



Minimization of Kraft pulp mill air pollution by optimization techniques
by Moun-Shung Mark Chi

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in CHEMICAL ENGINEERING

Montana State University

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Abstract:

An attempt was made to minimize the air pollution and maximize the return of a Kraft recovery furnace unit under various operating conditions. A mathematical model was set up by employing stoichiometry and thermodynamics to determine the chemical and thermal performance as well as the annual profit return from the Kraft recovery furnace unit. A computer program was written to calculate the factors of interest.

The mathematical model developed to minimize odorous emission and maximize annual return in a Kraft recovery furnace unit was tested on the tabulated data of G. N. Thoen and his co-workers (1). The results indicated that emission of air pollutant and the annual return were dependent upon operating conditions of the Kraft recovery furnace unit, and the factors such as excess oxygen and secondary air affected both the odorous emission and the annual return from the Kraft recovery furnace unit.

The mathematical model was also used to calculate the heat used to produce steam, losses of material, chemicals recovered, and annual return.

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BY OPTIMIZATION TECHNIQUES

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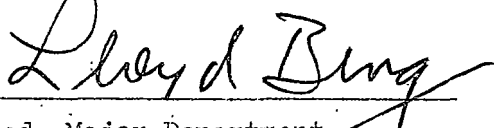
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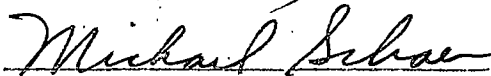
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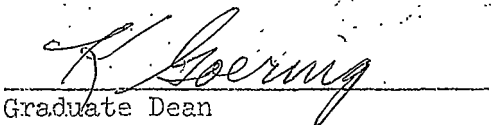
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ABSTRACT

An attempt was made to minimize the air pollution and maximize the return of a Kraft recovery furnace unit under various operating conditions. A mathematical model was set up by employing stoichiometry and thermodynamics to determine the chemical and thermal performance as well as the annual profit return from the Kraft recovery furnace unit. A computer program was written to calculate the factors of interest.

The mathematical model developed to minimize odorous emission and maximize annual return in a Kraft recovery furnace unit was tested on the tabulated data of G. N. Thoen and his co-workers (1). The results indicated that emission of air pollutant and the annual return were dependent upon operating conditions of the Kraft recovery furnace unit, and the factors such as excess oxygen and secondary air affected both the odorous emission and the annual return from the Kraft recovery furnace unit.

The mathematical model was also used to calculate the heat used to produce steam, losses of material, chemicals recovered, and annual return.

INTRODUCTION

Over sixty percent of the United States' supply of wood pulp is produced by the Kraft pulping process. But the process, especially the Kraft recovery furnace unit, creates an air pollution problem by discharging hydrogen sulfide, methyl mercaptan, sulfur dioxide, and other sulfur-containing gases into the atmosphere. In addition to the air pollution problem, it results in a chemical and heat loss. Since the Kraft recovery furnace unit releases a large volume of odorous gases and fumes, scrubbing and furnace operations are very difficult.

The recovery cycle of the Kraft pulping process makes the process profitable and also creates an air pollution problem. The recovery cycle is shown in Figure 1. In the Kraft pulping process, wood chips are cooked with a solution of caustic soda and sodium sulfide to remove the lignin from the cellulose fibers. The pulp is then separated from the cooking solution or black liquor. The cooking chemicals in the black liquor are recovered to make the process economical and to solve the disposal problem.

During the recovery operation, weak black liquor is concentrated from approximately 17% solids to about 50% solids in multiple effect evaporators. Further concentrating from 50% solids to 70% solids is carried out in direct contact evaporators using the hot flue gases of the recovery furnace. In this operation, sodium sulfate is added to the strong black liquor making up for chemicals lost in the process. The concentrated black liquor is then burned in the recovery furnace to

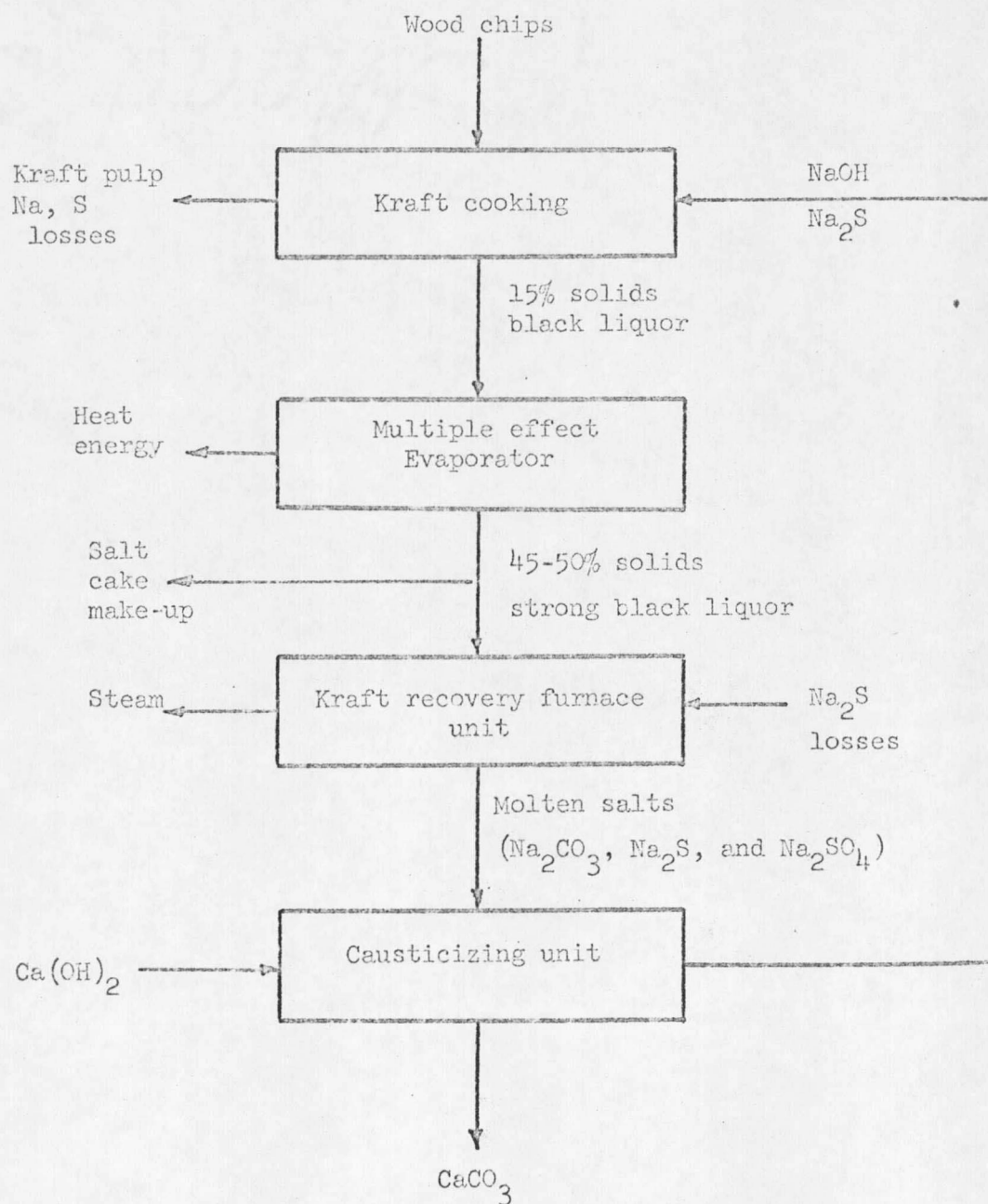


Figure 1. Kraft Recovery Cycle.

recover a portion of the heat by oxidation of the organic material and to recover chemicals in the form of molten salt. The molten salt consists of sodium carbonate and sodium sulfide and a minor amount of sodium sulfate. The recovered chemicals are then reused in the process.

In order to solve this complex air pollution problem, a literature survey was first made to obtain all of the operating conditions that affect the release of odorous compounds.

Irwin B. Douglass made studies in the area of the emission sources (2). He discussed the chemistry involved in odor formation and in the destruction of malodorous compounds by burning, chlorination and treatment with ozone. He suggested that continuous monitoring of the stack gases for hydrogen sulfide would give the greatest promise for minimizing the emission of malodors.

Murray and Rayner (3) concluded that the direct contact evaporator was a source of hydrogen sulfide atmospheric contamination. They found that emission of hydrogen sulfide in the stack gases of the Kraft recovery furnace unit was favored by high concentration of sulfide ion and low pH level in the liquor, and by low concentration of hydrogen sulfide in the flue gases entering the direct contact evaporator.

Hendrickson and Harding (4) pointed out that black liquor oxidation reduced malodorous gas emission of the Kraft recovery furnace. According to Landry and Logwell (5), the oxidation of black liquor prior to burning in the recovery furnace led to large reduction in

sulfur-containing gases discharged to the atmosphere and therefore improved the chemical recovery.

Thomas and his co-workers (6) made an investigation into the understanding of the furnace operation from both a chemical and an engineering point of view. They were able to explain the pyrolysis and the combustion of black liquor. Although the explanation was made on an experiment conducted in a laboratory instead of in a Kraft recovery furnace itself, they suggested that the same mechanism actually occurred in the furnace. They proposed that the combustion of black liquor in the recovery furnace consisted of the following steps:

1. The concentrated black liquor was sprayed into the recovery furnace. Water in the black liquor was evaporated.
2. Then the high temperature in the recovery furnace caused the black liquor solids to pyrolyze. The products of pyrolysis of black liquor are low molecular weight hydrocarbons, sulfur-containing compounds, and sodium-containing compounds.
3. Finally, the combustion of pyrolysis gases destroyed most of the low molecular weight hydrocarbons and sulfur-containing compounds. Incomplete combustion of pyrolysis gases caused a serious air pollution problem.

Thoen and his co-authors (1) investigated odorous emission in the Kraft recovery furnace stack gases under various combustion conditions. They indicated that the operating conditions affecting the air pollut-

ant emission were excess oxygen, turbulence, percent of secondary air, and fineness of the black liquor spray. They also found that when the $\text{SO}_2\text{-H}_2\text{O}$ concentration was minimized, indicating sufficient oxygen and good turbulence, the steam production was maximized for a given rate of feed.

In this work, a mathematical model based on engineering principles was developed to solve the air pollution problem economically. The mathematical model was used to find the best operating conditions for maximizing recovery of chemicals and heat, and minimizing the cost for air pollution control.

RESEARCH OBJECTIVES

The main objective of this research project was to develop a technique in the form of a mathematical model to find the optimum operating conditions for air pollution control on Kraft recovery furnace stack gases. Optimum operating conditions are those which give the minimum air pollution and the maximum chemical and heat recovery from the Kraft recovery furnace unit.

The most important consideration of this research project is to solve the complex problems of heat and mass balance, and predict the annual return from the Kraft recovery furnace unit for given operating conditions and, as a result, find the optimum operating conditions by utilizing available data.

THEORY AND ASSUMPTION

The mathematical model developed to optimize the Kraft recovery furnace unit operation relating to air pollution is based upon engineering principles, thermodynamics, and reasonable assumptions. The mathematical model serves as a tool to find the best operating conditions for the Kraft recovery unit in that it gives maximum annual return and minimum air pollution. The model also enables us to analyze the performance of the Kraft recovery furnace unit.

Kraft Recovery Furnace Unit

The Kraft recovery furnace unit is shown schematically in Figure 2. The heat generated in the Kraft recovery furnace is used for the chemical reactions taking place in the furnace and for steam production. The chemicals recovered are reused in the Kraft pulping process. Therefore, the function of Kraft recovery furnace units is to recover chemicals and produce steam from black liquor.

During combustion of black liquor in the furnace, the water in the black liquor is evaporated and the carbonaceous matter formed in the process of cooking wood chips in the digester is burned. The inorganic chemicals in the black liquor are fused and the sodium sulfate in the presence of carbon and a reducing atmosphere is reduced to sodium sulfide. The recovered chemicals in the form of molten salt are sodium carbonate, sodium sulfide, and a small amount of sodium sulfate. The recovered chemicals are further processed in the caustizing process to produce white liquor (NaOH and Na_2S).

