

**DESIGN OF A PLANT TO PRODUCE 3 TONNES PER DAY
OF CAUSTIC POTASH FROM COCOA POD HUSK**

BY

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2000/9591EH

**DEPARTMENT OF CHEMICAL ENGINEERING
SCHOOL OF ENGINEERING AND ENGINEERING
TECHNOLOGY,
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA, NIGER STATE.**

OCTOBER, 2006.

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MINNA, NIGER STATE.**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENT
FOR THE AWARD OF BACHELOR OF ENGINEERING IN
CHEMICAL ENGINEERING.**

OCTOBER, 2006.

DECLARATION

I, Ladan Bashini John (2000/9591EH) hereby declare that this design project titled "Design of a plant to produce 3 tonnes per day of caustic potash from cocoa pod husk" carried out under the supervision of Professor K. R. Onifade and presented in partial fulfillment of the requirement for the award of Bachelor of Engineering (B.Eng) degree in Chemical Engineering has not been presented for any degree elsewhere, to the best of my knowledge.



LADAN BASHINI JOHN



DATE

CERTIFICATION

This is to certify that this research project titled “Design of a plant to produce 3 tonnes per day of caustic potash from cocoa pod husk” was carried out by Ladan Bashini John (2000/9591EH) with group B1 members and Submitted to the Department of Chemical Engineering, school of engineering Technology, Federal University of Technology, Minna, Niger State, in partial fulfillment of the requirement for the award of Bachelor of Engineering (B. Eng) degree in Chemical Engineering.

PROF. K. R. ONIFADE
(PROJECT SUPERVISOR)

DATE

DR.M.O. EDOGA
(HEAD OF DEPARTMENT)

DATE

EXTERNAL EXAMINER

DATE

DEDICATION

This design project is dedicated to the Lord Jesus Christ.

I also dedicate it to my father and mother Mr. and Mrs. John Burman Ladan.

May God Almighty bless you all in Jesus Christ's name, Amen.

ACKNOWLEDGEMENT

The successful completion of this work is not by my efforts at all, but by the special grace of God Almighty, and the contribution of my supervisor, lecturers, family members, friends, course mates and well wishers.

I would like to express my profound gratitude to my supervisor Prof. K.R. Onifade for his guidance.

I wish to also thank the Head of department of Chemical Engineering, Dr.M.O.Edoga.

Not forgetting Engr. A.K.Jimoh, Engr. Kovo Abdulsalam.

Special thanks and appreciations to my uncle and his wife Mr and Mrs L.D.Jibro for their moral and financial supports.

Profound appreciation to brother Israel Yamusa and family, Mr Jacob Madaki and family.

Finally, to my younger ones and my* cousins, I say to you all thank you so very much for your prayers. God bless you all.

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EXECUTIVE SUMMARY

This design was carried out to design a plant to produce 3tonnes/day of caustic potash using cocoa pod husk. The plant for the production of caustic potash will actually need a dryer, furnace, leaching tank, filter, evaporator and storage tank where the product will be stored. The material balances were carried out with the aid of Microsoft excel while the energy balance were carried out using MathCAD 2000 professional whereas the design of equipment was done with HYSYS. From the calculation of the design, it was discovered that 73777.77kg/day of cocoa pod husk will be required as the starting mass of the husk for production of the required capacity. The results of the economic analysis showed that the plant needs ₦509080073.15 as the total capital investment to set up the plant. Finally, the plant was found to be economically viable with the rate of return of 25.39% and pay back period of 3.94 years.

CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

The shells of the cocoa are called pod husk. The husk after being burnt to ashes and leached can also give some chemical compounds such as potassium hydroxide, which has high concentration and can be used in the manufacture of soap. Its ashes can also be mixed with animal feed but a minimum quantity is used because the Theobromine it contains is toxic to animals when accumulated in their bodies. The husk can be used in making fibre, board manufacture because of its high cellulose content (about 45%) but is of low quality because of its high protein and low fibre content. It is also contains nitrogen and phosphorous therefore can be used as a source of manure for growing plants (Jeremiah, 1991).

Potassium hydroxide (KOH), commonly known as caustic potash, is the largest volume potassium chemical for non-fertilizer use. It is produced by the electrolysis of potassium chloride using membrane or mercury cell technology. The co-products are chlorine and hydrogen.

(www.oxy.com/OXYCHEM/Products/caustic_potash/caustic_potash.htm)

Some uses of KOH include acrylate ester copolymer coating, defoaming agents used in the manufacture of paper, formulation aid for food, pH control agent, polyethylene resins, textile processing. (http://en.wikipedia.org/wiki/Caustic_potash)

Cocoa, common name for a powder derived from the fruit seeds of the cacao tree and for the beverage prepared by mixing the powder with milk. When cocoa is prepared, most of the cocoa butter is removed in the manufacturing process. After the fat is

separated and the residue is ground, small percentages of various substances may be added, such as starch to prevent caking, or potassium bicarbonate to neutralize the natural acids and astringents and make the cocoa easy to dissolve in liquids. Cocoa has a high food value, containing as much as 20 percent protein, 40 percent carbohydrate, and 40 percent fat. It is also mildly stimulating because of the presence of theobromine, an alkaloid that is closely related to caffeine (Encarta, 2006).

1.2 Aim and objectives of the study

This project is aimed at designing a plant for the production of caustic potash from cocoa pod husk. This aim will be achieved via the realization of the following objectives:

- (1) Preparation of a flow diagram of the plant.
- (2) Calculation of the material balances of the components across the individual units.
- (3) Calculation of the energy balances of the components across the individual units.
- (4) Carry out the detail design of all the units of the plant.
- (5) Preparation of the cost estimation of the plant.
- (6) Others

1.3 Design Data

The process data required in this design project were sourced from literatures (past projects and textbooks) and internet. In a situation where particular pieces of information were not available, reasonable assumptions were made.

Further, all operating conditions specified in the process were obtained from literatures (past projects and textbooks) and the internet.

1.4 Need for the study

Cocoa pod just has hitherto been regarded as waste. However recent research results show that it can be commercially used in the production of caustic potash.

1.5 Problem Statement

Design a plant to produce 3 tonnes/day of caustic potash from cocoa pod husk.

1.5.1 Service available

- a. Cooling water at 100 lb/in² at a maximum temperature of 35°C.
- b. Dry saturated steam at 10 atmospheres.

1.5.2 Product specification

The purity of caustic potash should not be less than 99% (99 percent).

1.5.3 Other requirements

1. All the equipments must be designed.
2. In addition to the hard copies, electronic copy of the report must be submitted in a diskette.

1.5.4 Bonus marks

Extra marks will be given for use of process simulator package in:

- a. preparing flow diagram/flow sheet.
- b. the design of the equipment.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Caustic potash

A caustic white solid, KOH, used as bleach and in the manufacture of soaps, dyes, alkaline batteries, and many potassium compounds. Also called caustic potash, lye; Also called potash. (www.answers.com/topic/potassium-hydroxide)

The chemical compound potassium hydroxide, (KOH) sometimes known as caustic potash, potassa, potash lye, and potassium hydrate, is a metallic base. It is a very alkaline compound used in agriculture to correct the pH of acidic soils. It can also be used as a fungicide or even an herbicide.

(www.oxy.com/OXYCHEM/Products/caustic_potash/caustic_potash.htm)

Potassium hydroxide (KOH), commonly known as caustic potash, is the largest volume potassium chemical for non-fertilizer use. It is produced by the electrolysis of potassium chloride using membrane or mercury cell technology. The co-products are chlorine and hydrogen.

(www.oxy.com/OXYCHEM/Products/caustic_potash/caustic_potash.htm)

Caustic potash is a strong base and is available in liquid and dry forms. It has universal applications in soaps and detergents, fertilizers, and industrial operations. It is also used in molten salts, dyes, pharmaceuticals, and photographic chemicals.

(www.oxy.com/OXYCHEM/Products/caustic_potash/caustic_potash.htm)

2.1.1 Properties of caustic potash

Table 1.1: Properties of caustic potash

Properties	Description
Other names	Potash lye
Molecular formula	KOH
Molar mass	56.1 g/mol
Appearance	white solid, deliquescent
Density and phase	2.04 g/cm ³ , solid
Solubility in water	110 g/100 ml (25 °C)
Melting point	380 °C
Boiling point	1324 °C
Phase behaviour	Solid, liquid, gas
Spectral data	UV, IR, NMR, MS
Other anions	Potassium oxide Potassium peroxide Potassium superoxide
Other cations	Lithium hydroxide Sodium hydroxide Rubidium hydroxide Caesium hydroxide

Source: http://en.wikipedia.org/wiki/Caustic_potash

2.1.2 Uses of caustic potash

Potassium Hydroxide is used in chemical manufacturing including potassium carbonate and other potassium chemicals, fertilizers, phosphates, agrochemicals,

alkaline batteries and dyes. It is also widely used in soap and bleaching industry.

(www.chemicaland21.com/arokorhi/industrialchem/inorganic/KOH1.htm)

It is a major industrial chemical used as a base in a wide variety of chemical processes. It is used as a catalyst in reactions like the production of biodiesel, the advantage of using potassium hydroxide (KOH) and not sodium hydroxide (NaOH) is that NaOH "clumps" and KOH does not.

Some uses of KOH include acrylate ester copolymer coating, defoaming agents used in the manufacture of paper, formulation aid for food, pH control agent, polyethylene resins, textile processing. (http://en.wikipedia.org/wiki/Caustic_potash)

Other uses include in veterinary medicine in disbudding calves horns and to dissolve scales and hair; manufacture of cleansers; in wart removal and as a cuticle solvent. This type of compound is also used in washing powders, some denture cleaners, non-phosphate detergents, and drain or pipe cleaners.

