood ratio increased to 3.55.

2. Cook time to desired yield increased to 199 minutes (from 183 minutes) and this resulted in a production rate reduction to 466.1 tons per day.

3. Net steam production decreases because of higher process heat requirements in the digester.

The economic performance of this example was:

Production rate, tons/day	466.1
Gross profit, $/day	17,200.
Profit, $/ton	368.91
Makeup chemical costs, $/ton	8.81

Example 3

This example is an attempt to raise the production rate back to 500 tons per day while maintaining the higher liquor-to-wood ratio from example 2. This can be accomplished by increasing the active alkali on wood used in cooking. The excess chemicals should speed up the process but they also increase the recovery system costs.

The result of increasing the active alkali from 16.7 to 17.5 percent on wood reduces the cook time from 199 minutes to 185 minutes and the production rate is thereby increased to 497.5 tons per day. The salt cake makeup requirements are increased by about 5%.

This example involves economic performance thusly:

Production rate, tons/day	497.5
Gross profit, $/day	18,400.
Profit, $/ton	369.51
Makeup chemical costs, $/ton	9.23

Example 4

The production rate in example 3 showed that it had been restored closer to the original level, but the gross profit was still lower than the base case. To alter this effect, the active alkali was increased again to 17.9% to evaluate if the original gross profit can be attained. By altering the active alkali content, the cook time was reduced to 178 minutes.

The economic parameters are as follows:

Production rate, tons/day	514.8
Gross profit, $/day	19,000.
Profit, $/ton	369.81
Makeup chemical costs, $/ton	9.45

As shown, the total profit exceeds the base case level but profits per ton are lower due to increased chemical demand.

Example 5

In this example the active alkali has been lowered back to 17.8%, the active alkali concentration has been decreased from 7 to 5.5 and the sulfidity of the cooking liquor is altered from 32.3% to 30.4%. This brings the cook time back up to 184 minutes as in the base case and the production rate is comparable.

The economic parameters indicate the change:

Production rate, tons/day	499.3
Gross profit, $/day	18,400.
Profit, $/ton	368.01
Makeup chemical costs, $/ton	9.29

Example 6

This example differs from the others in that it examines the effect a pollution abatement process modification has on the economic parameters. It is designed to reduce sulfur losses from 34 to 20%. The other major alteration is the additional charge of $250 per day in the fixed charges of pulp process to cover depreciation and operation of the new equipment. The use of soda ash in addition to salt cake as a makeup chemical is also provided for. The sulfidity of the cooking liquor is changed back to 32.3% as in the base case. The major results are as follows:

1. After the change, about 40% of the makeup chemical must be soda ash to maintain sulfidity at 32.3%. Sulfidity would go out of range if an attempt was made to operate with salt cake only as a makeup chemical.

2. Makeup chemical costs drop as a result of the reduced sulfur losses, but the increased fixed charges offset this reduction.

The economic parameters are:

Production rate, tons/day	497.5
Gross profit, $/day	18,400.
Profit, $/ton	369.18
Makeup chemical costs, $/ton	9.08

Table 2 shows the six examples listed together for ease of analysis.

TABLE 2

	Production Rate Tons/day	Gross Profit $/day	Profit $/ton	Makeup Chemical Costs $/ton
Example 1				
Base case	500.0	18,600.	372.99	8.81
Example 2				
Increased black liquor recirculation	466.1	17,200.	368.91	8.81
Example 3				
Increased active alkali	497.5	18,400.	369.51	9.23
Example 4				
Increased active alkali	514.8	19,000.	369.81	9.45
Example 5				
Decreased active alkali Decreased active alkali concentration Decreased sulfidity	499.3	18,400.	368.01	9.29
Example 6				
Increased fixed cost Decreased total sulfur loss Increased sulfidity	497.5	18,400.	369.18	9.06

CONCLUSION

In conclusion, this thesis has attempted to educate the reader in first the history of modelling, some of the intricacies of developing a model and the hands-on usage of a kraft mill mathematical model program. There is considerable discussion as to the PDP-11 system usage in the body of the report and in Appendix B. The actual program as it is stored on the cassette is contained in Appendix A. Examples of the programs effective usage are discussed along with a presentation of reasonable data input (see Table 1). It is hoped that the organization and straight forwardness of the programming techniques allows its ease of acceptance in both a class room and research setting.