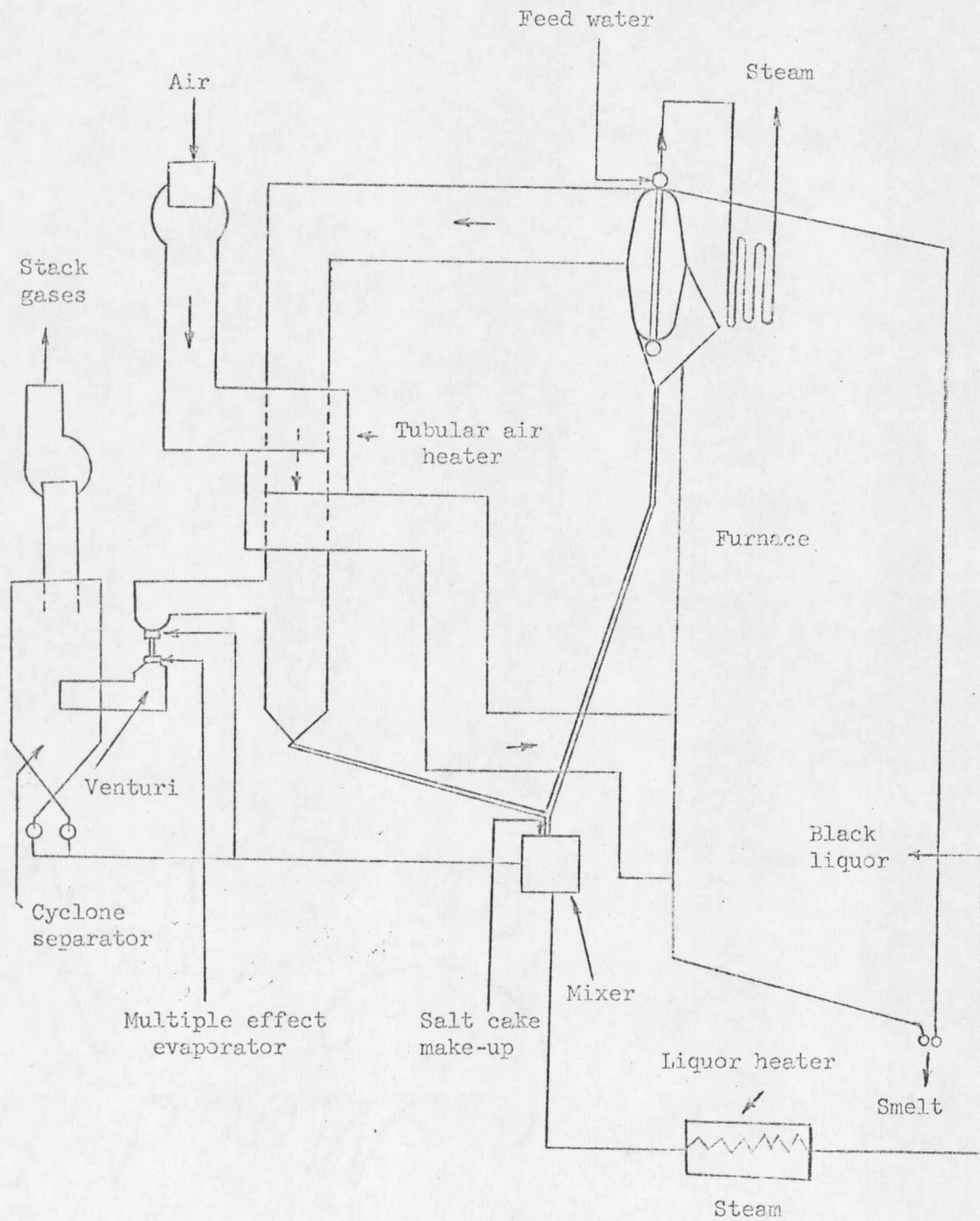


Figure 2. Kraft Recovery Furnace Unit.

A large quantity of sodium compounds and sulfur compounds are lost in the stack gases leaving the Kraft recovery furnace unit. The loss of chemicals in the stack gases is not only costly but also creates an air pollution problem around the mill and the community.

In order to abate the air pollution from the Kraft recovery furnace economically, many operating conditions pertaining to air pollution are investigated to find how they affect the annual return. These operating conditions are the percent of secondary air, the percent of excess oxygen in the stack gases, the exiting stack gas temperature, the concentration of solids in black liquor entering the unit, the soot blowers, the oxidation of black liquor prior to recovery furnace, the fineness of spray of black liquor, and the overload condition of the furnace.

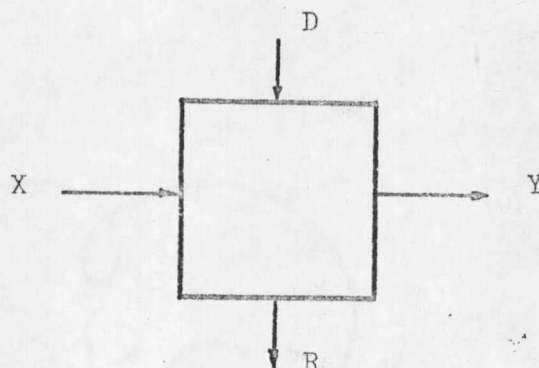


Figure 3. Single Stage Optimization.

Single Stage Optimization

The technique used to optimize the operation of the Kraft recovery furnace unit as described above is a mathematical model of single stage optimization. The model is shown as a block diagram in Figure 3. The

block represents the Kraft recovery furnace unit where X is the input state of the raw materials such as the physical and chemical properties of black liquor and ambient air, Y denotes the output state of the products from the unit, (i.e., the physical and chemical properties of molten salts and stack gases), D represents the operating conditions of the unit, and R denotes the annual return from the unit at a given X, Y, and D. The optimum operating conditions are those that give the maximum annual return R and minimum air pollution for a given input state X. A detailed discussion of this optimization model as applied to the Kraft recovery furnace unit is given below.

The input state X includes the properties of all raw materials entering the unit; namely, the temperature, the concentration, the elemental analysis of black liquor, the enthalpy of steam entering the direct contact liquor heater, the temperature and moisture content of ambient air, and the properties of salt cake make-up mixed with the black liquor.

The output state Y is defined as the properties of all the products formed in the Kraft recovery furnace unit. The products are steam, stack gases, fumes, and molten salts. The output state Y together with the input state enable us to carry out calculations of mass and heat balance at the particular operating condition D.

The annual return is the difference between the total costs and the total profit from the products. The individual costs and profits are listed below:

Cost Terms

1. Raw materials (black liquor and salt cake make-up)
2. Depreciation
3. Maintenance and engineering
4. Labor and labor benefits
5. Income tax and property tax
6. Loss of chemicals in the stack gases and fumes.

Profit Terms

1. Molten salts
2. Steam

It is obvious that the annual return depends largely on the cost of the raw materials, the steam production, the yield of molten salts, and the loss of chemicals (air pollutants and particulated matter) in the stack gases, since the other cost terms are fixed.

Mass Balance Calculations

By making a mass balance on the Kraft recovery furnace unit we can determine the quantity of each product leaving the unit. We can then make a heat balance to determine the energy absorbed by the unit for producing steam.

In these calculations we must know the loading capacity of the furnace, the properties of black liquor to the direct contact evaporator, the molten salts leaving the unit, and the excess oxygen in the stack gases. For convenience of calculations, the properties of black liquor to the direct contact evaporator are expressed in terms of temperature, solids concentration, composition in the form of an elemental analysis, and the properties of molten salts in terms of percentage

of each component. The block diagram of the mass balance is shown in Figure 4 below:

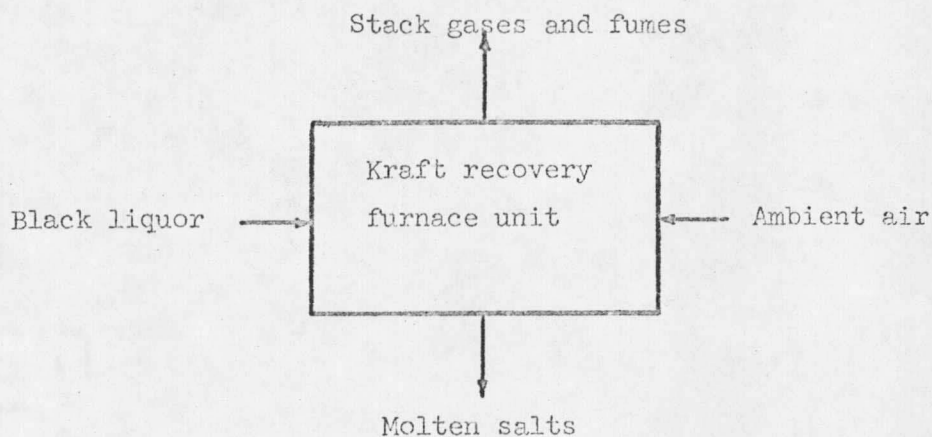


Figure 4. Block Diagram of Mass Balance for Kraft Recovery Furnace Unit.

Assuming complete combustion of black liquor in the Kraft recovery furnace, the gaseous products are sulfur dioxide, carbon dioxide, water vapor, excess oxygen, and inert oxygen. Making a mass balance with sodium as a basis, we can obtain the quantity of each component of molten salts leaving the unit. The difference between the sulfur in the black liquor and salt cake make-up, and the sulfur in the molten salt is equal to the sulfur leaving the unit as sulfur dioxide. The same method is applied to the carbon to find the carbon dioxide leaving the unit. The water in the black liquor and air are calculated respectively by knowing the solids concentration of the black liquor and the moisture content in the air entering the unit. The water formed due to the complete combustion is found by making a mass balance on hydrogen.

Oxygen and nitrogen in the stack gases are calculated by knowing the amount of air introduced into the unit.

Heat Balance Calculations

The net heat absorbed by the unit to produce steam can be estimated by making a heat balance on the unit. The terms involved in the heat balance calculations are listed as follows:

Heat Input

Gross heating value of black liquor

Sensible heat of air introduced into the unit

Heat of the steam entering the direct contact evaporator

Sensible heat of the black liquor

Heat Losses

Heat lost in dry stack gases

Heat lost due to water in the stack gases

Heat lost due to molten salts leaving the unit

Heat lost due to reduction of the salt cake make-up

Heat lost due to chemical reaction correction

Heat lost due to radiation

Heat lost due to miscellaneous items

Since there is no accumulation of heat in the unit, the net heat absorbed for steam production is the difference between the total heat input and the total heat loss.

V. P. Owens (7) reported the gross heating values in the black liquor in the United States range from 6080 Btu per lb dry solids to 7145 Btu per lb solids. The normal figure is 6600 Btu per lb dry solids. The gross heating value of black liquor is main heat input to the unit.

The excess air at ambient air temperature enters the recovery furnace for the complete combustion of the black liquor. It also serves as a heat sink because heat is lost due to the excess oxygen and nitrogen leaving the stack. The heat lost due to water in the stack gases includes heat lost due to moisture in the air, heat lost due to water formed in combustion, and heat lost due to evaporation of water in the black liquor.

The molten salts, which consist of sodium sulfide, sodium carbonate, and a small amount of sodium sulfate, leave the unit at 1400°F. The heat lost due to the molten salts is made up of the heat of fusion and the sensible heat of each component. The estimated value by Clement et al (8) is 532 Btu per lb of molten salts.

The salt cake make-up or sodium sulfate is reduced to sodium sulfide in the presence of carbon in the Kraft recovery furnace according to the reaction



The heat lost due to the reduction of salt cake is calculated from the heat of formation of each of the chemicals in the reaction.

The heat lost due to radiation is estimated as one percent of the total heat input to the unit. The heat lost due to miscellaneous items is estimated as 2.5 percent of the total heat input to the unit.

Since the gross heating values of the black liquor were measured in a bomb calorimeter and since the combustion of the black liquor in the Kraft recovery furnace is different, the gross heating values of the black liquor must be corrected. The actual reactions for the combustion of the black liquor are very complicated. The heat lost due to reaction is determined from the difference of the total heat of formation of combustion products of the black liquor in the bomb calorimeter and the total heat of formation of combustion of the black liquor in the Kraft recovery furnace. The combustion products of the black liquor for both the bomb calorimeter and the Kraft recovery furnace are listed below:

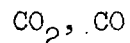
Products of Bomb Calorimeter

Gases:



Products of Kraft Recovery Furnace

Gases:



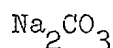
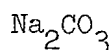
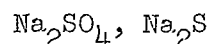
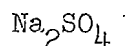
SO_2 , CH_3SH , H_2S , and a small amount of other sulfur-containing gases

Products of Bomb Calorimeter

Products of Kraft Recovery Furnace

Salts:

Salts:



Inert ashes

Inert ashes

The heat of formation of the carbon monoxide in the stack gases (due to incomplete combustion of black liquor in the Kraft recovery furnace) is given in units of Btu per lb carbon monoxide by the formula:

$$H_{fco} = 1245 \cdot \left(\frac{\text{CO}}{\text{CO} + \text{CO}_2} \right) \cdot \left(\text{CO}_2^* \cdot \frac{28}{44} \right).$$

The numbers 28 and 44 are the molecular weights of CO and CO₂, respectively. CO and CO₂ are percentages by volume of carbon monoxide and carbon dioxide in the flue gases. CO₂^{*} is carbon dioxide produced by complete combustion of black liquor in the recovery furnace. The same method is also applied to compute the heat loss due to the incomplete combustion of sulfur.