A very significant use of KOH in terms of significance to the average home consumer is that alkaline batteries use an aqueous solution of KOH as an electrolyte. Thus, potassium hydroxide helps to power flashlights, smoke detectors, and other battery powered household items. (http://en.wikipedia.org/wiki/Caustic_potash)

2.1.3 Caustic potash in food preparation

Food uses of lye include washing or chemical peeling of fruits and vegetables, chocolate and cocoa processing, caramel color production, poultry scalding, soft drink processing, and thickening ice cream. Olives are often soaked in lye to soften

them, while pretzels and German lye rolls are glazed with a lye solution before baking to make them crisp. (http://en.wikipedia.org/wiki/Caustic_potash)

Lye is used to make the Scandinavian delicacy known as lutefisk (from lutfisk, "lye fish"). Cod is soaked in lye to a jelly-like consistency, then served with bacon fat, potatoes, brunost sauce and mushy peas. Hominy is dried maize (corn) kernels reconstituted by soaking in lye-water. (http://en.wikipedia.org/wiki/Caustic_potash)

2.2 Cocoa

Cocoa, common name for a powder derived from the fruit seeds of the cacao tree and for the beverage prepared by mixing the powder with milk. (Encarta, 2004)

2.2.1 Discovery and Development of cocoa

The cocoa tree (*Theobroma Cacao*) is a native of the dense tropical Amazon forests. First cultivated by the Mayas of Yucatan and the Aztecs of Mexico, the crop has increased in commercial value since Montezuma began consuming a cocoa bean preparation called "chocolatl" regularly.

(www.hawaiianchocolate.com/growing_chocolate_history.html)



Fig. 1.1: Cocoa plant

Although Columbus initially brought the cocoa bean to Europe, it was his fellow countryman, Don Cortes, who recognized its commercial value as a drink and sent back to Spain cocoa beans and recipes for the preparation of chocolate. However, it was the Swedish botanist, Linnaeus, who, probably drawing on the Aztec belief that the cocoa tree had divine origins, gave the genus the name "Theobroma" or Food of the Gods. (www.hawaiianchocolate.com/growing_chocolate_history.html)

The Spaniards jealously guarded this increasingly popular drink, to which they added sugar as a sweetener. Cultivation of the cocoa tree by the Spaniards in their isolated colony in Trinidad was part of the effort to keep secret the cultivation and preparation of the cocoa bean. Eventually, the Spaniards sought to grow cocoa elsewhere including other West Indian Islands and the Philippines. (www.hawaiianchocolate.com/growing_chocolate_history.html)

The popularity of the chocolate drink spread to Italy, Holland and France and finally in the middle 1600s to England, but it remained a drink for the wealthy because of its high cost. By the early eighteenth century, however, prices began to drop and the commercial manufacture of chocolate began in Bristol, England, where the firm of J.S. Fry founded the first chocolate factory in 1728.

(www.hawaiianchocolate.com/growing_chocolate_history.html)

2.2.2 Botany and Propagation of cocoa

The term cacao, essentially a botanical name, refers to the tree; the pods and the unfermented beans found in the pods. The word cocoa, by contrast, refers to the fermented cocoa beans in bulk, and also to the manufactured powdered product used for drinks and in food manufacturing.

www.hawaiianchocolate.com/growing_chocolate_history.html

The cocoa beans are the seeds of the cacao tree species *Theobroma cacao* L., and the genus *Theobroma*. *Theobroma cacao* is the only species of commercial value and is divided into four distinct varieties: Hawaiian, Criollo, Trinitario, and Forastero.

Except for in Hawaii, the growing conditions required by the cacao tree are fairly precise with the usual areas of cultivation lying within 20 degrees latitude of the equator. Within these latitudes a temperature range of 21 to 32 degrees Centigrade (70 to 90 degrees Fahrenheit) is required. Soil conditions can vary considerably, but a firm roothold and moisture retention are necessary.

www.hawaiianchocolate.com/growing_chocolate_history.html

Traditionally, cacao trees are grown under shade trees to resemble their natural habitat, however, high yields have been obtained from trees growing in non-shaded areas when sufficient moisture and nutrients are made available to the trees. Cocoa trees, which begin bearing fruits after the age of five, generally live up to 100 years and are in their prime 30 to 40 years after maturity.

From the time the seedlings reach a height of 3 to 5 feet, they throw out 3 to 5 branches, and later, vertical "chupons" or suckers from points below "jorquettes" where branches fork. This pattern of growth is repeated until the height of maturity is reached.

Flowers, less than a half inch in diameter, are formed in small groups on the trunk and lower main branches of the trees. They are bisexual and produce pollen that is

too sticky to be dispersed by the wind. In its natural habitat, pollination occurs primarily through small midge: a tiny fly. Mature trees produce approximately 10,000 flowers per year of which 1000 become pollinated, and of which 100 develop into mature pods. These pods mature in 5 to 7 months during which time many wilt and drop off in a natural thinning process. The pod attains a length of 6 to 10 inches and a diameter of 3 to 4 inches. A pod normally contains 20 to 40 seeds surrounded by a mucilaginous pulp when the pod is ripe.

www.hawaiianchocolate.com/growing_chocolate_history.html

The pods are harvested regularly, for the trees bear mature fruit, flowers, and growing pods all at the same time. After removal from the branches by hand-cutting, the pods are taken to a central location for opening and removal of the beans and adhering pulp. The beans with pulp are then taken to the fermentary for fermenting and drying.

2.2.3 Varieties of Cocoa

The different varieties of cocoa are Criollo cocoa, which is the old Venezuelan criollo population, which include also the native or long, establish cocoa of Mexico and Central America. The pods are either red or yellow in color, narrow and long, when ripe usually deeply ten-furrowed, very warty and conspicuously pointed. The pod wall is relatively thin and easy to cut; seed plump almost round in section, fresh cotyledons either white or pale violets in color. The whole group is variable and occasionally trees may have smooth or scarcely pointed pods.

2.2.3.1 Amelonado

The Amelonado is the commonest type grown in West Africa. Amelonado cocoa pods are slightly rounded, smooth and green when unripe and turn yellow when ripe. It is not a very high yielding type but an advantage it has is that the pods are generally formed during the dry season, which reduces damages due to black pod diseases.

2.2.3.2 Amazonian Frosterous

The Amazonian cocoa comprises the ordinary cocoa of Brazil and West Africa. They are all called Amazonians because they are apparently distributed naturally throughout the basin of that river and its tributaries. The pods are yellow when ripe and are better known representation in cultivation. They are inconspicuously ridged and furrowed, smooth and round-ended or very blunt pointed. The pod wall is thick and often is a woody layer difficult to cut. The seeds are more or less flattened and fresh cotyledons are dark violet in color sometimes almost black seeds are the most important and more constant than the pod shape but they are not invariable.

2.2.4 Uses of cocoa

The cocoa pod is composed of about 42% beans, 2% sweetener (mucilage) and 56% husk. The cocoa bean is main product of the plant and it contains protein and fat and has a highly concentrated food value in relation to their bulk and weight. Also the carbohydrate present makes it an excellent high energy food. The processing of cocoa beans during manufacturing is mainly directed towards the production of eating chocolate, drinking cocoa and cocoa butter and a lesser extent manufacture of Theobromine. Cocoa butter is used in manufacture of cosmetics and pharmaceutical preparation, soap, ointment and food .

The cocoa tree too has its own usefulness they are grown in tropical regions of the world and they provide shading and resting place for the farmers also the trees after ageing can be used for firewood and logs for sawmill to be used in building and construction for private purposes and industrially.

2.3 Cocoa pod husk

The shells of the cocoa are called pod husk.

2.3.1 Chemical composition of cocoa pod husk

Table 2.2: Showing the chemical composition of Cocoa Pod Husk

Constituent	Percentage by Weight (%)
Water	57.79
Total dry matter	42.29
Glucose	1.16
Crude protein	9.69
Fatty substance	0.15
Crude fibre	33.90
Nitrogen –free extracts	42.21
Sucrose	0.18
Pectin	5.30
Theobromine	0.20

2.3.2 Chemical composition of ashed cocoa pod husk

Table 2.3: Showing the chemical composition of ashed cocoa pod husk.

Constituent	Percentage by Weight (%)
CaO	0.22-0.59
MgO	0.40-0.52
K ₂ O	2.85-5.87
P ₂ O ₅	0.30-0.49
SiO ₂	0.06-0.14
PH	6.10-7.00

2.3.3 Uses of Cocoa Pod Husk

The shells of the cocoa are called pod husk. The shells can be sacked for mulch used for the extraction of Theobromine to yield cocoa butter. Extracted Theobromine is converted to caffeine that subsequently added to beverages and medicine. The husk after being burnt to ashes and leached can also give some chemical compounds such as potassium hydroxide, which has high concentration and can be used in the manufacture of soap. It ashes can also be mixed with animal feed but a minimum quantity is used because the Theobromine it contains is toxic to animals when accumulated in their bodies. The husk can be used in making fibre, board manufacture because of its high cellulose content (about 45%) but is of low quality because of its high protein and low fibre content. It also contains nitrogen and phosphorous therefore can be used as a source of manure for growing plants (Jeremiah, 1991).

Figure 1 illustrates a mature cocoa pod as it appears on the tree, often growing from the trunk. This variety is of an elongated cylindrical shape with ten furrows. In size,

the fully grown pod is about six to ten inches long and three to four inches in diameter. Removal of a portion of the thick husk reveals the seeds inside which are covered with a pulp. (Figures 2 and 3) The oval-shaped cocoa beans are about one and a quarter inches long and vary in color from white to purple. Figures 4 to 8 are views of a seed and its cross-sections.

(www.hawaiianchocolate.com/growing_chocolate_thecocoapod.html)

Dried and fermented cocoa beans usually weigh from one-twentieth to one-thirtieth of an ounce. (www.hawaiianchocolate.com/growing_chocolate_thecocoapod.html)

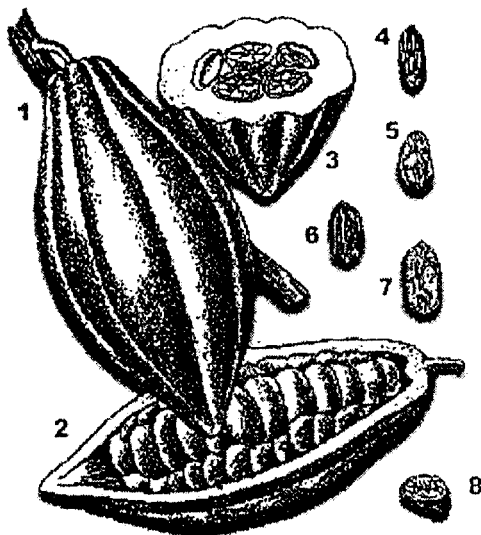


Fig. 2.2: Cocoa pod husk

Source: (www.hawaiianchocolate.com/growing_chocolate_thecocoapod.html)

2.3.4 Uses of cocoa pod husks

Cocoa pod husks can be used in several different ways:

As pelletised 100% cocoa pod husk it can be used as a substitute for corn and wheat bran in feed formulations for chickens, pigs and sheep. To produce the feed the fresh

cocoa pod husks are sliced into flakes. The flakes are partially dried to 60% moisture content, they are then minced or pelleted and dried.