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APPENDIX A

```
BEGIN    27-JUN-80  BASIC/CAPS  V01-01

1 COMMON L2$
2 A1=0
3 A2=0
4 A3=0
5 A4=0
6 C=0
7 C1=0
8 C2=0
9 C3=0
10 C4=0
11 C5=0
12 D=0
13 E1=0
14 E2=0
15 F=0
16 F1=0
17 F2=0
18 G1=0
19 G2=0
20 G3=0
21 G4=0
22 G5=0
23 H1=0
24 H2=0
25 H3=0
26 H4=0
27 H5=0
28 H6=0
29 K1=0
30 K2=0
31 K3=0
32 K4=0
33 L1=0
34 L2=0
35 N=0
36 P1=0
37 P2=0
38 P3=0
39 P4=0
40 P5=0
41 P6=0
42 R=0
43 R1=0
44 R2=0
45 R3=0
46 R4=0
47 S=0
48 S1=0
49 S2=0
50 S3=0
```

BEGIN continued

```
51 S4=Ø
52 T1=Ø
53 T2=Ø
54 U1=Ø
55 U2=Ø
56 V=Ø
57 V1=Ø
58 V2=Ø
59 V3=Ø
60 V4=Ø
61 W1=Ø
62 W2=Ø
63 W3=Ø
64 W4=Ø
65 W5=Ø
66 W6=Ø
67 X1=Ø
68 X2=Ø
69 X3=Ø
70 X4=Ø
71 X5=Ø
72 X6=Ø
73 Y=Ø
74 Z1=Ø
75 Z2=Ø
100 PRINT "THIS PROGRAM ILLUSTRATES A MODEL OF A KRAFT"
105 PRINT "MILL.  TWO DIFFERENT TYPES OF INPUT AND"
110 PRINT "OUTPUT ARE AVAILABLE.  PLEASE SELECT THE"
115 PRINT "METHOD DESIRED BY INDICATING Y OR N."
120 PRINT "DO YOU WANT THE LONG FORM FOR INPUT?"
125 INPUT L1$
130 PRINT "FOR OUTPUT?"
135 INPUT L2$
136 PRINT
137 PRINT
138 PRINT
139 PRINT
140 IF L1$="Y" THEN CHAIN "LONGI.BAS" LINE 200
145 CHAIN "SHORTI.BAS" LINE 700
```