Loss of Sulfur in the Stack Gases

The sulfur loss in the process is always made up by adding sodium sulfate to the black liquor. Therefore, the loss of sulfur in the stack gases must be taken into consideration. The sulfur loss in lb-moles per year is obtained by using the expression

$$L_s = R \cdot 1440 \cdot 365 \cdot \left(\frac{\text{SO}_2 + \frac{\text{H}_2\text{S}}{2} + \frac{\text{CH}_3\text{SH}}{3}}{10} \right) \cdot \left(\frac{1}{359} \right)$$

where R is the flow rate of stack gases in standard cubic feet per minute, and SO_2 , H_2S , and CH_3SH are in parts per million by volume in the stack gases.

COMPUTER PROGRAMMING

The purpose of the computer program is to present a technique to carry out the tedious calculations involved in the minimization of air pollution from a Kraft recovery furnace. The computer program consists of a main program and four subroutines. The complete programs are included in Appendix B.

Main Program

The main program is shown in block diagram in Figure 5. This program calls subroutine DATA to read in all data required for the calculations. The mass balance calculations are carried out by calling subroutine MASS. Subroutine HEAT is used to make the heat balance calculation. Finally, the results of calculations are printed out by calling subroutine OUTPUT.

The main program calculates the annual return from the results of mass and heat balance calculations. It also correlates the emission of major air pollutants (H_2S , SO_2 , and CH_3SH) to odor equivalent to hydrogen sulfide given by the formula

$$ODOR = PPMHS + PPMCHS * 0.0047 / 0.0021 + PFMSO2 * 0.0047 / 0.47$$

where ODOR denotes the odor equivalent to hydrogen sulfide; PPMHS, PPMCHS, and PFMSO2 represent the ppm by volume of hydrogen sulfide, methyl mercaptan, and sulfur dioxide, respectively. The correlation

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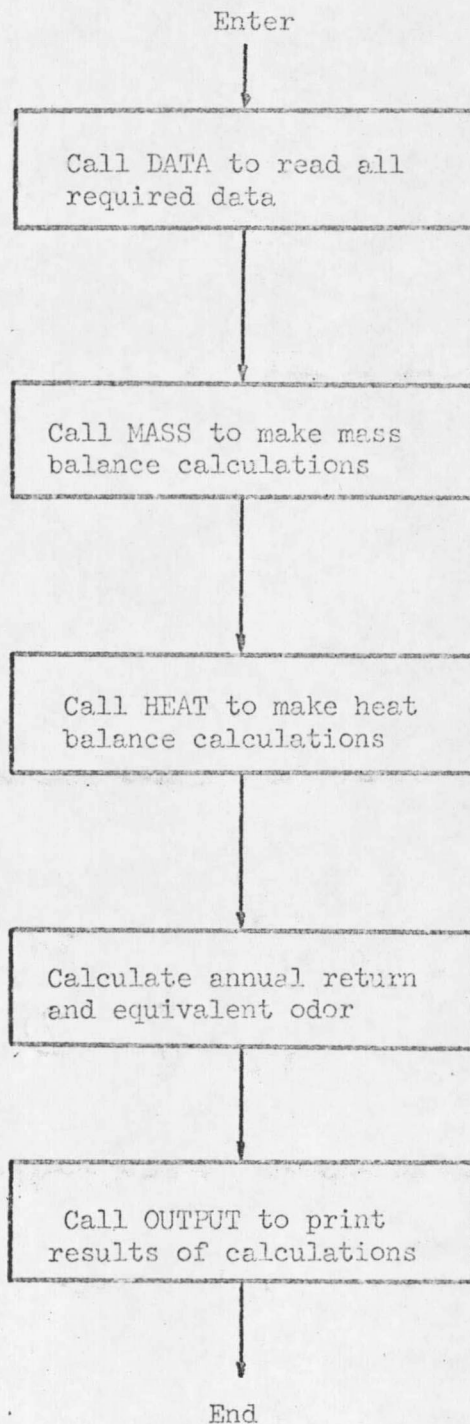


Figure 5. Block Diagram of Mainline Program.

Subroutine MASS

All terms in the subroutine MASS are calculated on the basis of 100 pounds of dry black liquor solids. By using stoichiometric relationships, subroutine MASS calculates the materials leaving and entering the Kraft recovery furnace for the given input state.

The sodium entering the unit in the form of black liquor must be equal to the sodium leaving the unit in the form of fumes and molten salts. Hence, the elemental analysis of the black liquor and percentages (as sodium) of each chemical in the molten salts can be used to compute the quantity of each chemical leaving the unit. On complete combustion of the black liquor in the Kraft recovery furnace, the gaseous products are sulfur dioxide, carbon dioxide, water, and a small amount of other sulfur-containing gases. The quantity of these gases for 100 pounds of black liquor (dry solids) can be calculated by making a mass balance on the Kraft recovery unit. For example, the sulfur in the form of stack gases leaving the stack can be found by subtracting the total sulfur in the black liquor and salt cake make-up entering the unit from the total sulfur in the molten salt and fumes leaving the unit. The same method is applied to calculate the carbon dioxide and water formed upon combustion of the black liquor.

The theoretical oxygen required for complete combustion of the black liquor is calculated from the difference of the oxygen output in the form of molten salts (Na_2S , Na_2CO_3 , and Na_2SO_4) and stack gases

and the oxygen input in the form of black liquor and salt cake make-up. Since we can find the percentage of excess oxygen in the stack gases by analysis, the actual amount of air entering the unit can then be calculated.

The total water leaving the stack includes the water evaporated from the black liquor, the water introduced to the direct contact liquor heater as steam, the water from the moisture in the air, and the water formed by combustion of the black liquor.

Subroutine HEAT

Subroutine HEAT is used in the calculation of the net heat available for producing steam in the Kraft recovery furnace unit. From the results of this, the calculation of steam production can be carried out in the main program.

The total heat entering the Kraft recovery furnace unit is the sum of the gross heating value and the sensible heat of the black liquor, the sensible heat in the air, and the heat in the steam entering the direct contact evaporator.

Heat lost due to the water in the stack gases is calculated by summing up heat loss for evaporating the water in the black liquor and the sensible heat of water vapor leaving the stack of the unit.

Heat lost due to the molten salts is calculated by the average heat of fusion and its sensible heat.

Heat loss of dry stack gases is the sensible heat carried out of the stack by excess oxygen, nitrogen, sulfur dioxide, and carbon dioxide.

Finally, the net heat gained for producing steam is calculated by the difference between heat input and the total heat loss in the unit.

Subroutines DATA and OUTPUT

Subroutine DATA reads in, according to a specified format, all the information required for the calculations in the mainline program.

Subroutine OUTPUT is called by the main program to print out all the results.

RESULTS AND DISCUSSION

The results of calculations using the mathematical model discussed in the previous sections indicates that it is possible to relate annual return to the operating conditions and air pollution in the Kraft recovery furnace unit. The operating conditions or parameters that affect the annual return and air pollution are investigated by employing the computer program.

Temperature of Stack Gases

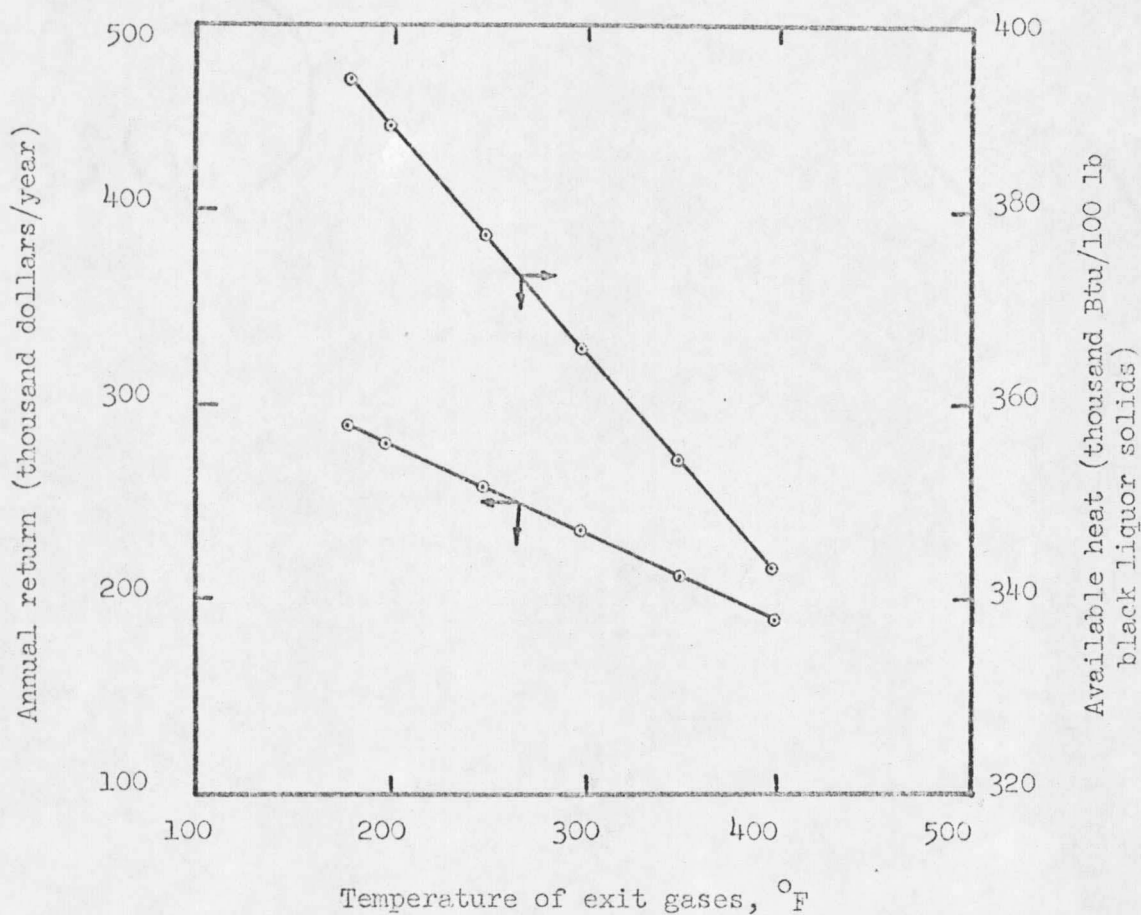
Figure 6 shows that the heat absorbed in the unit per 100 pounds of dry black liquor solids decreased as the temperature of stack gases increased. Annual return thus decreased because of the reduction of heat available for steam production. Hence, the Kraft recovery furnace unit would have much more steam production per pound of dry black liquor solids if the exit gas temperature were reduced.

Fume Emission

Fume emission is the percentage of solids in the black liquor leaving the unit in the form of particulate matter. Figure 7 shows that annual return drops drastically with an increase in fume emission. Fume emission represents one of the losses of material because it carries out sodium and sulfur compounds to the atmosphere. Fume emission not only decreases the annual return but also causes smoke haze.

Emission of Sulfur-Containing Gases

The major sulfur-containing gases are hydrogen sulfide, sulfur dioxide, and methyl mercaptan. The sulfur in these gases leaving the



Secondary air -- 41%

Excess oxygen in stack -- 3.4%

Strong liquor to DCE at 45% black liquor solids

Figure 6. The Influence of the Temperature of Exit Gases on Annual Return.