(www.icco.org/questions/animalfeed.htm)

It can be used as wet feed for pigs, mixed with corn and other ingredients.

Wet cocoa pod husk can be mixed with grass, cassava and other farm wastes as feed for rabbits, sheep, horses etc. (www.icco.org/questions/animalfeed.htm)

2.4 Leaching

Leaching is the removal of a soluble fraction in the form of a solution from an insoluble permeable solid phase with which it is associated. The separation usually involves selective dissolution with or without diffusion but in the extreme case of simple washing it consist of the displacement with some mixing of one interstitial liquid by another which is immiscible. The soluble constituent may be solid or liquid and it may be incorporated of the insoluble material. The insoluble cellular with selectivity permeable cell walls or surface activated. This process may be used either for the production of a concentrated solution of a valuable solid material or in order to remove an insoluble solid from a soluble material with which it is contaminated. Leaching is also known as solid-liquid extraction lixiviation, percolation, infusion, washing and decanting settling in Chemical Engineering practice. It is an industrial separation operation based on mass transfer (Jeremiah, 1991).

The proportion of soluble constituent present, its distribution throughout the solid the nature of the solid and particle size determine the method used for the extraction.

Generally, the process can be considered in three parts :

- 1) The change of phase of the solute as it dissolves in the solvent.
- 2) Its diffusion through the solvent in the pores of the solid to the outside of the particles.
- 3) The transfer of solute from the solution to in contact with the particles to the main bulk of the solution.

In some cases, the soluble materials are distributed in small isolated pockets in a material, which is impermeable to the solvent, and the material is crushed so that all the soluble material is exposed to the solvent.

2.4.1 General principles of leaching operation

Leaching is concerned with the extraction of soluble constituent from a solid by means of a solvent. The process may be used either for the production of a concentrated solution of a valuable solid material, or in order to remove an insoluble solid, such as a pigment from a soluble material with which it is contaminated. The proportion of soluble constituents present determines the method used for extraction. Its distribution throughout the solid the nature of the solid and the particle size. If the solute is uniformly dispersed in the solid, the material near the surface will be dissolved first. Leaving a porous structure in the solid residue. The solvent will then have to penetrate this outer layer before it can reach further solutes and the process will become progressively more difficult and the extraction rate will fall. If the solute forms a very high proportion of the solid, the porous structure may breakdown almost immediately to give a fine deposit of insoluble residue, and access of solvent to the solute will not be impeded. Generally, the process can be considered in the three parts.

- 1) The change of phase of the solute as it dissolves in the solvent.

- 2) Its diffusion through the solvent in the pores of the outside of the particle, and
- 3) The transfer of the solute from the solution in contact with the particles to the main bulk of the solution (Ojoh, 1992)

2.4.2 Processes of leaching

Leaching processes fall into two principal classes; those in which the leaching is accomplished by percolation (seeping of solvent through a bed of solids) and extracting liquid and subsequently separated from it.

Leaching operations are carried out under batch, semi-batch (unsteady state) as well as under completely continuous (steady state) conditions. The unsteady-state operations include those where the solids and liquids are contacted in purely batch wise fashion and also those where a batch of the solids contacted with a continually flowing stream of liquid (semi-batch method). The continuous steady state operation can be broadly classified into two major categories, according to whether it operates in stage wise or in a continuous contact fashion, viz, single-stage and counter-current multiple contact.

2.4.3 Mass transfer in leaching operation

Mass transfer rates within the porous residue are difficult to assess because it is impossible to define the shapes of the channels through which transfer must take place. It is possible however, to obtain an approximate indication of the rate of transfer from the particles to the bulk of the liquid, using the concept of a thin film as providing the resistance to transfer the equation for mass transfer may be written as

$$\frac{dm}{dt} = \frac{KA(CS - C)}{b} \dots\dots\dots(i)$$

The diffusion coefficient approximately equal to the liquid phase diffusivity. D_2 and it usually assumed constant for a batch process in which V , the total volume of solution, is assumed to remain constant, then:

$$dm = Vdc \dots \dots \dots (ii)$$

The time t taken for the concentration of the solution to rise from initial value to a value is found by integration on the assumption that both b and A remain constant

Rearranging equation (iii)

$$\int_{C_0}^C \frac{dc}{C_s - C} = \int_0^t \frac{(KA dt)}{Vb} \dots \dots \dots (iv)$$

$$\ln \frac{C_s - C_0}{C_s - C} = \frac{KA}{Vb} t \dots \dots \dots (v)$$

$$\frac{C_s - C}{C_s} = e^{-(KA/Vb)t} \dots \dots \dots (vi)$$

$$C = C_s(1 - e^{-(KA/Vb)t})$$

where A = area of the solid-liquid interface

b = effective thickness of the liquid film surrounding the particles.

C = concentration of the solute in the bulk of the solution at time t .

C_s = concentration of the saturated solution in the contact of the particle

M = mass of the solid transferred in time t .

2.4.4 Factors influencing rate of extraction

There are four main factors that influence the rate of extraction. (Egberongbe, 1998)

- i) Solvent
- ii) Particle size.
- iii) Agitation of the fluid
- iv) Temperature

2.4.4.1 Solvent

The liquid chosen should be a good selective solvent and its viscosity should be sufficiently low for it to circulate freely. Generally, a relatively pure solvent will be used initially but as some extraction process the concentration of solute will increase and the rate of extraction will progressively increase because the concentration gradient will be reduced, and also, because the solution will generally become more viscous. (Egberongbe, 1998)

2.4.4.12 Particle size

Particle size influences the extraction rate in a number of ways. The greater is the inter-facial areas between the solid and liquid and therefore the higher the rate of transfer of material and the smaller is the distance the solute must diffuse within the solid, on the other hand, the surface may not be so effectively used with a very fine material if circulation of the liquid is impede and separation of the particles from the liquid and drainage of the solid residue are more difficult. It is generally desirable that the range of particle size should be small so that each particle requires approximately the same time for extraction and in particular the production of a large amount of the material should be avoided as this may wedge in the interstices of the large particles and impede the flow of solvents. (Egberongbe, 1998)

2.4.4.3 Agitation of the fluid

Agitation of the solvent is important because these increase the eddy diffusion and therefore the transfer of material from the surface of the particle to the bulk of the solution. Further agitation of suspension of fine particle prevents sedimentation and more effectively used is made of the interfacial surface. (Egberongbe, 1998)

2.4.4.4 Temperature

The solubility of the material which is being extracted will increase with temperature to give a higher rate of extraction. Further, the diffusion coefficient will be expected to increase with rise in temperature and this will also increase the rate of extraction in some cases. The limit temperature is determined by secondary consideration, as for example the necessity to avoid enzyme action during the extraction of sugar. (Egberongbe, 1998)

2.5 Processing Technologies

2.5.1 Description of Various Processing Technologies of Cocoa Pod Husks

Cocoa pod husk is one of the by-products of cocoa constituents about 56% of the pod. The ash from the cocoa pod husk consists of oxides of calcium, magnesium, potassium, phosphorous and silicon. Potassium oxide, which is about 2.85% to 5.87%, is the only soluble oxide present in the cocoa pod husk ash and so leaching of caustic potash (KOH) can be easily achieved. Caustic potash is on high demand in the laboratory and industries, so there is need to produce it and since cocoa pod husk contains high percentage of K_2O , it can be the extraction of K_2O from cocoa pod husk.

The process used for this extraction is leaching and there are three operational methods available that is batch, semi-batch and continuous method.

2.5.1.1 Batch method

In this method, all the phases are stationary from a point of view outside the apparatus, which is no flow in or out through there may be relative motion within. This method is used in small scale industries where the raw materials is not much or

when the yields and quality of products cannot be achieved by continues method because of parameters such as very low rates and long residence time in the process equipment.

2.5.1.2 Semi batch

This method is similar to batch but the extraction process is repeated for more times with specific volume of water for each process. It gives more yield than batch method though more expensive because of the repeated processes and are usually used in the absence of continues and batch method.

2.5.1.3 Continuous method

There is constant flow of raw materials into the apparatus. It is processed by continuous passage of process water and removed continuously; there is continuous flow within the apparatus, constant concentration of the feed stream and unchanging conditions of temperature and pressure. This method makes it possible to obtain a high yield and uniform product quality. This method is used in this project work using soxhlet apparatus. There are four main steps involved in the production of KOH from cocoa pod husk.

- i. Preparation of the solid for leaching by drying, grinding, ashing and weighing of the cocoa pod husk.
- ii. Contact of liquid solvent with the solid to effect transfer of solvent from the solid back to the solvent this is leaching and a soxhlet apparatus is used.
- iii. Filtration involves the removal of impurities from the obtained solution.
- iv. Evaporation of the solution results in recovery of a residue that is the KOH product.

2.5.2 Detail description of the selected technology

The descriptions of the various processes involved in the continuous method of production of caustic potash from cocoa pod husk are as discussed below.

2.5.2.1 Drying of the fresh cocoa pod husk

After removing the seeds from the cocoa plant, the cocoa pod husk was passed to the dryer where it was dried so that it could be very easy to crush the husk. The temperature of the dryer was set to 130°C. All the moisture present evaporated at this temperature leaving the husk with very little or no moisture.

2.5.2.2 Ashing process

The ashing process took place inside the furnace where the chemical material was burnt leaving the non-combustible ash. The operating temperature of the furnace used for the ashing process was 600°C.