GUTS   27-JUN-80 BASIC/CAPS V01-01

```
540 COMMON L2$,W1,Y,W3,A1,A2,V3,C4,C3,D,T1,H5,V2,S,R1,E1,L1,L2
541 COMMON K1,K2,K3,K4,A4,S2,R3,N,C,Z2,F1,H2,H3,H4,E2,T2,P1,P2
542 COMMON P3,P4,P5,U1,U2,C5,F,V
543 COMMON W4,W5,W6,W2,V4,G4,G1,G5,V1,H1,X1,X2,X3,X4,X5,X6,A3
544 COMMON S1,R2,Z1,P6,S4,F2,G2,G3,S3,H6,C1,C2,R4,R
550 REM-WOOD REALTIONSHIPS
551 W4=W1/Y
552 W5=W4/(1-W3)
553 W6=W5-W4
554 W2=W4-W1
555 REM-WATER BALANCES IN COOKING AND WASHING
556 V4=W4*A1/A2
557 V1=V3-V4
558 G4=W1*(1-C4)/C4
559 H1=C3*W4+W6+D*(V4+V1)
560 G1=H1*(T2-212)/H5
561 G5=W6+D*(V4+V2)-G1-G4
562 REM-CHEMICAL FLOW DETERMINATION
563 X1=W1*(1-S)*A1/Y
564 X2=S*X1/(1-S)
565 X3=(1-R1)*X2/R1
566 X4=(1-E1)*X1/E1
567 X5=L1*(X2+X3)
568 X6=L2*(X1+X2+X3+X4)-X5
569 REM-COOKING AND PRODUCTION RELATIONSHIPS
570 A3=(X1+.5*X2)/W4
571 S1=X2/W4
572 R2=(D*(V4+V1)+W6)/W4
573 Z1=K1+K2*(A3-A4)/A4+K3*(S1-S2)/S2+K4*(R2-R3)/R3
574 P6=1440*N*C/(Z1+Z2)
575 REM-EVAPORATION AND BURNING
576 S4=W2+1.29*X1+1.26*X2+2.29*X3+1.71*X4
577 F2=S4/(S4+G5)
578 G2=S4*(1-F1)/F1
579 G3=G5-G2
580 S3=1.71*X1+1.26*X2+2.29*X3+1.71*X4
581 H6=H2*W2-H3*S3-H5*G2-H4-H5*G3/E2-H1*(T2-T1)
582 REM-ECONOMICS
583 C1=(P1*2.29*X5+P2*1.71*X6+(P3*U2+P4*U1)*X1)/2000
584 C2=C1-P5*H6/1.00000E+06
585 R4=V-C2-C5-F/P6
586 R=P6*R4
587 IF L2$="Y" THEN CHAIN "LONGO.BAS" LINE 800
588 CHAIN "SHORTO.BAS" LINE 1400
```

```
200 COMMON L2$,W1,Y,W3,A1,A2,V3,C4,C3,D,T1,H5,V2,S,R1,E1,L1,L2
201 COMMON K1,K2,K3,K4,A4,S2,R3,N,C,Z2,F1,H2,H3,H4,E2,T2,P1,P2
202 COMMON P3,P4,P5,U2,U1,C5,F,V
205 PRINT "INPUT DATA REQUESTED FOR:"
206 PRINT
210 PRINT "WOOD RELATIONSHIPS"
215 PRINT "WT. OF WOOD FIBER, LB/TON A.D. PULP"
220 INPUT W1
225 PRINT "PULPING YIELD, NONDIMENSIONAL"
230 INPUT Y