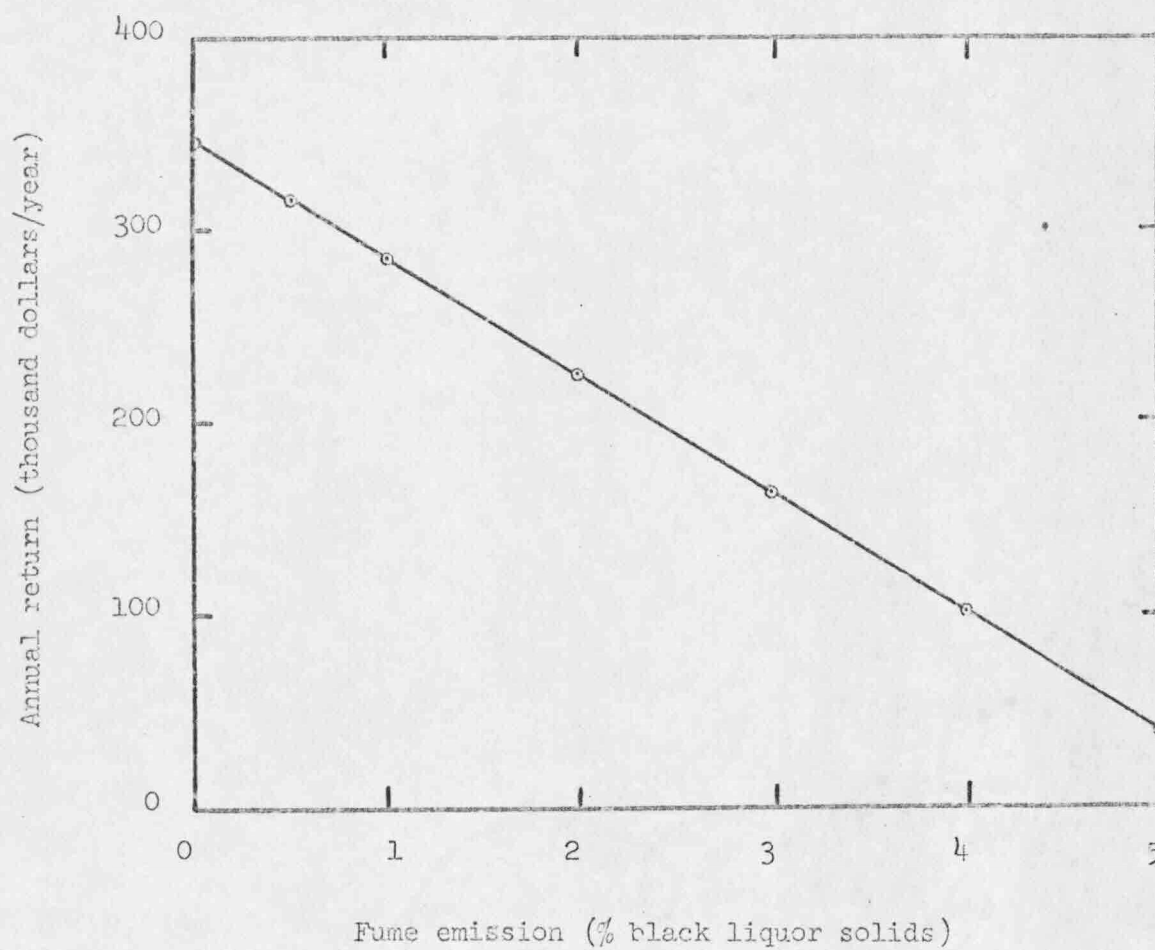


Figure 7. The Influence of the Emission of Fume on Annual Return.

unit is made up by adding salt cake (sodium sulfate). Figure 8 shows that annual return is decreased if the emission of these gases is increased. The emission of sulfur-containing gases represents a loss of material and an air pollution problem.

Solid Concentration of Black Liquor to the Unit

Figure 9 shows that as the percentage of solids in the black liquor is increased, the annual return from the unit is also increased. The heat required to evaporate the water in the black liquor and the heat carried out by the water vapor are not available to produce steam. The annual return from the unit can be increased by increasing solid concentration of the black liquor.

Percentage of Secondary Air to the Furnace

Figure 10 shows that heat for steam production per 100 pounds of black liquor solids is increased by increasing the percentage of secondary air -- the turbulence of air making the combustion of black liquor more complete. Sufficient oxygen indicated by the percent of excess oxygen in the stack gases also indicates good combustion in the furnace. Efficient combustion in the furnace leads to high heat recovery and low sulfur losses. The annual return is favored under conditions of high percentage of secondary air and excess oxygen. (See Figures 11 and 12).

Emission of Hydrogen Sulfide

In a good combustion atmosphere most of the hydrogen sulfide is oxidized to sulfur dioxide. The concentration of hydrogen sulfide in

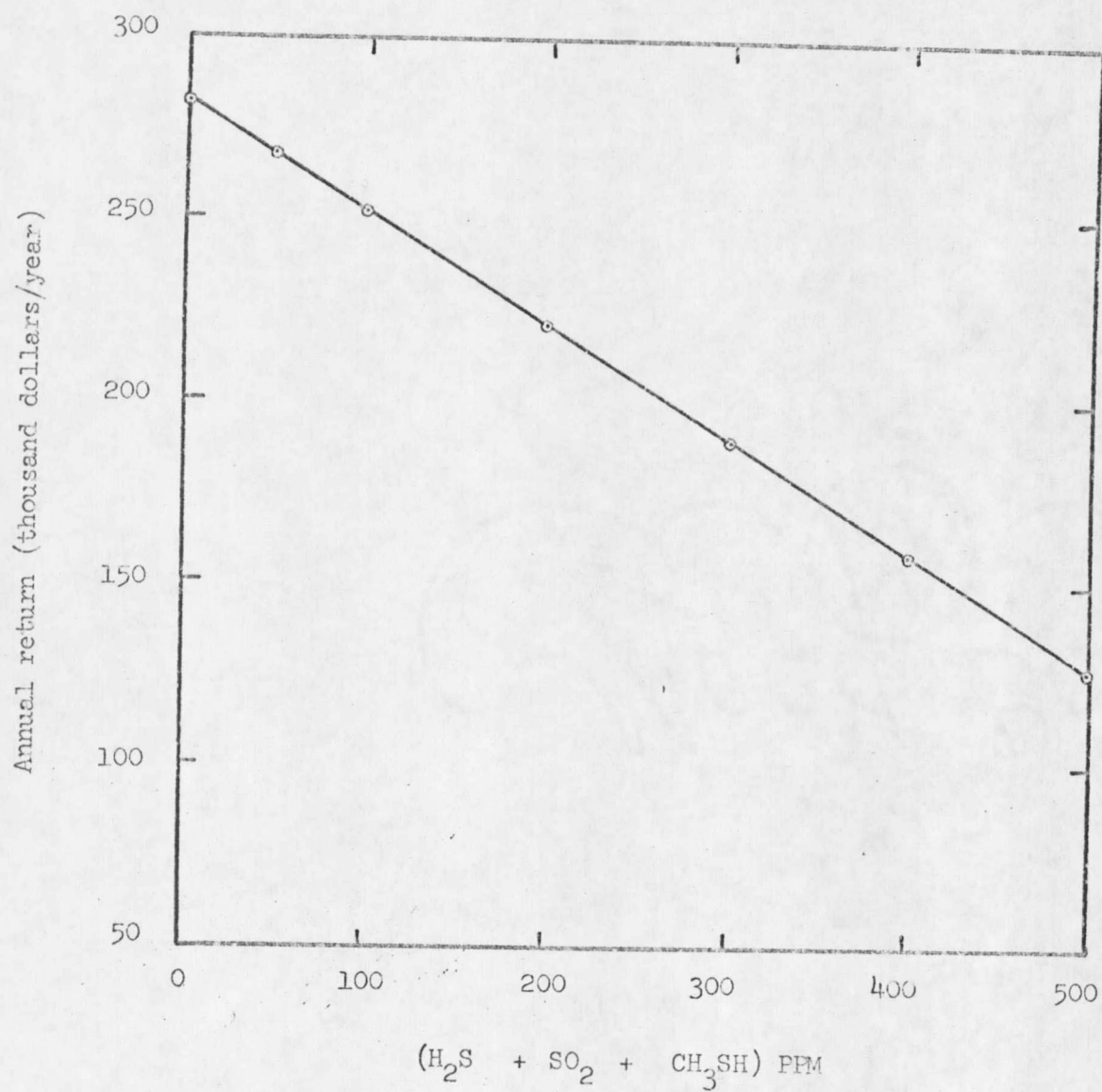


Figure 8. The Effect of Three Sulfur-Containing Gases on Annual Return.

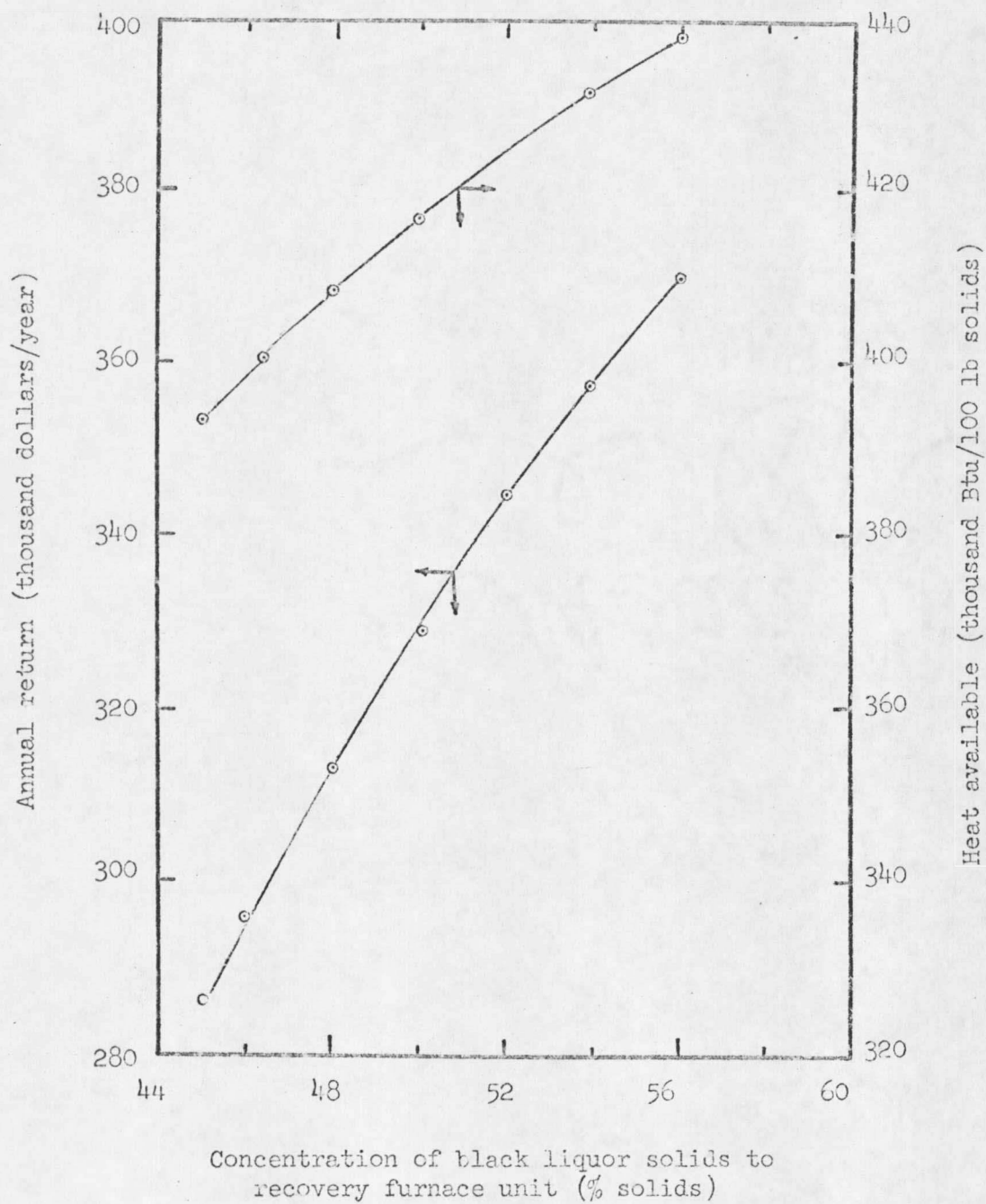
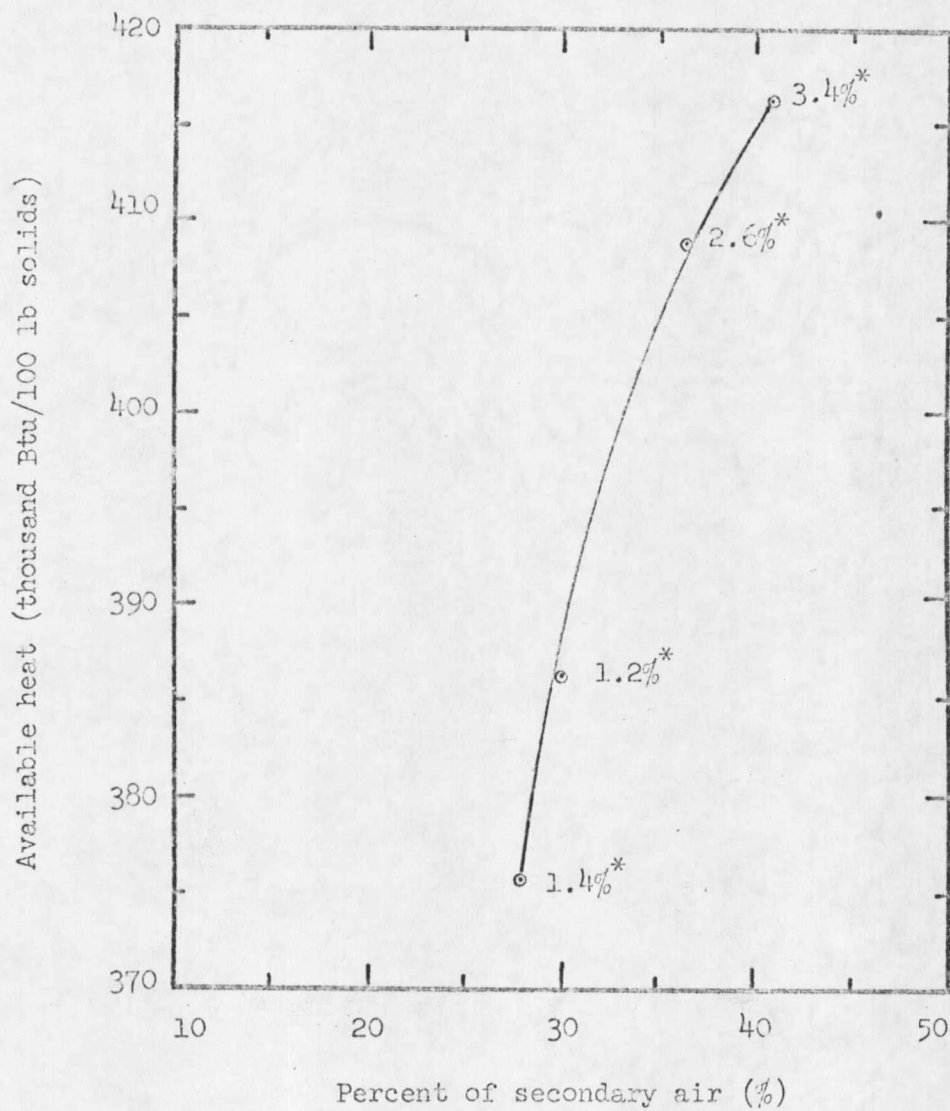