2.5.2.3 Leaching of the potash

Leaching is the removal of a soluble material from an insoluble permeable solid. The leaching process of this design work was carried out to dissolve the soluble part of the non-combustible ash leaving the other components undissolved in the mixture to be filtrated out later.

2.5.2.4 Filtration of the mixture

The insoluble-in-water materials were separated from the soluble one by passing the mixture through a filter where the extract remained on the screen while the filtrate passed down so that it could be collected.

2.5.2.5 Evaporation of potash solution

This is the last operation of the production of caustic potash from cocoa pod husk. It is obvious that the caustic potash is in aqueous form after the filtration. So, in order to obtain a high concentration of the caustic potash, it was necessary to remove the water contained in it. This was achieved by using a single effect evaporator where the water was evaporated leaving the highly-concentrated caustic potash as the final product.

2.5.2.6 Storage of caustic potash

The caustic potash produced is stored in a tank where it is taken for use anytime. The storage tank is made of stainless steel so the corrosive nature of the potash can be resisted.

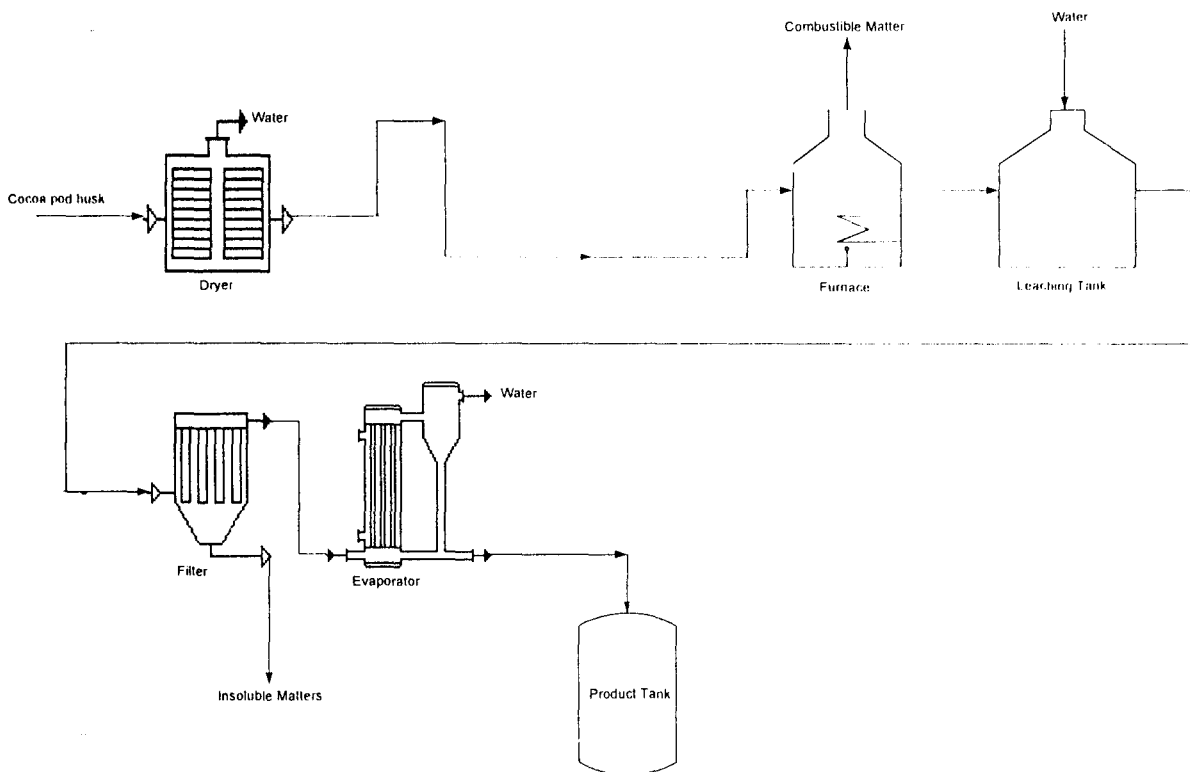


Fig. 2.1: Flow sheet for the production of caustic potash from cocoa pod husk

2.5.3 Justification of the selected technology

The selected technology of the production of caustic potash from cocoa pod husk in this project is the continuous method of leaching. This is based on the fact that it is the method used for large scale production.

CHAPTER THREE

MATERIAL BALANCES

100.0000 kg/day of cocoa pod husk

3.1: Composition of cocoa pod husk

	wt%
dry matter	28.3743
ash	0.5695
protein	4.7577
carbohydrate	0.0736
cellulose fibre	5.3027
cellulose-free extract	16.6446
cellulose	20.7247
cellulose	0.0884
cellulose	2.6022
cellulose	0.0982
Total	100.0000

Source: Egberongbe, 1998

Table 3.1 above, ash is taken to be the non-combustible material while the remaining components apart from water are grouped to be combustible materials.

3.2: Cocoa pod composition after grouping of the components

	wt%
combustible	28.3743
non-combustible	66.3230
cellulose	5.3027
Total	100.0000

In Egberongbe (1998), the composition of ash is as shown in Table 3.3 below:

3.3: Ash composition

	wt%
SiO ₂	7.7530
Al ₂ O ₃	6.8331
Fe ₂ O ₃	77.1353
CaO	6.4389
MgO	1.8397
Total	100.0000

Generally, the composition of the cocoa pod husk is taken as given below:

Composition of cocoa pod husk	wt%	kg/kmol	kg/m ³
dry matter	28.3743	18.0000	1000.0000
non-combustible	66.3230	12.0000	2260.0000
cellulose	0.4111	56.0000	2620.0000
cellulose	0.3623	40.0000	3650.0000
cellulose	4.0903	94.0000	2320.0000
cellulose	0.3414	142.0000	2387.0000
cellulose	0.0976	60.0000	2250.0000
Total	100.0000		

Material balances across the dryer:

Operation: Removal of water

Assumption: 100.0000 water removal

Comp.	IN		Addition		OUT		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
dry matter	28.3743	28.3743	0.0000	#DIV/0!	28.3743	100.0000	0.0000	0.0000
non-combustible	66.3230	66.3230	0.0000	#DIV/0!	0.0000	0.0000	66.3230	92.5967
cellulose	0.4111	0.4111	0.0000	#DIV/0!	0.0000	0.0000	0.4111	0.5740
cellulose	0.3623	0.3623	0.0000	#DIV/0!	0.0000	0.0000	0.3623	0.5059
cellulose	4.0903	4.0903	0.0000	#DIV/0!	0.0000	0.0000	4.0903	5.7106
cellulose	0.3414	0.3414	0.0000	#DIV/0!	0.0000	0.0000	0.3414	0.4767
cellulose	0.0976	0.0976	0.0000	#DIV/0!	0.0000	0.0000	0.0976	0.1362
Total	100.0000	100.0000	0.0000	#DIV/0!	28.3743	100.0000	71.6257	100.0000

Material balances across the furnace
 Operation: Combustion of the cocoa pod husk
 Assumption: 100.0000 kg of the combustible materials

	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Combustible	66.3230	92.5967	0.0000	#DIV/0!	66.3230	100.0000	0.0000	0.0000
	0.4111	0.5740	0.0000	#DIV/0!	0.0000	0.0000	0.4111	7.7530
	0.3623	0.5059	0.0000	#DIV/0!	0.0000	0.0000	0.3623	6.8331
	4.0903	5.7106	0.0000	#DIV/0!	0.0000	0.0000	4.0903	77.1353
	0.3414	0.4767	0.0000	#DIV/0!	0.0000	0.0000	0.3414	6.4389
	0.0976	0.1362	0.0000	#DIV/0!	0.0000	0.0000	0.0976	1.8397
Total	71.6257	100.0000	0.0000	#DIV/0!	66.3230	100.0000	5.3027	100.0000

Material balances across the leaching tank
 Operation: Dissolution of the potassium oxide using water
 Assumption: Water added is = 150.0000 kg entering the leaching tank

	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Combustible	0.0000	0.0000	7.9540	100.0000	0.0000	#DIV/0!	7.9540	60.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000
	0.4111	7.7530	0.0000	0.0000	0.0000	#DIV/0!	0.4111	3.1012
	0.3623	6.8331	0.0000	0.0000	0.0000	#DIV/0!	0.3623	2.7332
	4.0903	77.1353	0.0000	0.0000	0.0000	#DIV/0!	4.0903	30.8541
	0.3414	6.4389	0.0000	0.0000	0.0000	#DIV/0!	0.3414	2.5756
	0.0976	1.8397	0.0000	0.0000	0.0000	#DIV/0!	0.0976	0.7359
Total	5.3027	100.0000	7.9540	100.0000	0.0000	#DIV/0!	13.2567	100.0000

Material balances across the filter
 Operation: Separation of the insoluble materials from the caustic potash
 Assumption: 100.0000 kg of insoluble materials are removed

	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Combustible	7.9540	60.0000	0.0000	#DIV/0!	0.0000	0.0000	7.9540	66.0399
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
	0.4111	3.1012	0.0000	#DIV/0!	0.4111	33.9080	0.0000	0.0000
	0.3623	2.7332	0.0000	#DIV/0!	0.3623	29.8851	0.0000	0.0000
	4.0903	30.8541	0.0000	#DIV/0!	0.0000	0.0000	4.0903	33.9601
	0.3414	2.5756	0.0000	#DIV/0!	0.3414	28.1609	0.0000	0.0000
	0.0976	0.7359	0.0000	#DIV/0!	0.0976	8.0460	0.0000	0.0000
Total	13.2567	100.0000	0.0000	#DIV/0!	1.2124	100.0000	12.0443	100.0000

Material balances across the evaporator
 Operation: Removal of water
 Assumption: 99.4806 kg of water is removed

	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
Combustible	7.9540	66.0399	0.0000	#DIV/0!	7.9127	100.0000	0.0413	1.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
	4.0903	33.9601	0.0000	#DIV/0!	0.0000	0.0000	4.0903	99.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
Total	12.0443	100.0000	0.0000	#DIV/0!	7.9127	100.0000	4.1316	100.0000

Material balances across the storage tank
 Operation: Reduction of temperature of the product
 Assumption: 100% material recovery