235 PRINT "MOISTURE CONTENT, LB/LB"
240 INPUT W3
241 PRINT
245 PRINT "WATER BALANCES IN COOKING AND WASHING"
250 PRINT "ACTIVE ALKALI ON O.D. WOOD, LB/LB"
255 INPUT A1
260 PRINT "ACTIVE ALKALI CONCENTRATION, LB/CUBIC FT"
265 INPUT A2
270 PRINT "VOLUME OF TOTAL COOKING LIQUOR, CUBIC FT/TON A.D. PULP"
275 INPUT V3
280 PRINT "CONSISTENCY OF PULP OFF WASHER, LB WATER/LB PULP"
285 INPUT C4
290 PRINT "SPECIFIC HEAT OF WOOD SOLIDS, BTU/LB-F"
295 INPUT C3
300 PRINT "DENSITY OF WATER, LB/CUBIC FT"
305 INPUT D
310 PRINT "TOP COOKING TEMPERATURE, F"
315 INPUT T2
320 PRINT "LATENT HEAT OF WATER, BTU/LB"
325 INPUT H5
330 PRINT "VOLUME OF FRESH WATER TO WASHER, CUBIC FT/TON A.D. PULP"
335 INPUT V2
336 PRINT
340 PRINT "CHEMICAL FLOW DETERMINATION"
345 PRINT "SULFIDITY OF COOKING LIQUOR"
350 INPUT S
355 PRINT "FURNACE REDUCTION RATIO, NONDIMENSIONAL"
360 INPUT R1
365 PRINT "CAUSTIC CONVERSION EFFICIENCY, NONDIMENSIONAL"
370 INPUT E1
375 PRINT "TOTAL SULFUR LOSS FRACTION, NONDIMENSIONAL"
380 INPUT L1
385 PRINT "TOTAL SODIUM LOSS FRACTION, NONDIMENSIONAL"
390 INPUT L2
391 PRINT
395 PRINT "COOKING AND PRODUCTION RELATIONSHIPS"
400 PRINT "CONSTANT IN COOKING MODEL, MIN"
405 INPUT K1
410 PRINT "CHANGE IN COOK TIME PER CHANGE IN EFFECTIVE ALKALI, MIN"
415 INPUT K2
420 PRINT "CHANGE IN COOK TIME PER CHANGE IN EFFECTIVE SULFIDE, MIN"
425 INPUT K3
430 PRINT "CHANGE IN COOK TIME PER CHANGE IN LIQUOR TO WOOD, MIN"
435 INPUT K4
440 PRINT "NORMALIZING VALUE OF EFFECTIVE ALKALI, LB/LB"
445 INPUT A4
450 PRINT "NORMALIZING SULFIDE CONTENT, NONDIMENSIONAL"
455 INPUT S2
460 PRINT "NORMALIZING LIQUOR TO WOOD RATIO, NONDIMENSIONAL"
465 INPUT R3
470 PRINT "NUMBER OF DIGESTERS"
473 INPUT N
```