Figure 9. The Effect of the Black Liquor Concentration on Annual Return and Available Heat.



* indicating % of excess oxygen in stack

Figure 10. The Influence of Percent of Excess Oxygen on Available Heat.

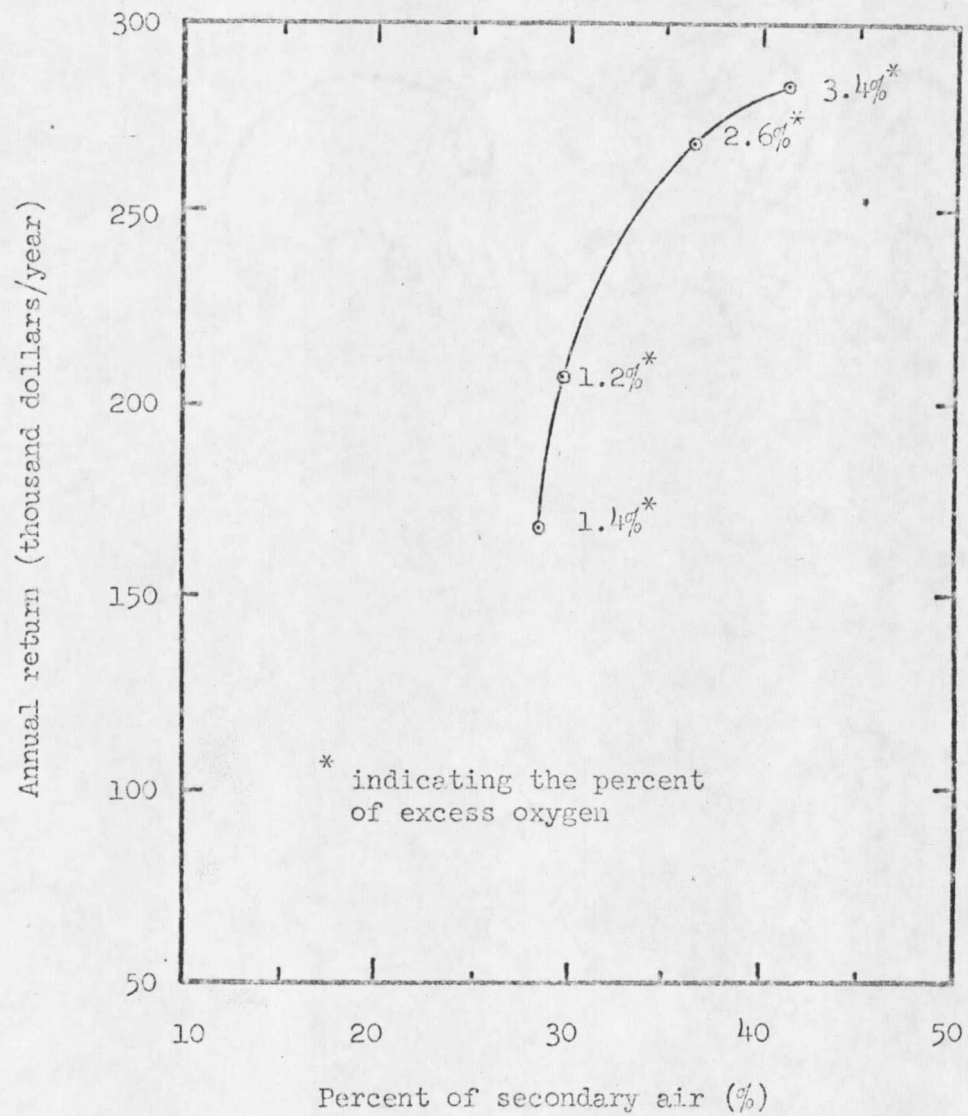


Figure 11. The Effect of the Secondary Air on Annual Return.

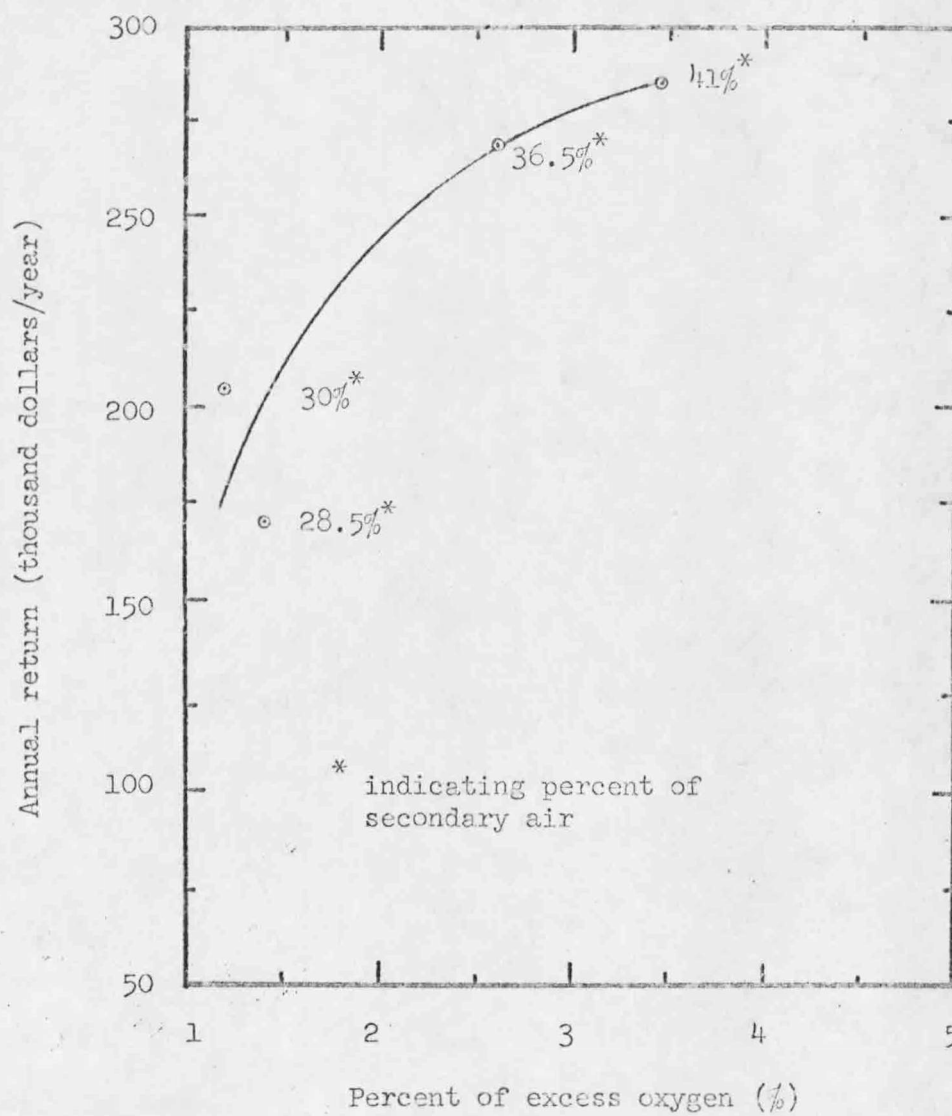


Figure 12. The Effect of Excess Oxygen on Annual Return.

the stack gases indicates whether the combustion in the recovery furnace is good or poor. Figure 13 shows that the annual return is high for low concentrations of hydrogen sulfide in the stack gases.

Velocity of Secondary Air

Comparing Table I and Table II, we find that the velocity of the secondary air entering the furnace affects the annual return and the air pollution. A high secondary air velocity provides turbulence in the recovery furnace and hence increases the efficiency of combustion of black liquor. On efficient combustion of black liquor, the sulfur loss from the exit gas is reduced and the heat recovery is increased. It is postulated that the fume emission is a function of secondary air velocity since particulate matter leaving the furnace depends on the velocity of gases in the furnace. Therefore, secondary air can be used to minimize air pollution and maximize annual return.

Soot Blowers

When the furnace is operating under poor combustion conditions, soot blowers can be used to reduce air pollution and to increase annual return as indicated in Table III and Table IV. The soot blowers provide additional turbulence in the combustion zone.