	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
kg/day	0.0413	1.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0413	1.0000
wt%	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
	4.0903	99.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	4.0903	99.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
Total	4.1316	100.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	4.1316	100.0000

Calculation of scale up factor
 Assumption: 1.0000 ton/day = 1016.0600 kg/day
 Reaction rate of caustic potash = 3.0000 ton/day which is equal to 3048.1800 kg/day
 Caustic potash obtained from the basis = 4.1316 kg/day
 Therefore, the scale-up factor is given equal to = 737.7777

Material Balances

Material balances across the dryer
 Operation: Removal of water
 Assumption: 100.0000 water removal

	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
kg/day	20933.9475	28.3743	0.0000	#DIV/0!	20933.9475	100.0000	0.0000	0.0000
wt%	48931.6080	66.3230	0.0000	#DIV/0!	0.0000	0.0000	48931.6080	92.5967
	303.3120	0.4111	0.0000	#DIV/0!	0.0000	0.0000	303.3120	0.5740
	267.3258	0.3623	0.0000	#DIV/0!	0.0000	0.0000	267.3258	0.5059
	3017.6970	4.0903	0.0000	#DIV/0!	0.0000	0.0000	3017.6970	5.7106
	251.9032	0.3414	0.0000	#DIV/0!	0.0000	0.0000	251.9032	0.4767
	71.9723	0.0976	0.0000	#DIV/0!	0.0000	0.0000	71.9723	0.1362
Total	73777.7658	100.0000	0.0000	#DIV/0!	20933.9475	100.0000	52843.8183	100.0000

Material balances across the furnace
 Operation: Combustion of the cocoa pod husk
 Assumption: 100.0000 the combustible materials

	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
kg/day	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
wt%	48931.6080	92.5967	0.0000	#DIV/0!	48931.6080	100.0000	0.0000	0.0000
	303.3120	0.5740	0.0000	#DIV/0!	0.0000	0.0000	303.3120	7.7530
	267.3258	0.5059	0.0000	#DIV/0!	0.0000	0.0000	267.3258	6.8331
	3017.6970	5.7106	0.0000	#DIV/0!	0.0000	0.0000	3017.6970	77.1353
	251.9032	0.4767	0.0000	#DIV/0!	0.0000	0.0000	251.9032	6.4389
	71.9723	0.1362	0.0000	#DIV/0!	0.0000	0.0000	71.9723	1.8397
Total	52843.8183	100.0000	0.0000	#DIV/0!	48931.6080	100.0000	3912.2103	100.0000

Material balances across the leaching tank
 Operation: Dissolution of the potassium oxide using water
 Assumption: Water added is = 150.0000 kg entering the leaching tank

Comp.	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
O	0.0000	0.0000	5868.3154	100.0000	0.0000	#DIV/0!	5868.3154	60.0000
Combustible	0.0000	0.0000	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000
CO	303.3120	7.7530	0.0000	0.0000	0.0000	#DIV/0!	303.3120	3.1012
CO2	267.3258	6.8331	0.0000	0.0000	0.0000	#DIV/0!	267.3258	2.7332
H2O	3017.6970	77.1353	0.0000	0.0000	0.0000	#DIV/0!	3017.6970	30.8541
H2SO5	251.9032	6.4389	0.0000	0.0000	0.0000	#DIV/0!	251.9032	2.5756
H2SO2	71.9723	1.8397	0.0000	0.0000	0.0000	#DIV/0!	71.9723	0.7359
Total	3912.2103	100.0000	5868.3154	100.0000	0.0000	#DIV/0!	9780.5257	100.0000

Material balances across the filter
 Operation: Separation of the insoluble materials from the caustic potash
 Assumption: 100.0000 kg insoluble materials are removed

Comp.	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
O	5868.3154	60.0000	0.0000	#DIV/0!	0.0000	0.0000	5868.3154	66.0399
Combustible	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
CO	303.3120	3.4012	0.0000	#DIV/0!	303.3120	33.9080	0.0000	0.0000
CO2	267.3258	2.7332	0.0000	#DIV/0!	267.3258	29.8851	0.0000	0.0000
H2O	3017.6970	30.8541	0.0000	#DIV/0!	0.0000	0.0000	3017.6970	33.9601
H2SO5	251.9032	2.5756	0.0000	#DIV/0!	251.9032	28.1609	0.0000	0.0000
H2SO2	71.9723	0.7359	0.0000	#DIV/0!	71.9723	8.0460	0.0000	0.0000
Total	9780.5257	100.0000	0.0000	#DIV/0!	894.5133	100.0000	8886.0125	100.0000

Material balances across evaporator
 Operation: Removal of water
 Assumption: 99.4806 kg water is removed

Comp.	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
O	5868.3154	66.0399	0.0000	#DIV/0!	5837.8325	100.0000	30.4830	1.0000
Combustible	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
H2O	3017.6970	33.9601	0.0000	#DIV/0!	0.0000	0.0000	3017.6970	99.0000
H2SO5	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
H2SO2	0.0000	0.0000	0.0000	#DIV/0!	0.0000	0.0000	0.0000	0.0000
Total	8886.0125	100.0000	0.0000	#DIV/0!	5837.8325	100.0000	3048.1800	100.0000

Material balances across the storage tank
 Operation: Reduction of temperature of the product
 Assumption: 0% material recovery

Comp.	IN				OUT			
	Input		Addition		Loss		Output	
	kg/day	wt%	kg/day	wt%	kg/day	wt%	kg/day	wt%
O	30.4830	1.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	30.4830	1.0000
Combustible	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
CO	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
H2O	3017.6970	99.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	3017.6970	99.0000
H2SO5	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
H2SO2	0.0000	0.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	0.0000	0.0000
Total	3048.1800	100.0000	0.0000	#DIV/0!	0.0000	#DIV/0!	3048.1800	100.0000

CHAPTER FOUR

4.0 ENERGY BALANCES

Components and their molecular weights:

$$\begin{array}{c}
 \left(\begin{array}{c}
 \text{H}_2\text{O} \\
 \text{Combustible} \\
 \text{CaO} \\
 \text{MgO} \\
 \text{K}_2\text{O} \\
 \text{P}_2\text{O}_5 \\
 \text{SiO}_2
 \end{array} \right)
 \end{array}
 \quad
 \text{mw} :=
 \quad
 \begin{array}{c}
 \left(\begin{array}{c}
 18.0000 \\
 12.0000 \\
 56.0000 \\
 40.0000 \\
 94.0000 \\
 142.0000 \\
 60.0000
 \end{array} \right)
 \cdot \frac{\text{kg}}{\text{kmol}}$$

Thermodynamic Properties:

$$\text{coeff} := \begin{pmatrix}
 18.2964 & 0.47212 & -0.0013388 & 1.3142 \cdot 10^{-6} & -285.84 & 40.65 \\
 11.18 & 0.01095 & -489100 & 0 & 0 & 0 \\
 41.84 & 0.0203 & -452000 & 0 & -635.6 & 0 \\
 45.44 & 0.005008 & -873200 & 0 & -601.83 & 0 \\
 37.4332 & 0.001077 & -0.00000035 & 3.9 \cdot 10^{-11} & -436.68 & 0 \\
 -9.928 & 0.950497 & -0.00107424 & 4.49929 \cdot 10^{-7} & -1506 & 0 \\
 36.07 & 0.0397 & -0.0000288 & 7.87 \cdot 10^{-9} & -851 & 0
 \end{pmatrix}
 \begin{array}{c}
 \left(\begin{array}{c}
 \text{H}_2\text{O} \\
 \text{Combustible} \\
 \text{CaO} \\
 \text{MgO} \\
 \text{K}_2\text{O} \\
 \text{P}_2\text{O}_5 \\
 \text{SiO}_2
 \end{array} \right)$$

(Himmelblau, 1998)

$$a := \frac{\text{coeff} \langle 1 \rangle}{\text{mw}} \cdot \frac{\text{kJ}}{\text{kmol} \cdot \text{K}}$$

$$b := \frac{\text{coeff} \langle 2 \rangle}{\text{mw}} \cdot \frac{\text{kJ}}{\text{kmol} \cdot \text{K}^2}$$

$$c := \frac{\text{coeff} \langle 3 \rangle}{\text{mw}} \cdot \frac{\text{kJ}}{\text{kmol} \cdot \text{K}^3}$$

$$d := \frac{\text{coeff} \langle 4 \rangle}{\text{mw}} \cdot \frac{\text{kJ}}{\text{kmol} \cdot \text{K}^4}$$

$$H_r := \frac{\text{coeff} \langle 5 \rangle}{\text{mw}} \cdot 10^3 \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$H_v := \frac{\text{coeff} \langle 6 \rangle}{\text{mw}} \cdot \frac{\text{kJ}}{\text{kmol}}$$

Reference temperature: $T_r := 298 \cdot \text{K}$

(Perry, 1998)

4.1 Energy Balances on Dryer

Material flows of the dryer

$$m' := \begin{pmatrix} 20933.9475 & 0.0000 & 20933.9475 & 0.0000 \\ 48931.6080 & 0.0000 & 0.0000 & 48931.6080 \\ 303.3120 & 0.0000 & 0.0000 & 303.3120 \\ 267.3258 & 0.0000 & 0.0000 & 267.3258 \\ 3017.6970 & 0.0000 & 0.0000 & 3017.6970 \\ 251.9032 & 0.0000 & 0.0000 & 251.9032 \\ 71.9723 & 0.0000 & 0.0000 & 71.9723 \end{pmatrix} \cdot \frac{\text{kg}}{\text{day}}$$