LONGI continued

```
476 PRINT "CAPACITY OF DIGESTERS (A.D. TONS), TONS/BATCH"
479 INPUT C
481 PRINT "DIGESTER FILL AND DOWN TIME PER BATCH, MIN"
483 INPUT Z2
484 PRINT
485 PRINT "EVAPORATION AND BURNING"
486 PRINT "SOLIDS FRACTION IN LIQUOR TO FURNACE, NONDIMENSIONAL"
487 INPUT F1
490 PRINT "HEAT OF COMBUSTION OF LIGNIN, BTU/LB"
491 INPUT H2
492 PRINT "HEAT OF FUSION OF SMELT, BTU/LB"
493 INPUT H3
494 PRINT "HEAT LOSSES FROM FURNACE, BTU/TON A.D. PULP"
495 INPUT H4
496 PRINT "EVAPORATOR STEAM ECONOMY, NONDIMENSIONAL"
497 INPUT E2
498 PRINT "TEMPERATURE OF DIGESTER CONTENTS AS LOADED, F"
499 INPUT T1
500 PRINT
501 PRINT "ECONOMICS"
502 PRINT "PRICE OF SALT CAKE, $/TON"
503 INPUT P1
504 PRINT "PRICE OF SODIUM CARBONATE, $/TON"
505 INPUT P2
506 PRINT "PRICE OF MAKEUP LIME, $/TON"
507 INPUT P3
508 PRINT "PRICE OF KILN FUEL, $/TON"
509 INPUT P4
510 PRINT "VALUE OF PROCESS HEAT, $/MBTU"
511 INPUT P5
512 PRINT "USAGE OF MAKEUP LIME, LB/LB NAOH"
513 INPUT U2
514 PRINT "USAGE OF KILN FUEL, MBTU/TON NAOH"
515 INPUT U1
516 PRINT "COST OF WOOD USED, $/TON A.D. PULP"
517 INPUT C5
518 PRINT "FIXED CHARGES OF PULP PROCESS, $/DAY"
519 INPUT F
520 PRINT "VALUE OF SLUSH UNBLEACHED PULP, $/TON A.D. PULP"
521 INPUT V
522 PRINT
523 PRINT
524 PRINT "ARE ALL THE NUMBERS CORRECT? (Y OR N)"
525 INPUT L5$
526 PRINT
527 PRINT
528 PRINT
529 PRINT
530 IF L5$="Y" THEN CHAIN "GUTS.BAS" LINE 550
531 GO TO 200
```

```
SHORTI  27-JUN-80  BASIC/CAPS  V01-01

700 COMMON L2$,W1,Y,W3,A1,A2,V3,C4,C3,D,T1,H5,V2,S,R1,E1,L1,L2
701 COMMON K1,K2,K3,K4,A4,S2,R3,N,C,Z2,F1,H2,H3,H4,E2,T2,P1,P2,P3
702 COMMON P4,P5,U1,U2,C5,F,V
705 PRINT "PLEASE INPUT DATA REQUESTED SEPARATED BY COMMAS"
708 PRINT "INPUT DATA FOR:"
709 PRINT
710 PRINT "WOOD RELATIONSHIPS"
712 PRINT "WF,Y,WM"
713 INPUT W1,Y,W3
714 PRINT
715 PRINT "WATER BALANCES IN COOKING AND WASHING"
716 PRINT "AA,AC,VTL,CW,CPS"
717 INPUT A1,A2,V3,C4,C3
718 PRINT "DW,TT,HLW,VFW"
719 INPUT D,T2,H5,V2
720 PRINT
721 PRINT "CHEMICAL FLOW DETERMINATION"
722 PRINT "S,RD,EC,LST,LNT"
723 INPUT S,R1,E1,L1,L2
724 PRINT
725 PRINT "COOKING AND PRODUCTION RELATIONSHIPS"
726 PRINT "K1,K2,K3,K4,AEN"
727 INPUT K1,K2,K3,K4,A4
728 PRINT "SCN,RLWN,N,C,ZF"
729 INPUT S2,R3,N,C,Z2
730 PRINT
731 PRINT "EVAPORATION AND BURNING"
732 PRINT "FSE,HCL,HFS,HLF,EEV,TL"
733 INPUT F1,H2,H3,H4,E2,T1
734 PRINT
735 PRINT "ECONOMICS"
736 PRINT "P1,P2,P3,P4,P5"
737 INPUT P1,P2,P3,P4,P5
738 PRINT "UL,UF,CWU,F,V"
739 INPUT U2,U1,C5,F,V
740 PRINT
741 PRINT
742 PRINT "ARE ALL THE NUMBERS CORRECT? (Y OR N)"
743 INPUT L6$
744 PRINT
745 PRINT
746 PRINT
747 PRINT
748 IF L6$="Y" THEN CHAIN "GUTS.BAS" LINE 550
749 GO TO 700
```