Black Liquor Spray

Tables VI and VII show that a coarse spray of black liquor has the advantages of reducing air pollution and increasing annual return for both the oxidized and unoxidized liquor. When a fine spray is used, the air pollution is increased because of entrainment of a small amount

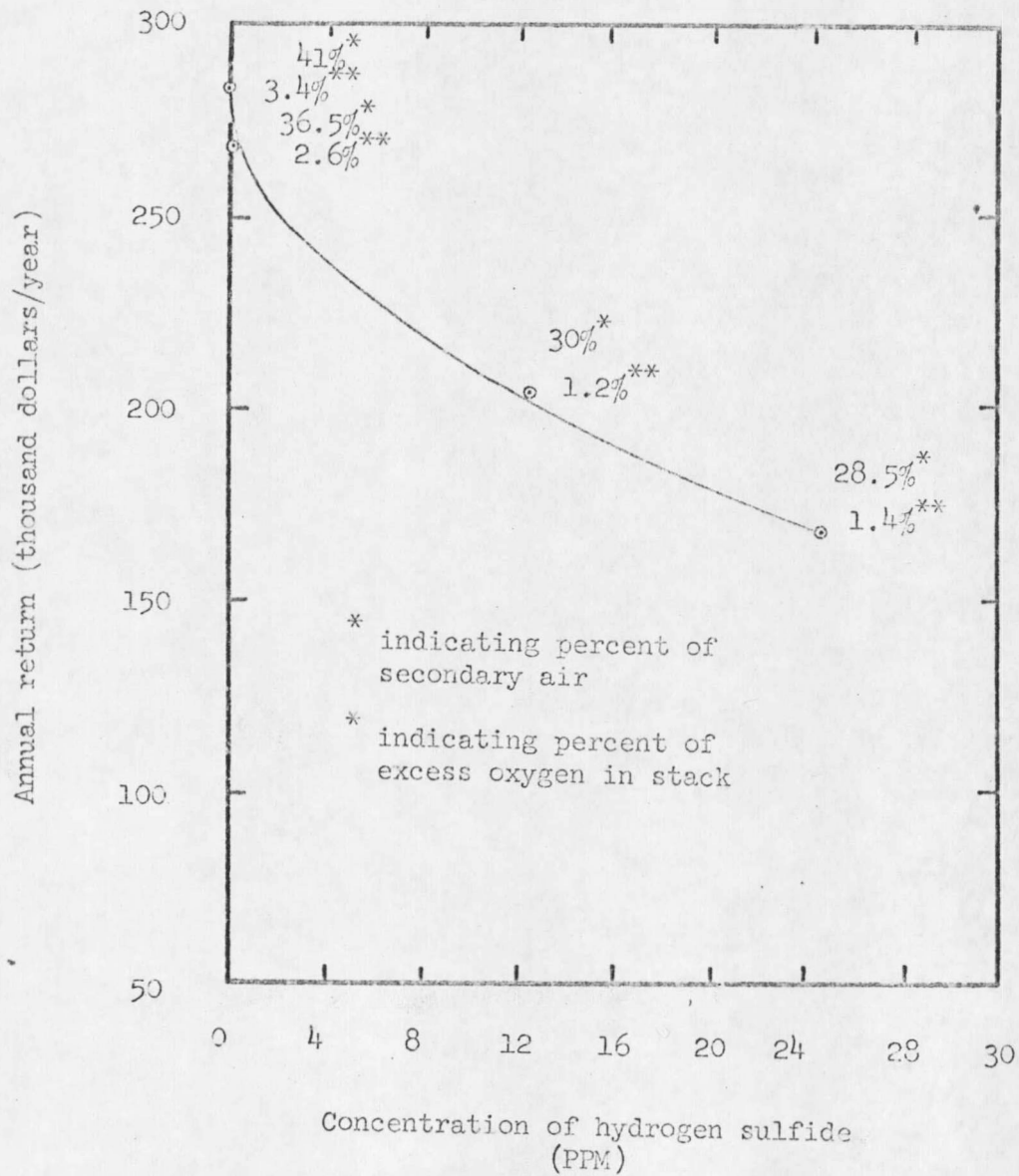


Figure 13. The Effect of Concentration of Hydrogen Sulfide on Annual Return.

of black liquor in the upper part of the recovery furnace where burning is poor.

Oxidation of Black Liquor

Table XV and Table XVI indicate the difference between unoxidized liquor and oxidized liquor. The oxidized liquor appears to be more favorable than the unoxidized liquor.

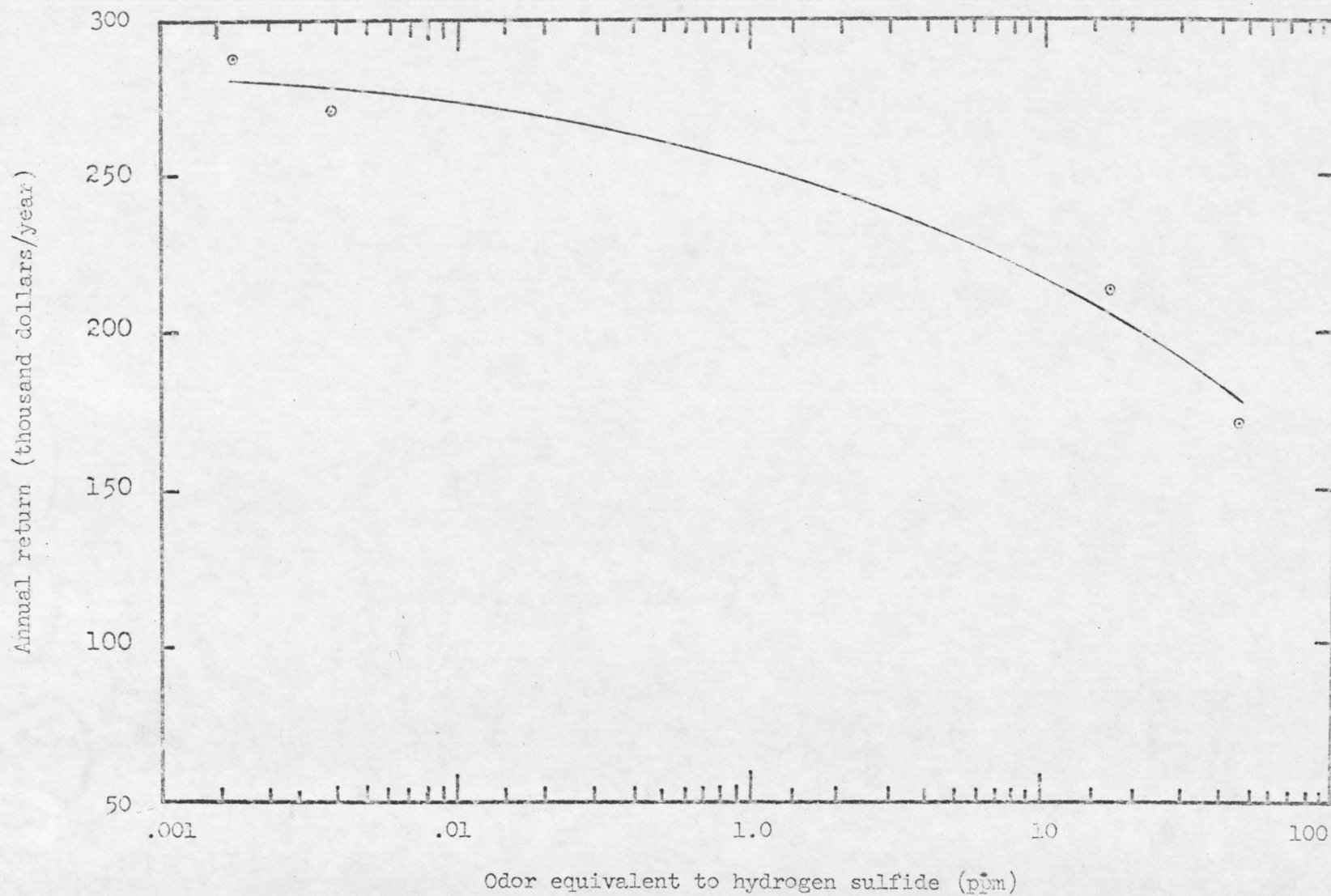


Figure 14. The Effect of Odor Equivalent to Hydrogen Sulfide on Annual Return.

CONCLUSIONS

1. The mathematical model can give annual return and odor equivalent to hydrogen sulfide with given operating conditions.
2. The complicated air pollution problem of a Kraft recovery furnace unit can be effectively optimized by the mathematical model with monitored data obtained on analysis equipment at various operating conditions.
3. The mathematical model along with the computer program can help obtain a better understanding of how the operating conditions affect the annual return and air pollution.

APPENDICES

APPENDIX A

ODOR THRESHOLD FOR AIR POLLUTANTS OF A KRAFT MILL

<u>Chemical</u>	<u>Odor Threshold</u>	<u>Description of Odor</u>
Hydrogen Sulfide	0.0047 ppm	Boiled egg
Methyl Mercaptan	0.0021 ppm	Sulfidy, pungent
Sulfur Dioxide	0.47 ppm	Oppressive

The above data are from Reference (9).

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APPENDIX B

MAIN PROGRAM AND SUBROUTINES

```

1      C      MAIN PROGRAM
2      C
3      COMMON TAX,CST,CMaint,CNAS,CNACB,CNASB,CLABOR,HST,XNAS,XNASB,
4      1XNACB,XNA,XC,XH,XS,XB,XINERT,SC,SBLR,TBLR,TA,RH,BLBTU,FUME,SBLI,
5      2TRLI,SBLE,TBLE,TSTACK,TITLE1,TITLE2,TITLE3,TITLE4,TITLE5,TITLE6,
6      3CAP,PERCAP,RATE,PPMSB2,PPMHS,PPMCHS,PERCB2,PERCB,EX9XY,TOTNA,
7      4WTNAS,WTNASB,WTNACB,SALT,PCDIX,PHB,PSB,ACTAIR,HSEND,AIR,ANA,GAIR,
8      5EXAIR,HNET,RETUN,BDOR,BTH,AH0
9      C      READ INPUT DATA
10     900 CALL DATA
11     IF(CAP.EQ.0.0) GO TO 600
12     C
13     C      CALL SUBROUTINE MASS TO MAKE MASS BALANCE CALCULATIONS
14     CALL MASS
15     C      CALL SUBROUTINE HEAT TO MAKE HEAT BALANCE CALCULATIONS
16     CALL HEAT
17     C      CALCULATE DEPRECIATION OVER TEN YEAR PERIOD
18     DEP = CST/100
19     C
20     C      CALCULATE ANNUAL RETURN
21     C      1ST TERM = PROFIT OF MOLTEN SALT AND FUME LOSS, 2ND TERM = PROFIT
22     C      OF STEAM ASSUMING 50 CENTS PER 1000 LB STEAM
23     C      3RD DEPRECIATION, 4TH SALT CAKE MAKE UP, 5TH MAINTAINACE COST,
24     C      6TH PROPERTIES TAX TEN PERCENT, 7TH BLACK LIQUOR COST, 8TH LABOR
25     C      9TH MATERIAL LOSS DUE TO H2S, SO2, AND CH3SH IN THE STACK GASES
26     RETUN = (WTNAS * CNAS/2000. + WTNACB * CNACB /100. + WTNASB * CNASB /
27     12000.)*( 1. - FUME)* CAP * PERCAP * 365. /100. + ( HNET/1146.2) *
28     2(0.5 /1000.) * CAP * PERCAP * 365./100. - DEP * SC * CNAS * CAP *
29     3PERCAP * 365./100. * 2000.) - CMaint * 0.1 * CST
30     4*((XS * 142./32.) * CNASB/2000. + (XNA - (XS*142./32.)*2. * 23./142.
31     5)*(106./12.*23.))*CNACB/100.) * CAP * PERCAP * 365./100.
32     6-CLABOR = (RATE *(PPMHS + PPMBS2 + PPMCHS)/1.0E 06)*1440.*365./
33     7359. *142. * CNASB/2000.
34     C      IF RETURN IS NEGATIVE THEN NO INCOME TAX
35     IF ( RETUN .LE. 0.0) GO TO 750
36     RETUN = (1. - TAX) * RETUN
37     C      CORRELATE ALL AIR POLLUTANTS TO EQUIVALENT BDOR STRENGTH OF H2S

```

```
38      750 6D6R = PPMHS + PPMCHS * 0.0047/0.0021 + PPM602 * 0.0047/0.47
39      C      CALL SUBROUTINE OUTPUT TO PRINT OUT ALL RESULTS OF CALCULATION
40      CALL OUTPUT
41      GO TO 900
42      600 CALL EXIT
43      END
```

```

1      SUBROUTINE DATA
2      OCCOMMON TAX,CST,CMaint,CNAS,CNAC0,CNAS0,CLAB0R,HST,XNAS,XNAS0,
3      1XNAC0,XNA,XC,XH,XS,X0,XINERT,SC,SBLR,TBLR,TA,RH,BLBTU,FUME,SBLI,
4      2TBLI,SBLE,TBLE,TSTACK,TITLE1,TITLE2,TITLE3,TITLE4,TITLE5,TITLE6,
5      3CAP,PERCAP,RATE,PPMS02,PPMHS,PPMCHS,PERC02,PERC0,EX0XY,T0TNA,
6      4WTNAS,WTNAS0,WTNAC0,SALT,PCDI0X,PH0,PS0,ACTAIR,H0END,AIR,ANA,0AIR,
7      5EXAIR,HNET,RETUN,0D0R,0TH,AH0
8      490 READ (105,300) TITLE1,TITLE2,TITLE3,TITLE4,TITLE5,TITLE6
9      READ (105,105) CAP, PERCAP, RATE
10     IF (CAP .EQ. 0.0) GO TO 800
11     READ (105,105) TAX,CST,CMaint,CNAS,CNAC0,CNAS0,CLAB0R
12     C      ENTHALPY OF STEAM TO DIRECT CONTACT LIQUOR HEATER
13     READ (105, 104) HST
14     C      COMPOSITION OF SMELT (PERCENT WEIGHT AS SODIUM)
15     READ (105, 105) XNAS, XNAS0, XNAC0
16     C      DATA OF ELEMENTAL LIQUOR ANALYSIS
17     READ (105,105) XNA, XC,XH, XS, X0, XINERT
18     C      THE SALT CAKE ADDED TO RF PER 100LB OF BL SOLID
19     READ (105, 104) SC
20     C      COMP AND TEMP OF LIQUOR AS FIRED IN RECOVERY FURNACE
21     READ (105, 105) SBLR, TBLR
22     C      TEMPERATURE AND MOISTURE IN AMBIENT AIR
23     READ (105, 105) TA, RH
24     C      GROSS LIQUOR HEATING VALUE PER POUND BL SOLID
25     READ (105, 106) BLBTU
26     C      LOSS OF FUME
27     READ (105, 104) FUME
28     C      TEMP AND COMP OF BL TO DCE AND FROM DCE
29     READ (105, 105) SBLI, TBLI, SBLE, TLE
30     C      TEMP OF STACK
31     READ (105,105) TSTACK
32     READ (105,105) PPMS02,PPMHS,PPMCHS,PERC02,PERC0,EX0XY