Temperature

$$\begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 303 \\ 0 \\ 373 \\ 373 \end{pmatrix} \cdot \text{K}$$

$$m'_{i_1} := m' \langle 1 \rangle$$

$$m'_{i_a} := m' \langle 2 \rangle$$

$$m'_{i_l} := m' \langle 3 \rangle$$

$$m'_{i_o} := m' \langle 4 \rangle$$

$$T_i = 303 \text{ K}$$

$$T_a = 0 \text{ K}$$

$$T_l = 373 \text{ K}$$

$$T_o = 373 \text{ K}$$

Energy In

Energy of input

$$\begin{aligned} \Delta H_i := & m'_{i_1} \cdot \left[\int_{T_r}^{T_i} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{i_3} \cdot \left[\int_{T_r}^{T_i} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{i_5} \cdot \left[\int_{T_r}^{T_i} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{i_7} \cdot \int_{T_r}^{T_i} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_i = -9.042 \times 10^{14} \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy in: } \Delta H_{in} := \Delta H_i$$

$$\Delta H_{in} = -9.042 \times 10^{14} \frac{\text{kJ}}{\text{day}}$$

Energy Out

Energy of Loss

$$T_1 = 373 \text{ K}$$

$$\begin{aligned} \Delta H_1 := & m'_{l_1} \cdot \left[\int_{T_r}^{T_1} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{l_2} \cdot \left[\int_{T_r}^{T_1} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{l_3} \cdot \left[\int_{T_r}^{T_1} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{l_4} \cdot \left[\int_{T_r}^{T_1} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{l_5} \cdot \left[\int_{T_r}^{T_1} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{l_6} \cdot \left[\int_{T_r}^{T_1} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{l_7} \cdot \int_{T_r}^{T_1} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_1 = 6.596 \times 10^6 \frac{\text{kJ}}{\text{day}}$$

Energy of Output

$$T_0 = 373 \text{ K}$$

$$\begin{aligned} \Delta H_0 := & m'_{o_1} \cdot \left[\int_{T_r}^{T_0} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_0} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{o_3} \cdot \left[\int_{T_r}^{T_0} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_0} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{o_5} \cdot \left[\int_{T_r}^{T_0} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_0} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{o_7} \cdot \int_{T_r}^{T_0} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_0 = -1.698 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy out: } \Delta H_{\text{out}} := \Delta H_1 + \Delta H_0$$

$$\Delta H_{\text{out}} = -1.698 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

$$\text{Heat load: } Q_1 := \Delta H_{\text{out}} - \Delta H_{\text{in}}$$

$$Q_1 = 1.607 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

4.2 Energy Balances on Furnace

Material flows of the furnace

$$m' := \begin{pmatrix} 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 48931.6080 & 0.0000 & 48931.6080 & 0.0000 \\ 303.3120 & 0.0000 & 0.0000 & 303.3120 \\ 267.3258 & 0.0000 & 0.0000 & 267.3258 \\ 3017.6970 & 0.0000 & 0.0000 & 3017.6970 \\ 251.9032 & 0.0000 & 0.0000 & 251.9032 \\ 71.9723 & 0.0000 & 0.0000 & 71.9723 \end{pmatrix} \cdot \frac{\text{kg}}{\text{day}}$$

Temperature

$$\begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 373 \\ 0 \\ 500 \\ 500 \end{pmatrix} \cdot \text{K}$$

$$m'_{i_1} := m' \langle 1 \rangle$$

$$m'_{i_2} := m' \langle 2 \rangle$$

$$m'_{i_3} := m' \langle 3 \rangle$$

$$m'_{i_4} := m' \langle 4 \rangle$$

$$T_i = 373 \text{ K}$$

$$T_a = 0 \text{ K}$$

$$T_l = 500 \text{ K}$$

$$T_o = 500 \text{ K}$$

Energy In

Energy of input

$$\begin{aligned} \Delta H_i := & m'_{i_1} \cdot \left[\int_{T_r}^{T_i} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{i_3} \cdot \left[\int_{T_r}^{T_i} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{i_5} \cdot \left[\int_{T_r}^{T_i} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{i_7} \cdot \int_{T_r}^{T_i} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_i = 1.698 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy in: } \Delta H_{\text{in}} := \Delta H_i$$

$$\Delta H_{\text{in}} = 1.698 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

Energy Out

Energy of Loss

$$T_1 = 500 \text{ K}$$

$$\begin{aligned} \Delta H_1 := & m'_{l_1} \cdot \left[\int_{T_r}^{T_1} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{l_2} \cdot \left[\int_{T_r}^{T_1} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{l_3} \cdot \left[\int_{T_r}^{T_1} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{l_4} \cdot \left[\int_{T_r}^{T_1} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{l_5} \cdot \left[\int_{T_r}^{T_1} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{l_6} \cdot \left[\int_{T_r}^{T_1} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{l_7} \cdot \int_{T_r}^{T_1} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_1 = -6.551 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

Energy of Output

$$T_0 = 500 \text{ K}$$

$$\begin{aligned} \Delta H_0 := & m'_{o_1} \cdot \left[\int_{T_r}^{T_0} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_0} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{o_3} \cdot \left[\int_{T_r}^{T_0} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_0} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{o_5} \cdot \left[\int_{T_r}^{T_0} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_0} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{o_7} \cdot \int_{T_r}^{T_0} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_0 = -2.721 \times 10^{14} \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy out: } \Delta H_{\text{out}} := \Delta H_1 + \Delta H_0$$

$$\Delta H_{\text{out}} = -6.578 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

$$\text{Heat load: } Q_3 := \Delta H_{\text{out}} - \Delta H_{\text{in}}$$

$$Q_3 = 4.88 \times 10^{16} \frac{\text{kJ}}{\text{day}}$$

4.3 Energy Balances on Leaching Tank

Material flows of the leaching tank

$$m' := \begin{pmatrix} 0.0000 & 5868.3154 & 0.0000 & 5868.3154 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 303.3120 & 0.0000 & 0.0000 & 303.3120 \\ 267.3258 & 0.0000 & 0.0000 & 267.3258 \\ 3017.6970 & 0.0000 & 0.0000 & 3017.6970 \\ 251.9032 & 0.0000 & 0.0000 & 251.9032 \\ 71.9723 & 0.0000 & 0.0000 & 71.9723 \end{pmatrix} \cdot \frac{\text{kg}}{\text{day}}$$

Temperature

$$\begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} = \begin{pmatrix} 500 \\ 303 \\ 0 \\ 370 \end{pmatrix} \cdot \text{K}$$

$$m'_i := m' \langle 1 \rangle$$

$$m'_a := m' \langle 2 \rangle$$

$$m'_l := m' \langle 3 \rangle$$

$$m'_o := m' \langle 4 \rangle$$

$$T_i = 500 \text{ K}$$

$$T_a = 303 \text{ K}$$

$$T_l = 0 \text{ K}$$

$$T_o = 370 \text{ K}$$

Energy In

Energy of input

$$\begin{aligned} \Delta H_i := & m'_{i_1} \cdot \left[\int_{T_r}^{T_i} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{i_3} \cdot \left[\int_{T_r}^{T_i} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{i_5} \cdot \left[\int_{T_r}^{T_i} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{i_7} \cdot \int_{T_r}^{T_i} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_i = -2.721 \times 10^{14} \frac{\text{kJ}}{\text{day}}$$

Energy of addition

$$T_a = 303 \text{ K}$$

$$\begin{aligned} \Delta H_a := & m'_{a_1} \cdot \left[\int_{T_r}^{T_a} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{a_2} \cdot \left[\int_{T_r}^{T_a} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{a_3} \cdot \left[\int_{T_r}^{T_a} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{a_4} \cdot \left[\int_{T_r}^{T_a} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{a_5} \cdot \left[\int_{T_r}^{T_a} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{a_6} \cdot \left[\int_{T_r}^{T_a} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{a_7} \cdot \int_{T_r}^{T_a} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_a = 1.222 \times 10^5 \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy in: } \Delta H_{\text{in}} := \Delta H_i + \Delta H_a$$

$$\Delta H_{\text{in}} = -2.721 \times 10^{14} \frac{\text{kJ}}{\text{day}}$$

Energy Out

Energy of Output

$$T_o = 370 \text{ K}$$

$$\begin{aligned} \Delta H_o := & m'_{o_1} \cdot \left[\int_{T_r}^{T_o} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{o_3} \cdot \left[\int_{T_r}^{T_o} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{o_5} \cdot \left[\int_{T_r}^{T_o} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{o_7} \cdot \int_{T_r}^{T_o} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_o = -6.679 \times 10^{13} \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy out: } \Delta H_{\text{out}} := \Delta H_o$$

$$\Delta H_{\text{out}} = -6.679 \times 10^{13} \frac{\text{kJ}}{\text{day}}$$

$$\text{Heat load: } Q_4 := \Delta H_{\text{out}} - \Delta H_{\text{in}}$$

$$Q_4 = 2.053 \times 10^{14} \frac{\text{kJ}}{\text{day}}$$

4.5 Energy Balances on Filter

Material flows of the filter

$$m' := \begin{pmatrix} 5868.3154 & 0.0000 & 0.0000 & 5868.3154 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 303.3120 & 0.0000 & 303.3120 & 0.0000 \\ 267.3258 & 0.0000 & 267.3258 & 0.0000 \\ 3017.6970 & 0.0000 & 0.0000 & 3017.6970 \\ 251.9032 & 0.0000 & 251.9032 & 0.0000 \\ 71.9723 & 0.0000 & 71.9723 & 0.0000 \end{pmatrix} \cdot \frac{\text{kg}}{\text{day}}$$

Temperature

$$\begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 370 \\ 0 \\ 300 \\ 350 \end{pmatrix} \cdot \text{K}$$

$$m'_i := m' \langle 1 \rangle$$

$$m'_a := m' \langle 2 \rangle$$

$$m'_l := m' \langle 3 \rangle$$

$$m'_o := m' \langle 4 \rangle$$

$$T_i = 370 \text{ K}$$

$$T_a = 0 \text{ K}$$

$$T_l = 300 \text{ K}$$

$$T_o = 350 \text{ K}$$

Energy In

Energy of input

$$\begin{aligned} \Delta H_i := & m'_{i_1} \cdot \left[\int_{T_r}^{T_1} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_1} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{i_3} \cdot \left[\int_{T_r}^{T_1} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_1} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{i_5} \cdot \left[\int_{T_r}^{T_1} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_1} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{i_7} \cdot \int_{T_r}^{T_1} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$
$$\Delta H_i = -6.679 \times 10^{13} \frac{\text{kJ}}{\text{day}}$$