LONGO.BAS

```
800 COMMON W4,W5,W6,V4,G4,G1,G5,V1,H1,X1,X2,X3,X4,
801 COMMON S1,R2,Z1,P6,S4,G2,F2,G3,S3,H6,C1,C2,R4,
802 PRINT "WOOD RELATIONSHIPS"
804 PRINT "(WS)   WT. OF WOOD SOLIDS, LB/TON A.D. PULP";TAB(52);
806 PRINT USING " -#####.",W4
808 PRINT "(WT)   TOTAL WT. OF WET WOOD, LB/TON A.D. PULP";TAB(52);
810 PRINT USING " -#####.",W5
812 PRINT "(WW)   WT. OF WOOD WATER, LB/TON A.D. PULP";TAB(52);
814 PRINT USING " -#####.",W6
816 PRINT "(WL)   WT. OF WOOD LIGNIN, LB/TON A.D. PULP";TAB(52);
818 PRINT USING " -#####.",W2
820 PRINT
822 PRINT "WATER BALANCES IN COOKING AND WASHING"
824 PRINT "(VWL)  VOLUME OF WHITE LIQUOR, CUBIC FT/TON"
825 PRINT "        A.D. PULP",TAB(52);
828 PRINT USING "   -###.#",V4
830 PRINT "(GP)   WATER LEAVING SYSTEM WITH PULP, LB/TON"
832 PRINT "        A.D. PULP",TAB(52);
834 PRINT USING "-######.",G4
835 PRINT "(GB)   BLOW FLOW RATE, LB/TON A.D. PULP",TAB(52);
836 PRINT USING " -#####.",G1
837 PRINT "(GW)   WATER IN LIQUOR TO EVAPORATOR,"
838 PRINT "        LB/TON A.D. PULP",TAB(52);
839 PRINT USING "-######.",G5
840 PRINT "(VBL)  VOLUME OF BLACK LIQUOR TO DIGESTERS,"
841 PRINT "        CUBIC FT/TON A.D. PULP",TAB(52);
842 PRINT USING "   -###.#",V1
844 PRINT "(HCD)  HEAT CAPACITY OF DIGESTER CONTENTS,"
846 PRINT "        (BTU/F)/TON A.D. PULP",TAB(52);
848 PRINT USING "-######.",H1
850 PRINT
852 PRINT "CHEMICAL FLOW DETERMINATION"
854 PRINT "(X1)   WT. OF CAUSTIC (AS NA20) IN COOK LIQUOR,"
856 PRINT "        LB/TON A.D. PULP",TAB(52);
858 PRINT USING "  -####.#",X1
860 PRINT "(X2)   WT. OF SULFIDE (AS NA20) IN COOK LIQUOR,"
862 PRINT "        LB/TON A.D. PULP",TAB(52);
864 PRINT USING "  -####.#",X2
866 PRINT "(X3)   WT. OF SULFATE (AS NA20) IN COOK LIQUOR,"
868 PRINT "        LB/TON A.D. PULP",TAB(52);
870 PRINT USING "    -##.#",X3
872 PRINT "(X4)   WT. OF CARBONATE (AS NA20) IN COOK LIQUOR,"
874 PRINT "        LB/TON A.D. PULP",TAB(52);
876 PRINT USING "  -####.#",X4
878 PRINT "(X5)   WT. OF MAKEUP SALT CAKE (AS NA20),"
880 PRINT "        LB/TON A.D. PULP",TAB(52);
882 PRINT USING "   -###.##",X5
884 PRINT "(X6)   WT. OF MAKEUP CARBONATE (AS NA20),"
886 PRINT "        LB/TON A.D. PULP",TAB(52);
888 PRINT USING "    -##.##",X6
890 PRINT
892 PRINT "COOKING AND PRODUCTION RELATIONSHIPS"
894 PRINT "(AE)   EFFECTIVE ALKALI ON O.D. WOOD, LB/LB";TAB(52);
896 PRINT USING "    -##.##",A3
898 PRINT "(SC)   EFFECTIVE SULFIDE IN COOKING LIQUOR,"
900 PRINT "        LB/LB WOOD",TAB(52);
902 PRINT USING "    -##.####",S1
904 PRINT "(RLW)  LIQUOR-TO-WOOD RATIO, LB/LB",TAB(52);
906 PRINT USING "    -##.#",R2
908 PRINT "(ZC)   COOK TIME (INCLUDING HEATUP), MIN",TAB(52);
910 PRINT USING "  -####.#",Z1
912 PRINT "(PR)   PRODUCTION RATE, TONS A.D. PULP/DAY";TAB(52);
914 PRINT USING "  -####.#",P6
```

```
MLONGO  27-JUN-80  BASIC/CAPS  V01-01

950 COMMON W4,W5,W6,V4,G4,G1,G5,V1,H1,X1,X2,X3,X4,X5,X6,A3
951 COMMON S1,R2,Z1,P6,S4,G2,F2,G3,S3,H6,C1,C2,R4,R
952 PRINT "EVAPORATION AND BURNING"
954 PRINT "(SW)   BLACK LIQUOR SOLIDS IN LIQUOR TO EVAPORATOR,"
956 PRINT "        LB/TON A.D. PULP",TAB(52);
958 PRINT USING " -#####.",S4