```

33 300 FORMAT(6A4)
34 111 FORMAT(10X, 5F20.3)
35 104 FORMAT(3F10.0)
36 105 FORMAT(7F10.0)
37 106 FORMAT(2F10.0)
38 800 RETURN
39 END

SUBROUTINE MASS

```

COMMON TAX,CST,CMaint,CNAS,CNAC0,CNAS0,CLAB0R,HST,XNAS,XNAS0,
1XNAC0,XNA,XC,XH,XS,X0,XINERT,SC,SBLR,TBLR,TA,RH,BLBTU,FUME,SBLI,
2TBLI,SBLI,TBLE,TSTACK,TITLE1,TITLE2,TITLE3,TITLE4,TITLE5,TITLE6,
3CAP,PERCAP,RATE,PPMS02,PPMHS,PPMCHS,PERC02,PERC0,EX0XY,T0TNA,
4WTNAS,WTNAS0,WTNAC0,SALT,PCDIOX,PH0,PS0,ACTAIR,H0END,AIR,ANA,0AIR,
5EXAIR,HNET,RETUN,0D0R,0TH,AH0

```

TOTAL SODIUM IN FURNACE

$T0TNA = XNA + SC * 46./142.$

WEIGHT OF CHEMICALS IN MOLTEN SALT

$WTNAS = (XNAS * T0TNA * 78./((2. * 23.)))/100.$

$WTNAS0 = (XNAS0 * T0TNA * 142./((2. * 23.)))/100.$

$WTNAC0 = (XNAC0 * T0TNA * 106./((2. * 23.)))/100.$

SULFUR IN MOLTEN SALT

$SMS = WTNAS * 32./78. + WTNAS0 * 32./142.$

SULFUR IN STACK GASES

$SG = XS + SC * 32./142. - SMS$

MOLTEN SALT FROM RF UNIT

$SALT = (WTNAS + WTNAS0 + WTNAC0 + XINERT) * (1. - FUME)$

PRODUCT OF IDEAL COMBUSTION

$PCDIOX = (XC - WTNAC0 * 12./106.) * 44./12.$

WATER FORMED

$PH0 = XH * 18./2.$

SULFUR DIOXIDE FORMED

$PS0 = SG * 64./32.$

THEORETICAL OXYGEN FOR IDEAL COMBUSTION

$0TH = PCDIOX * 32./44. + PH0 * 16./18. + PS0 * 32./63.7 +$

$1WTNAS0 * 64./142. + WTNAC0 * 48./106. + SC * 64./42. - X0$

THEORETICAL DRY AIR TO AIR HEATER AND WINDBOXES

$ATH = 0TH / 0.232$

```

36      ACTAIR = ATH
37      100 ACTAIR = ACTAIR + 0.01 * ATH
38      C      MOISTURE IN AIR TO AIR HEATER AND WINDBOXES
39      AH0 = ACTAIR * RH
40      C      WATER LEAVING UNIT
41      H0END = 100. * ((100. - SBLI)/SBLI) + 100. * ((100. - SBLR)/SBLR
42      1 - ((100. - SBLE)/SBLE) + PH0 + AH0
43      C      DRY AIR TO THE UNIT
44      AIR = ACTAIR * (1. - RH)
45      C      NITROGEN IN AIR
46      ANA = AIR * 0.786
47      C      OXYGEN IN AIR
48      OAIR = 0.232 * AIR
49      CALOXY = (OAIR - 0TH) * 100. / (PCDI0X + H0END + PS0 + ANA + OAIR
50      10TH)
51      IF (CALOXY * LE * EXOXY) GO TO 100
52      C      CALCULATE PERCENT OF EXCESS AIR
53      EXAIR = 100. * AIR / ATH - 100.
54      RETURN
55      END

```

SUBROUTINE HEAT

```

COMMON TAX,CST,CMAINT,CNAS,CNAC0,CNAS0,CLAB0R,HST,XNAS,XNAS0,
1XNAC0,XNA,XC,XH,XS,X0,XINERT,SC,SBLR,TBLR,TA,RH,BLBTU,FUME,SBLI,
2TBLI,SBLE,TBLE,TSTACK,TITLE1,TITLE2,TITLE3,TITLE4,TITLE5,TITLE6,
3CAP,PERCAP,RATE,PPMS02,PPMHS,PPMCHS,PERC02,PERC0,EX0XY,T0TNA,
4WTNAS,WTNAS0,WTNAC0,SALT,PCDI0X,PH0,PS0,ACTAIR,H0END,AIR,ANA,0AIR,
5EXAIR,HNET,RETUN,0D0R,0TH,AH0

```

C CALCULATION OF HEAT BANLANCES

C CALCULATION OF HEAT INPUT

$HIN = BLBTU * 100. * (100. - SBLI) * 100. * (TBLI - TA) / SBLI$
 $1 + 100. * 0.45 * (TBLI - TA) + HST * 100. * ((100. - SBLE) / SBLE - ($
 $2100. - SBLR) / SBLR)$

C CALCULATION OF HEAT LOSSES

C HEAT LOSS IN STACK GASES

$HSTACK = (0AIR - 0TH + ANA + PS0 + PCDI0X) * 0.24 * (TSTACK - TA)$

C HEAT LOSS OF WATER IN STACK

$HH0 = (AH0 * 0.48 * (TSTACK - TA)) + PH0 * (1040. + 0.48 *$
 $1(TSTACK - TA)) + (100. * (100. - SBLI) / SBLI + 100. * ((100. - SBLR) /$
 $2SBLR - (100. - SBLE) / SBLE)) * (1040. + 0.48 * (TSTACK - TA))$

C HEAT LOSS IN MOLTEN SALT

C 532 BTU IS THE HEAT REQUIRED TO MELT 1 LB OF SALT

$HSALT = 532. * SALT$

C REDUCTION OF SALT CAKE MAKE UP, 3000. BTU/LB NA2S04

$HSC = 3000. * SC$

C CALCULATION OF RADIATION LOSS ASSUMING ONE PERCENT OF HEAT INPUT

$HR = HIN * 0.01$

C UNACCOUNTED FOR AND MANUFACTURERS MARGIN FOR 2.5 PERCENT

$HUMM = HIN * 0.025$

```

32      C      HEAT OF REACTION CORRECTION
33      C      FOR BOMB CALORIMETER
34      DNAS0 = XS * 142./32.
35      DNAC0 = ( XNA - DNAS0 * 2. * 23. / 142.) * 106./(2. * 23.)
36      DC02 = (XC - DNAC0 * 12./106.)* 44./12.
37      DH0 = XH * 18.016/2.016
38      HREA = DC02 * 3847. + DH0 * 6832. + DNAC0 * 4577. + DNAS0 * 4190.
39      1-PCDI0X*3847.* PERC02/( PERC0 + PERC02 )
40      2-PCDI0X*1245.* PERC0/( PERC0 + PERC02 ) * 28./44.
41      3- FSD * 1995. * PPMH02/( PPMH0 + PPMH02 + PPMCHS )
42      4-PS0*252.*(34./64.)*PPMH0/(PPMH0+PPMH02+PPMCHS)
43      5-PS0*86.*(48./64.)*PPMCHS/(PPMH0+PPMH02+PPMCHS)
44      6-WTNAC0*4577.-2070.*(XNA -WTNAC0*2.*23./106.)*78./(2.*23.)
45      7-PH0*6832. - WTNAS0 * 4190.
46      C      NET HEAT RECOVERED
47      HNET = HIN - HSTACK - HH0 - HSALT - HSC - HR - HUMM - HREA
48      RETURN
49      END

```

SUBROUTINE OUTPUT

C

```

COMMON TAX,CST,CMAINT,CNAS,CNAC0,CNAS0,CLAB0R,HST,XNAS,XNAS0,
1XNAC0,XNA,XC,XH,XS,X0,XINERT,SC,SBLR,TBLR,TA,RH,BLBTU,FUME,SBLI,
2TBLI,SBLE,TBLE,TSTACK,TITLE1,TITLE2,TITLE3,TITLE4,TITLE5,TITLE6,
3CAP,PERCAP,RATE,PPMS02,PPMHS,PPMCHS,PERC02,PERC0,EX0XY,T0TNA,
4WTNAS,WTNAS0,WTNAC0,SALT,PCDI0X,PH0,PS0,ACTAIR,H0END,AIR,ANA,0AIR,
5EXAIR,HNET,RETUN,0D0R,0TH,AH0

```

C

```

10 WRITE(108,200)
11 200 FORMAT(1H1,T25,'RESULTS OF CALCULATION'//)
12 WRITE (108,301) TITLE1,TITLE2,TITLE3,TITLE4,TITLE5,TITLE6
13 301 FORMAT(T25,6A4//)
14 WRITE (108,201) CAP
15 201 FORMAT (T25,'CAPACITY OF RE',F15.0,' LBS BL SOLID PER DAY'//)
16 WRITE (108,202) PPMHS,PPMCHS,PPMS02
17 202 FORMAT(T25,'EMISSION OF AIR POLLUTANTS'/T25,1H2S',F6.2,' PPM',
18 14X,'CH3SH',F6.2,' PPM',4X,'SO2',F6.2,' PPM'//)
19 WRITE (108,203) 0D0R
20 203 FORMAT(T25,'0D0R EQ H2S ',F8.4,' PPM'//)
21 WRITE(108,204) XNAS,XNAS0,XNAC0
22 204 FORMAT(T25,'COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM'/
23 1T25,'NA2S',F8.2,8X,'NA2S04',F8.2,8X,'NA2C03',F8.2)
24 WRITE (108,249) CNAS,CNAS0,CNAC0
25 249 FORMAT (T25,4X,F8.2,' $/TON',8X,F8.2,' $/TON',8X,F8.2,' $/100 LBS'
26 1//)
27 WRITE (108,205) XNA,XC,XH,XS,X0,XINERT
28 205 FORMAT (T25,'ELEMENTAL BL LIQUOR ANALYSIS'/T25,1H1',F8.2,5X,
29 1'C',F8.2,5X,1H1',F8.2,5X,'S',F8.2,5X,'O',F8.2,5X,'INERT',F8.2//)
30 WRITE(108,206) SC
31 206 FORMAT(T25,'SALT CAKE MAKEUP',F8.4,' LB PER 100 LB BL SOLID'//)
32 WRITE(108,207)TBLI,SBLI,TBLE,SBLE,TBLR,SBLR

```

```

33 207 FORMAT(T25,'STRONG LIQUOR TO DCE AT',F5.0,' F AND',F6.2,' PERCENT'
34 1/T38,'FROM DCE AT',F5.0,' F AND',F6.2,' PERCENT'/
35 2T38,'IN THE RF AT',F5.0,' F AND',F6.2,' PERCENT'/)
36 WRITE(108,208) TSTACK
37 208 FORMAT(T25,'STACK GAS LEAVING DCE AT',F5.0,' F'/)
38 WRITE(108,209) TA,RH
39 209 FORMAT(T25,'AMBIENT AIR TEMP',F5.0,' F',8X,'MOISTURE IN AIR ',
40 1F6.3,' LB/LB AIR'/)
41 WRITE(108,210) BLBTU
42 210 FORMAT(T25,'GROSS LIQUOR HEATING VALUE',F12.2,' BTU PER LB SOLID'
43 1/)
44 WRITE(108,211) FUME
45 211 FORMAT(T25,'LOSS OF FUME',F10.3,' PER LB OF BL SOLID'/)
46 WRITE(108,214) EXOXY
47 214 FORMAT(T25,'EXCESS O2 IN STACK',F5.2,' PERCENT')
48 WRITE(108,212) ACTAIR, EXAIR
49 212 FORMAT(T25,'AIR TO RF',F10.2,' LBS PER 100 LB BL SOLID', 4X,
50 1'EXCESS AIR',F6.2,' PERCENT'/)
51 WRITE(108,213) HNET, RETUN
52 213 FORMAT(T25,'NET HEAT RECOVERED',F15.0,' BTU PER 100 LB BL SOLID'/
53 1T25,'RETURN FROM THE RF UNIT',F20.0,' $/YEAR'/)
54 RETURN
55 END

```

APPENDIX C

RESULTS OF CALCULATION

Table I. Results of calculation.