Total energy in: $\Delta H_{in} := \Delta H_i$

$$\Delta H_{in} = -6.679 \times 10^{13} \frac{\text{kJ}}{\text{day}}$$

Energy Out

Energy of Loss

$$T_1 = 300 \text{ K}$$

$$\begin{aligned} \Delta H_l := & m'_{l_1} \cdot \left[\int_{T_r}^{T_1} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{l_2} \cdot \left[\int_{T_r}^{T_1} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{l_3} \cdot \left[\int_{T_r}^{T_1} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{l_4} \cdot \left[\int_{T_r}^{T_1} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{l_5} \cdot \left[\int_{T_r}^{T_1} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{l_6} \cdot \left[\int_{T_r}^{T_1} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{l_7} \cdot \int_{T_r}^{T_1} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$
$$\Delta H_l = 1.481 \times 10^{12} \frac{\text{kJ}}{\text{day}}$$

Energy of Output

$$T_o = 350 \text{ K}$$

$$\begin{aligned} \Delta H_o := & m'_{o_1} \cdot \left[\int_{T_r}^{T_o} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{o_2} \cdot \left[\int_{T_r}^{T_o} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{o_3} \cdot \left[\int_{T_r}^{T_o} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{o_4} \cdot \left[\int_{T_r}^{T_o} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{o_5} \cdot \left[\int_{T_r}^{T_o} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{o_6} \cdot \left[\int_{T_r}^{T_o} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{o_7} \cdot \int_{T_r}^{T_o} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_o = 1.341 \times 10^9 \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy out: } \Delta H_{\text{out}} := \Delta H_i + \Delta H_o$$

$$\Delta H_{\text{out}} = -1.481 \times 10^{12} \frac{\text{kJ}}{\text{day}}$$

$$\text{Heat load: } Q_5 := \Delta H_{\text{out}} - \Delta H_i$$

$$Q_5 = 6.531 \times 10^{13} \frac{\text{kJ}}{\text{day}}$$

4.6 Energy Balances on Evaporator

Material flows of the evaporator

$$m' := \begin{pmatrix} 5868.3154 & 0.0000 & 5837.8325 & 30.4830 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 3017.6970 & 0.0000 & 0.0000 & 3017.6970 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{pmatrix} \cdot \frac{\text{kg}}{\text{day}}$$

Temperature

$$\begin{pmatrix} T_i \\ T_a \\ T_l \\ T_o \end{pmatrix} := \begin{pmatrix} 350 \\ 0 \\ 317 \\ 310 \end{pmatrix} \cdot \text{K}$$

$$m'_i := m' \langle 1 \rangle$$

$$m'_a := m' \langle 2 \rangle$$

$$m'_l := m' \langle 3 \rangle$$

$$m'_o := m' \langle 4 \rangle$$

$$T_i = 350 \text{ K}$$

$$T_a = 0 \text{ K}$$

$$T_l = 317 \text{ K}$$

$$T_o = 310 \text{ K}$$

Energy In

Energy of input

$$\begin{aligned} \Delta H_i := & m'_{i_1} \cdot \left[\int_{T_r}^{T_i} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{i_2} \cdot \left[\int_{T_r}^{T_i} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{i_3} \cdot \left[\int_{T_r}^{T_i} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{i_4} \cdot \left[\int_{T_r}^{T_i} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{i_5} \cdot \left[\int_{T_r}^{T_i} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{i_6} \cdot \left[\int_{T_r}^{T_i} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{i_7} \cdot \int_{T_r}^{T_i} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$
$$\Delta H_i = 1.341 \times 10^6 \frac{\text{kJ}}{\text{day}}$$

Total energy in: $\Delta H_{in} := \Delta H_i$

$$\Delta H_{in} = 1.341 \times 10^6 \frac{\text{kJ}}{\text{day}}$$

Energy Out

Energy of Loss

$$T_l = 317 \text{ K}$$

$$\begin{aligned} \Delta H_l := & m'_{l_1} \cdot \left[\int_{T_r}^{T_l} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{l_2} \cdot \left[\int_{T_r}^{T_l} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{l_3} \cdot \left[\int_{T_r}^{T_l} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{l_4} \cdot \left[\int_{T_r}^{T_l} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{l_5} \cdot \left[\int_{T_r}^{T_l} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{l_6} \cdot \left[\int_{T_r}^{T_l} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{l_7} \cdot \int_{T_r}^{T_l} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$
$$\Delta H_l = 4.627 \times 10^5 \frac{\text{kJ}}{\text{day}}$$

Energy of Output

$$T_0 = 310 \text{ K}$$

$$\begin{aligned} \Delta H_0 := & m'_{O_1} \cdot \left[\int_{T_r}^{T_0} (a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3) dT \right] + m'_{O_2} \cdot \left[\int_{T_r}^{T_0} (a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3) dT \right] \dots \\ & + m'_{O_3} \cdot \left[\int_{T_r}^{T_0} (a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3) dT \right] + m'_{O_4} \cdot \left[\int_{T_r}^{T_0} (a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3) dT \right] \dots \\ & + m'_{O_5} \cdot \left[\int_{T_r}^{T_0} (a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3) dT \right] + m'_{O_6} \cdot \left[\int_{T_r}^{T_0} (a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3) dT \right] \dots \\ & + m'_{O_7} \cdot \int_{T_r}^{T_0} (a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3) dT \end{aligned}$$

$$\Delta H_0 = 1.606 \times 10^4 \frac{\text{kJ}}{\text{day}}$$

$$\text{Total energy out: } \Delta H_{\text{out}} := \Delta H_1 + \Delta H_0$$

$$\Delta H_{\text{out}} = 4.788 \times 10^5 \frac{\text{kJ}}{\text{day}}$$

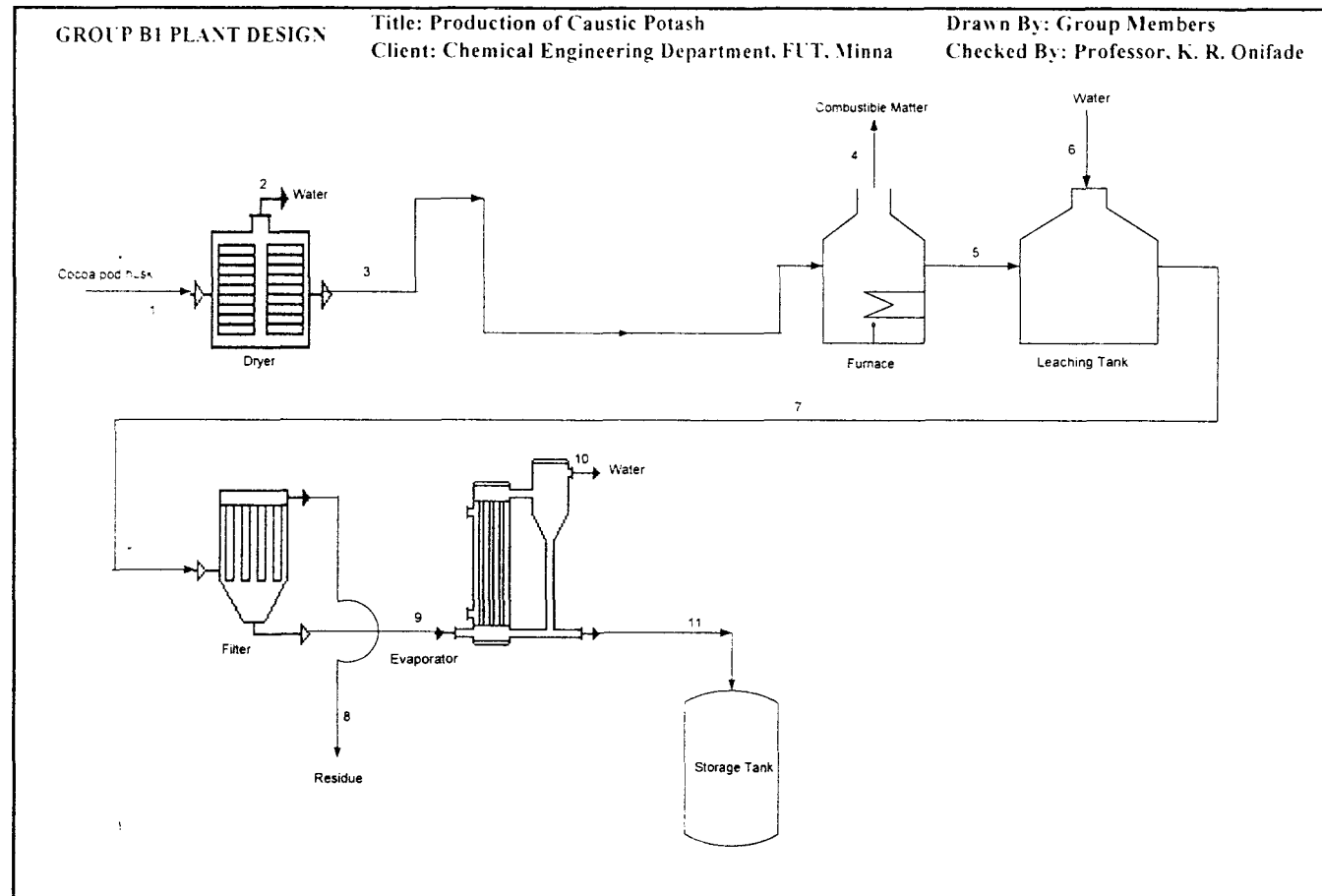
$$\text{Heat load: } Q_6 := \Delta H_{\text{out}} - \Delta H_{\text{in}}$$

$$Q_6 = -8.626 \times 10^5 \frac{\text{kJ}}{\text{day}}$$

CHAPTER FIVE

5.0 FLOW SHEET/DIAGRAM

5.1 FLOWSHEETING





TEAM LND
 Calgary, Alberta
 CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3 1\Cases\Dryer.hsc

Unit Set: SI

Date/Time: Sun Oct 29 09:43:26 2006

Heater: Dryer

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
Feed 1	

Outlet Stream

STREAM NAME	TO UNIT OPERATION
Product 1	

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Q1	

PARAMETERS

Pressure Drop:	15.00 kPa *	Duty:	4.800e+004 kJ/h *	Volume:	0.1000 m3
Function:	Not Selected	Zones:	1		