960 PRINT "(FSW)  SOLIDS FRACTION IN LIQUOR TO EVAPORATOR,"
962 PRINT "        NONDIMENTIONAL",TAB(52);
964 PRINT USING "    -##.###",F2
966 PRINT "(GE)   WATER IN LIQUOR FROM EVAPORATOR,"
968 PRINT "        LB/TON A.D. PULP",TAB(52);
970 PRINT USING " -#####.",G2
972 PRINT "(GEV)  EVAPORATION RATE FROM EVAPORATOR,"
974 PRINT "        LB/TON A.D. PULP",TAB(52);
976 PRINT USING "-######.",G3
978 PRINT "(SS)   SOLIDS IN SMELT, LB/TON A.D. PULP";TAB(52);
980 PRINT USING " -#####.",S3
982 PRINT "(HP)   HEAT PRODUCED IN RECOVERY PROCESS,"
984 PRINT "        BTU/TON A.D. PULP",TAB(52);
986 PRINT USING "     -#.##^^^^^",H6
988 PRINT
990 PRINT "ECONOMICS"
992 PRINT "(CC)   CHEMICALS COST, $/TON A.D. PULP",TAB(52);
994 PRINT USING "   -###.##",C1
996 PRINT "(CNP)  RECOVERY SYSTEM NET COST, $/TON A.D. PULP";TAB(52);
998 PRINT USING "   -###.##",C2
1000 PRINT "(RT)   RETURN PER TON OF PULP, $/TON A.D. PULP";TAB(52);
1002 PRINT USING "   -###.##",R4
1004 PRINT "(R)    TOTAL RETURN ON PROCESS, $/DAY",TAB(52);
1006 PRINT USING "     -#.##^^^^^",R
1008 PRINT
1010 PRINT
1012 PRINT
1014 PRINT
1016 PRINT "DO YOU WISH TO TRY AGAIN? (Y OR N)"
1018 INPUT T3$
1020 PRINT
1022 PRINT
1024 PRINT
1026 PRINT
1028 IF T3$="Y" THEN CHAIN "BEGIN.BAS" LINE 1
1030 STOP
```

```
1400 COMMON W4,W5,W6,V4,G4,G1,G5,V1,H1,X1,X2,X3,X4,X5,X6,A3
1401 COMMON S1,R2,Z1,P6,S4,F2,G2,G3,S3,H6,C1,C2,R4,R
1402 PRINT "WOOD RELATIONSHIPS"
1404 PRINT USING "WS      -#####.",W4
1406 PRINT USING "WT      -#####.",W5
1408 PRINT USING "WW      -#####.",W6
1410 PRINT USING "WL      -#####.",W2
1412 PRINT
1414 PRINT "WATER BALANCES IN COOKING AND WASHING"
1416 PRINT USING "VWL         -###.#",V4
1418 PRINT USING "GP      -######.",G4
1420 PRINT USING "GB      -#####.",G1
1422 PRINT USING "GW     -######.",G5
1424 PRINT USING "VBL         -###.#",V1
1426 PRINT USING "HCD    -######.",H1
1428 PRINT
1430 PRINT "CHEMICAL FLOW DETERMINATION"
1432 PRINT USING "X1        -####.#",X1
1434 PRINT USING "X2        -####.#",X2
1436 PRINT USING "X3          -##.#",X3
1438 PRINT USING "X4        -####.#",X4
1440 PRINT USING "X5         -###.##",X5
1442 PRINT USING "X6          -##.##",X6
1444 PRINT
1446 PRINT "COOKING AND PRODUCTION RELATIONSHIPS"
1448 PRINT USING "AE          -##.##",A3
1450 PRINT USING "SC          -##.####",S1
1452 PRINT USING "RLW         -##.#",R2
1454 PRINT USING "ZC        -####.#",Z1
1456 PRINT USING "PR        -####.#",P6
1458 PRINT
1460 PRINT "EVAPORATION AND BURNING"
1462 PRINT USING "SW      -#####.",S4
1464 PRINT USING "FSW         -##.###",F2
1466 PRINT USING "GE      -#####.",G2
1468 PRINT USING "GEV    -######.",G3
1470 PRINT USING "SS      -#####.",S3
1472 PRINT USING "HP             -#.##^^^^^",H6
1474 PRINT
1476 PRINT "ECONOMICS"
1478 PRINT USING "CC          -###.##",C1
1480 PRINT USING "CNP         -###.##",C2
1482 PRINT USING "RT          -###.##",R4
1484 PRINT USING "R              -#.##^^^^^",R
1486 PRINT
1488 PRINT
1490 PRINT
1492 PRINT
1494 PRINT "DO YOU WISH TO TRY AGAIN? (Y OR N)"
1496 INPUT T3$
1497 PRINT
1498 PRINT
1499 PRINT
1500 PRINT
1501 IF T3$="Y" THEN CHAIN "BEGIN.BAS" LINE 1
1502 STOP
```