65 FT/SEC FOR SEC AIR

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 84.50 PPM CH₃SH 12.40 PPM SO₂ 47.10 PPM

odor EQ H₂S 112.7234 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
----	-------	---	-------	---	------	---	------	---	-------	-------	------

SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT.

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 1.40 PERCENT

AIR TO RF 526.20 LBS PER 100 LB BL SOLID EXCESS AIR 9.56 PERCENT

NET HEAT RECOVERED 417246. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 241078. \$/YEAR

Table II. Results of calculation.

180 FT/SEC AT SEC AIR

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.01 PPM CH₃SH 0.00 PPM SO₂ 0.20 PPM

ORDER EQ H₂S 0.0140 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
----	-------	---	-------	---	------	---	------	---	-------	-------	------

SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF. AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 1.40 PERCENT

AIR TO RF 526.20 LBS PER 100 LB BL SOLID EXCESS AIR 9.56 PERCENT

NET HEAT RECOVERED

418258. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT

236954. \$/YEAR

Table III. Results of calculation.

POOR COMB Sootblower off

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 56.40 PPM CH₃SH 7.96 PPM SO₂ 57.20 PPM

ORDER EQ H₂S 74.7872 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

Na ₂ S	28.50	Na ₂ SO ₄	1.50	Na ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
----	-------	---	-------	---	------	---	------	---	-------	-------	------

SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 1.40 PERCENT

AIR TO RF 526.20 LBS PER 100 LB BL SOLID EXCESS AIR 9.56 PERCENT

NET HEAT RECOVERED 402415. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 219598. \$/YEAR

Table IV. Results of calculation.

POOR COMB SOOTBLOWERS ON

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H2S 12.60 PPM CH3SH 0.74 PPM SO2 53.00 PPM

ODSR EQ H2S 14.7862 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA2S 28.50 NA2SO4 1.50 NA2CO3 70.00
126.75 \$/TON 24.50 \$/TON 2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA 18.30 C 42.60 H 3.60 S 3.60 O 31.70 INERT 0.20

SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O2 IN STACK 1.40 PERCENT

AIR TO RF 526.20 LBS PER 100 LB BL SOLID EXCESS AIR 9.56 PERCENT

NET HEAT RECOVERED

402954. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT

237504. \$/YEAR

Table V. Results of calculation.

GOOD COMB SOOTBLOWERS ON

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.00 PPM CH₃SH 0.00 PPM SO₂ 0.04 PPM

ORDER EQ H₂S 0.0004 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP. 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6500.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 2.60 PERCENT

AIR TO RF 568.87 LBS PER 100 LB BL SOLID EXCESS AIR 18.44 PERCENT

NET HEAT RECOVERED 417295. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 235167. \$/YEAR

Table VI. Results of calculation.

UNOX LO FINE SPRAY

CAPACITY OF RF 2400000 LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 2.40 PPM CH₃SH 0.12 PPM SO₂ 10.70 PPM

ODOR EQ H₂S 2.7756 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

Na ₂ S	28.50	Na ₂ SO ₄	1.50	Na ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 3.00 PERCENT

AIR TO RF 583.09 LBS PER 100 LB BL SOLID EXCESS AIR 21.40 PERCENT

NET HEAT RECOVERED 416632 BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 279871 \$/YEAR

Table VII. Results of calculation.

UNEX LO COARSE SPRAY

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.02 PPM CH₃SH 0.00 PPM SO₂ 2.12 PPM

ODOR EQ H₂S 0.0412 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

Na ₂ S	28.50	Na ₂ SO ₄	1.50	Na ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 3.00 PERCENT

AIR TO RF 583.09 LBS PER 100 LB BL SOLID EXCESS AIR 21.40 PERCENT

NET HEAT RECOVERED 416928. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 283824. \$/YEAR

Table VIII. Results of calculation.

EX LG FINE SPRAY

CAPACITY BF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.37 PPM CH₃SH 0.12 PPM SO₂ 9.80 PPM

ODOR EQ H₂S 0.7366 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 3.20 PERCENT

AIR TO RF 587.83 LBS PER 100 LB BL SOLID EXCESS AIR 22.39 PERCENT

NET HEAT RECOVERED 416747. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 280988. \$/YEAR

Table IX. Results of calculation.

8X LG COARSE SPRAY

CAPACITY OF RF 2400000 LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.00 PPM CH₃SH 0.00 PPM SO₂ 0.08 PPM

ODOR EQ H₂S 0.0008 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 3.20 PERCENT

AIR TO RF 587.83 LBS PER 100 LB BL SOLID EXCESS AIR 22.39 PERCENT

NET HEAT RECOVERED 416826 BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 284258 \$/YEAR

Table X. Results of calculation.

35% SECONDARY AIR AT 180°

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.00 PPM CH₃SH 0.00 PPM SO₂ 0.08 PPM

900R EG H₂S 0.0008 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	6	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 2.10 PERCENT

AIR TO RF 549.90 LBS PER 100 LB BL SOLID EXCESS AIR 14.49 PERCENT

NET HEAT RECOVERED

RETURN FROM THE RF UNIT

417764. BTU PER 100 LB BL SOLID
286051. \$/YEAR

Table XI. Results of calculation.

35% SECONDARY AIR AT 180°

CAPACITY OF RF 2400000, LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H2S 0.00 PPM CH3SH 0.00 PPM SO2 0.01 PPM

ODOR EQ H2S 0.0001 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA2S	28.50	NA2SO4	1.50	NA2CO3	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O2 IN STACK 4.80 PERCENT

AIR TO RF 658.93 LBS PER 100 LB BL SOLID EXCESS AIR 37.19 PERCENT

NET HEAT RECOVERED 415067. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 280919. \$/YEAR

Table XII. Results of calculation.

35% SECONDARY AIR AT 180°

CAPACITY OF RF 2400000. LBS. BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.00 PPM CH₃SH 0.00 PPM SO₂ 0.04 PPM

ODOR EQ H₂S 0.0004 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 4.40 PERCENT

AIR TO RF 639.97 LBS PER 100 LB BL SOLID EXCESS AIR 33.24 PERCENT

NET HEAT RECOVERED

415536. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT

281806. \$/YEAR

Table XIII. Results of calculation.

35% SECONDARY AIR AT 180°

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.00 PPM CH₃SH 0.00 PPM SO₂ 0.07 PPM

ODOR EQ H₂S 0.0007 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

Na ₂ S	28.50	Na ₂ SO ₄	1.50	Na ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP. 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 4.40 PERCENT

AIR TO RF 639.97 LBS PER 100 LB BL SOLID EXCESS AIR 33.24 PERCENT

NET HEAT RECOVERED 415536. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 281797. \$/YEAR

Table XIV. Results of calculation.

35% SECONDARY AIR AT 180°

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 0.00 PPM CH₃SH 0.00 PPM SO₂ 0.04 PPM

ODOR EQ H₂S 0.0004 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GRASS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 3.10 PERCENT

AIR TO RF 587.83 LBS PER 100 LB BL SOLID EXCESS AIR 22.35 PERCENT

NET HEAT RECOVERED 416826. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 284271. \$/YEAR

Table XV. Results of calculation.

UNOXIDIZED LIQUOR

CAPACITY OF RF 2400000 LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 72.40 PPM CH₃SH 3.45 PPM SO₂ 10.00 PPM

ODOR EQ H₂S 80.2214 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

Na ₂ S	28.50	Na ₂ SO ₄	1.50	Na ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 3.00 PERCENT

AIR TO RF 583.09 LBS PER 100 LB BL SOLID EXCESS AIR 21.40 PERCENT

NET HEAT RECOVERED 415493 BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 255509 \$/YEAR

Table XVI. Results of calculation.

OXIDIZED LIQUOR

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 4.16 PPM CH₃SH 1.42 PPM SO₂ 10.00 PPM

ODOR EQ H₂S 7.4381 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	B	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180° F AND 50.00 PERCENT
FROM DCE AT 180° F AND 64.00 PERCENT
IN THE RF AT 220° F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180° F

AMBIENT AIR TEMP 80° F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 3.10 PERCENT

AIR TO RF 587.83 LBS PER 100 LB BL SOLID EXCESS AIR 22.39 PERCENT

NET HEAT RECOVERED 416236. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 278394. \$/YEAR

Table XVII. Results of calculation.

SEC AIR AT 41.0%

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H2S 0.01 PPM CH3SH 0.00 PPM SO2 0.20 PPM

BDDR EQ H2S 0.0140 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA2S	28.50	NA2S84	1.50	NA2CO3	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O2 IN STACK 3.40 PERCENT

AIR TO RF 597.31 LBS PER 100 LB BL SOLID EXCESS AIR 24.36 PERCENT

NET HEAT RECOVERED 416499. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 283593. \$/YEAR

Table XVIII. Results of calculation.

SEC AIR AT 36.5

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H2S 0.01 PPM CH3SH 0.02 PPM SO2 0.10 PPM

ODOR EQ H2S 0.0528 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA2S	28.50	NA2SO4	1.50	NA2CO3	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O2 IN STACK 2.60 PERCENT

AIR TO RF 568.87 LBS PER 100 LB BL SOLID EXCESS AIR 18.44 PERCENT

NET HEAT RECOVERED 408623. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 268570. \$/YEAR

Table XIX. Results of calculation.

SEC AIR 28.5%

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H₂S 24.60 PPM CH₃SH 3.50 PPM SO₂ 96.70 PPM

ODOR EQ H₂S 33.4003 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA ₂ S	28.50	NA ₂ SO ₄	1.50	NA ₂ CO ₃	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O₂ IN STACK 1.40 PERCENT

AIR TO RF 526.20 LBS PER 100 LB BL SOLID EXCESS AIR 9.56 PERCENT

NET HEAT RECOVERED 375695. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 167556. \$/YEAR

Table XX. Results of calculation.

SEC AIR AT 30%

CAPACITY OF RF 2400000. LBS BL SOLID PER DAY

EMISSION OF AIR POLLUTANTS

H2S 12.60 PPM CH3SH 1.50 PPM SO2 53.00 PPM

ODOR EQ H2S 16.4871 PPM

COMPOSITION OF SMELT IN WEIGHT PERCENT AS SODIUM

NA2S	28.50	NA2SO4	1.50	NA2CO3	70.00
	126.75 \$/TON		24.50 \$/TON		2.50 \$/100 LBS

ELEMENTAL BL LIQUOR ANALYSIS

NA	18.30	C	42.60	H	3.60	S	3.60	O	31.70	INERT	0.20
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SALT CAKE MAKEUP 4.1700 LB PER 100 LB BL SOLID

STRONG LIQUOR TO DCE AT 180. F AND 50.00 PERCENT
FROM DCE AT 180. F AND 64.00 PERCENT
IN THE RF AT 220. F AND 62.80 PERCENT

STACK GAS LEAVING DCE AT 180. F

AMBIENT AIR TEMP 80. F MOISTURE IN AIR 0.013 LB/LB AIR

GROSS LIQUOR HEATING VALUE 6600.00 BTU PER LB SOLID

LOSS OF FUME 0.010 PER LB OF BL SOLID

EXCESS O2 IN STACK 1.20 PERCENT

AIR TO RF 521.46 LBS PER 100 LB BL SOLID EXCESS AIR 8.57 PERCENT

NET HEAT RECOVERED 386292. BTU PER 100 LB BL SOLID

RETURN FROM THE RF UNIT 205437. \$/YEAR

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pulp mill air pollution
by optimization techniques

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