APPENDIX B

To further assist the user, this appendix will cover those system features not covered in the thesis. These will include how to load CAPS-11 Monitor, initialize a new cassette tape or scratch an old cassette, usage of the paper tape punch for output, and some useful commands.

The CAPS-11 Monitor can be loaded in after the system is in BASIC by typing a control C(CTRL/C). This is done by depressing the CTRL button and holding it while the C button is pushed. This first control C terminates the program execution, closes all open files and produces one of the two following messages:

Messages	Meaning
STOP AT LINE xxxx	BASIC was executing a program when the CTRL/C was pressed ans has executed line xxxx (unless line xxxx is a multi-statement program line).
STOP	BASIC was in Edit mode (able to accept commands or program lines typed in) at time of CTRL/C.

In either case the program in memory is retained and BASIC then prints the READY message and awaits for a command or program line to be typed in. A CTRL/C typed during the initial dialogue has no effect on BASIC/CAPS.

Response to CTRL/C in BASIC/CAPS is not immediate if cassette input or output is in progress. A second CTRL/C immediately after the first causes BASIC to print:

REBOOT?

This feature allows the CAPS-11 Monitor or another version of BASIC to be loaded without having to go through the system bootstrap procedure.

To load the CAPS-11 Monitor, first place the CAPS-11 system cassette on cassette unit 0; set bit zero of the switch register to zero (if the system was brought up as described in the body of the thesis the bit should be on zero), and then type any response beginning with Y and ending with a carriage return. This reboots the CAPS-11 System. Any response not beginning with a Y cancels the reboot request and returns BASIC to the READY message leaving the stored program unchanged.

When CAPS-11 Monitor is up and running it is possible to do two important commands, ZERO a cassette and locate a DIRectory of what a cassette contains. Zeroing a cassette is for two purposes. First it scratches or "cleans" a cassette that has been utilized to hold programs being worked on and second it can initialize a new tape and prepare it for usage. To zero a cassette, wait for the system to print

CAPS-11 V01-01

and come back with a ".". At this point, the system is ready for commands from the terminal. Mount the cassette to be zeroed on cassette unit 0. Type in

.ZERO 0: or if the tape is in unit 1 .ZERO 1:

This will cause the cassette to run for a minute and then halt with the terminal coming back with a ".". At this point a check can be made to see if the cassette is clean by typing in

.DIR

the system will search the tape and if a program exists it will be listed including the date saved. This is also the same method used to determine what is on a cassette tape if no directory is included with it. To return to BASIC, refer to the section System Start-Up starting at step 4 in the main body of this paper.

If the output (or input for that matter) is desired on paper tape, then before typing has begun feed the tape through the paper punch on the left hand side of the teletype and press the ON button down. This will cause the terminal and punch to run simultaneously.

The commands SAVE, REPLACE, OLD and RUN are essential to equipment usage. These four commands are utilized extensively in data retrieval along with program usage.

The SAVE command can be used in a couple different forms. Four examples are shown below:

SAVE LP:

Lists the program in memory on the line printer.

SAVE BEGIN

Saves the program in memory as file BEGIN.BAS on cassette unit 0.

SAVE 1:BEGIN

Saves the program in memory as file BEGIN.BAS on cassette unit 1.

SAVE PP:

Punches the program in memory on the high speed punch.

The REPLACE command is used for program altering and saving. Two examples follow:

REPLACE PROGRM

Deletes the file PROGRM.BAS from cassette unit 0 and then saves the program in memory as file PROGRM.BAS on cassette unit 0.

REPLACE 1:PROGRM

Same as above but saves the program on cassette unit 1.

The OLD command is used when requesting a program or file to be entered into memory for usage. This command must proceed a LIST command in order to load memory with the program before it can be typed on the terminal. Two examples are listed below:

OLD LONGI.BAS

> The OLD command SCRatches the program in memory, loads the program in file LONGI.BAS on cassette unit 0 and changes the program name to LONGI. At this time a LIST command can be used to see what this file contains.

OLD 1:FOOBAR
APPEND 0:SUBR1

> The OLD command SCRatches the program in memory, loads the program in file FOOBAR.BAS on cassette unit 1, and changes the program name to FOOBAR. The APPEND command merges this program with the program in file SUBR1.BAS on cassette unit 0 and does not changes the program name.

The RUN command is used to locate and run an existing program. An example follows:

RUN BEGIN

> The RUN command SCRatches the program in memory and then loads and runs the program in the file BEGIN.BAS on cassette unit 0. The program name is changed to BEGIN but no header is printed.

The use of a CHAIN command was used extensively in the Kraft Mill Model program to allow for enough memory space to run the total program. This command can be used as a command or as a part of the internal workings of a program. An example of a command follows:

CHAIN "PR:"

> SCRatches the program in memory and then loads and runs the program in the high-speed paper tape reader.

To use this command internally with a program requires usage of the internal command COMMON. This COMMON statement must come first in a program listing all the variables that are in "common" between the different programs chained together. The correct form of the CHAIN command can be seen in each of the Kraft Mill Model program and below:

140 CHAIN "SHORTI.BAS" LINE 700

> This is a program line containing the name of the program to be chained to and it's line number.

The last two pieces of helpful information are the DELETE key and control U. The DELETE key on the terminal allows the user to correct for spelling errors or whatever at the time of entry. Pressing down deletes the character just typed. For a large error in a line a control U is suggested. This will delete the total line of a program just entered. These commands do not work after a carriage return at the end of a line. The control U is done the same wasy as a control C.

For more information and examples, please refer to the BASIC-11 Language Reference Manual and BASIC/CAPS-11 User's Manual.