User Variables

SIMPLE HEAT LOSS PARAMETERS

Overall U (kJ/h-m2-C)	54.00	Ambient Temperature (C)	25.00	Overall Heat Transfer Area (m2) --	Heat Flow (kJ/h)
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PROPERTIES

Feed 1

	Overall	Liquid Phase	Aqueous Phase	Solid Phase
Vapour/Phase Fraction	0.0000	0.0025	0.2273	0.7701
Temperature: (C)	30.00 *	30.00	30.00	30.00
Pressure: (kPa)	101.0 *	101.0	101.0	101.0
Molar Flow (kgmole/h)	7.170	1.811e-002	1.630	5.522
Mass Flow (kg/h)	100.0 *	0.3623	33.31	66.32
Std Ideal Liq Vol Flow (m3/h)	7.103e-002	1.062e-004	3.054e-002	4.039e-002
Molar Enthalpy (kJ/kgmole)	-5.436e+004	-3.650e+004	-2.389e+005	47.01
Mass Enthalpy (kJ/kg)	-3897	-1825	-1.169e+004	3.914
Molar Entropy (kJ/kgmole-C)	-3806	-81.34	-1.676e+004	5.227
Mass Entropy (kJ/kg-C)	-272.9	-4.067	-820.0	0.4352
Heat Flow (kJ/h)	3.897e+005	-661.1	-3.893e+005	259.6
Molar Density (kgmole/m3)	101.2	170.5	53.74	136.7
Mass Density (kg/m3)	1412	3410	1098	1642
Std Ideal Liq Mass Density (kg/m3)	1408	3410	1091	1642
Liq Mass Density @Std Cond(kg/m3)	1423	3410	1111	1642
Molar Heat Capacity (kJ/kgmole-C)	---	5.318	-40.38	8.663
Mass Heat Capacity (kJ/kg-C)	---	0.2659	-1.976	0.7212
Thermal Conductivity (W/m-K)	---	5.939	0.5942	---
Viscosity (cP)	---	0.1963	0.7424	---
Surface Tension (dyne/cm)	---	-0.4148	70.15	---
Molecular Weight	13.95	20.00	20.44	12.01
Z Factor	---	2.350e-004	7.457e-004	2.931e-004

Product 1

	Overall	Liquid Phase	Aqueous Phase	Solid Phase
Vapour/Phase Fraction	0.0000	0.0025	0.2273	0.7701
Temperature: (C)	100.0	100.0	100.0	100.0
Pressure: (kPa)	86.00	86.00	86.00	86.00
Molar Flow (kgmole/h)	7.170	1.811e-002	1.630	5.522
Mass Flow (kg/h)	100.0	0.3623	33.31	66.32
Std Ideal Liq Vol Flow (m3/h)	7.103e-002	1.062e-004	3.054e-002	4.039e-002
Molar Enthalpy (kJ/kgmole)	-4.766e+004	-3.595e+004	-2.118e+005	744.9
Mass Enthalpy (kJ/kg)	-3417	-1797	-1.036e+004	62.02
Molar Entropy (kJ/kgmole-C)	-3787	-79.73	-1.668e+004	7.289
Mass Entropy (kJ/kg-C)	-271.5	-3.986	-816.2	0.6069
Heat Flow (kJ/h)	-3.417e+005	651.2	-3.452e+005	4113
Molar Density (kgmole/m3)	98.79	170.5	50.80	136.7
Mass Density (kg/m3)	1378	3110	1098	1642
Std Ideal Liq Mass Density (kg/m3)	1408	3410	1091	1642
Liq Mass Density @Std Cond(kg/m3)	1423	3410	1111	1642



TEAM LND
Calgary, Alberta
CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3.1\Cases\Dryer.hsc

Unit Set: SI

Date/Time: Sun Oct 29 09:43:26 2006

Heater: Dryer (continued)

PROPERTIES

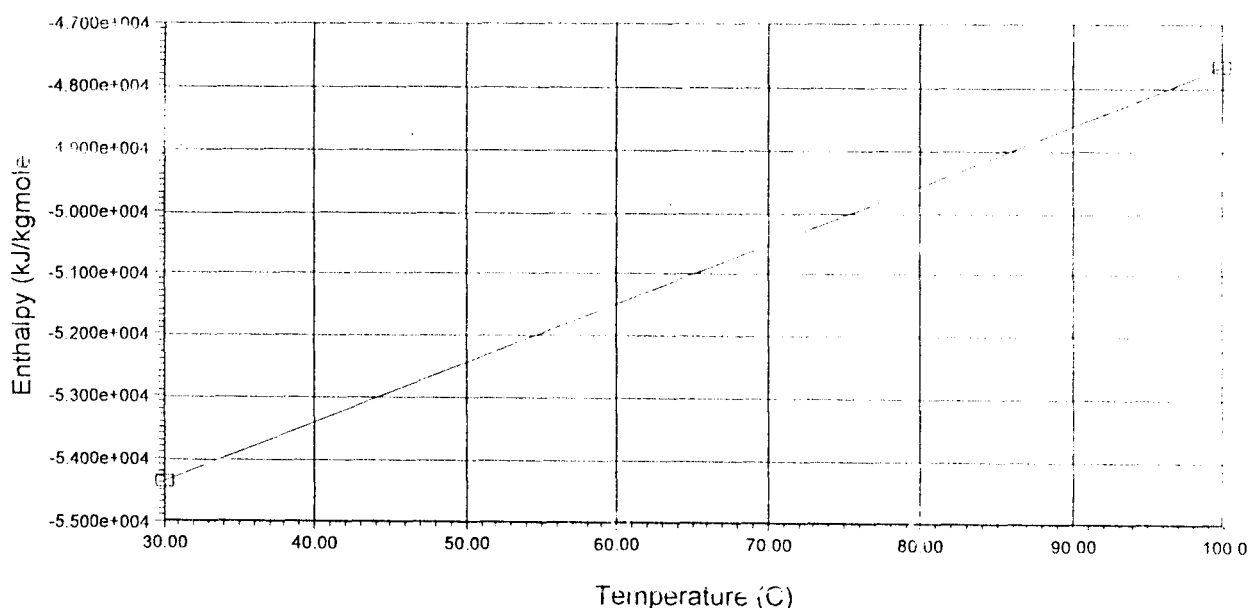
Product 1

	Overall	Liquid Phase	Aqueous Phase	Solid Phase
Molar Heat Capacity (kJ/kgmole-C)	194.4	10.28	817.1	11.22
Mass Heat Capacity (kJ/kg-C)	13.94	0.5142	39.98	0.9344
Thermal Conductivity (W/m-K)	---	5.703	0.6534	---
Viscosity (cP)	---	0.2126	0.2560	---
Surface Tension (dyne/cm)	---	-0.4070	57.71	---
Molecular Weight	13.95	20.00	20.44	12.01
Z Factor	---	1.626e-004	5.456e-004	2.028e-004

PERFORMANCE PROFILES

Zone	Pressure (kPa)	Temperature (C)	Vapour Fraction	Enthalpy (kJ/kgmole)
Inlet	101.00	30.00	0.0000	54356.15
Outlet	86.00	100.00	0.0000	47661.60

PERFORMANCE PLOT



PERFORMANCE TABLE

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)	Vapour Fraction
30.00	101.00	0.00	-54356.15	0.0000
100.00	86.00	47999.72	-47661.60	0.0000

DYNAMICS

Model Details: Supplied Duty

Zone	1	Delta P (kPa)	15.00
Volume (m3)	0.1000	Overall K (g/hr/sqrt(kPa-kg/m3))	0.7118
Duty (kJ/h)	4.800e+004		

Holdup Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	0.0000	0.0000	0.0000

Individual Zone Holdups: Zone 0

Delta P Specs and Duties

Heater: Dryer (continued)

Zone	dP Value (kPa)	dP Option	Duty (kJ/h)
0	15.00	not specified	4.800e+004

Zone Conductance Specifications

Zone	k (kg/hr/sqrt(kPa·kg/m ³))	Specification
0	0.7118	Disabled



TEAM LND
Calgary, Alberta
CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3.1\Cases\Furnace.hsc

Unit Set: SI

Date/Time: Sun Oct 29 09:56:37 2006

Heater: Furnace

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
Feed 1	

Outlet Stream

STREAM NAME	TO UNIT OPERATION
Product 1	

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Q1	

PARAMETERS

Pressure Drop:	20.00 kPa	Duty:	2.370e+006 kJ/h	Volume:	0.1000 m3
Function:	Not Selected	Zones:	1		

User Variables

SIMPLE HEAT LOSS PARAMETERS

Overall U (kJ/h-m2-C)	54.00	Ambient Temperature (C)	25.00	Overall Heat Transfer Area (m2)	---	Heat Flow (kJ/h)	---
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PROPERTIES

Feed 1

	Overall	Liquid Phase	Aqueous Phase	Solid Phase
Vapour/Phase Fraction	0.0000	0.0025	0.2273	0.7701
Temperature: (C)	100.0	100.0	100.0	100.0
Pressure: (kPa)	101.0	101.0	101.0	101.0
Molar Flow (kgmole/h)	7.170	1.811e-002	1.630	5.522
Mass Flow (kg/h)	100.0	0.3623	33.31	66.32
Std Ideal Liq Vol Flow (m3/h)	7.103e-002	1.062e-004	3.054e-002	4.039e-002
Molar Enthalpy (kJ/kgmole)	-4.766e+004	-3.595e+004	-2.118e+005	744.9
Mass Enthalpy (kJ/kg)	-3417	-1797	-1.036e+004	62.02
Molar Entropy (kJ/kgmole-C)	-3787	-79.73	-1.668e+004	7.289
Mass Entropy (kJ/kg-C)	-271.5	-3.986	-816.2	0.6069
Heat Flow (kJ/h)	-3.417e+005	-651.2	-3.452e+005	4113
Molar Density (kgmole/m3)	98.79	170.5	50.80	136.7
Mass Density (kg/m3)	1378	3410	1038	1642
Std Ideal Liq Mass Density (kg/m3)	1408	3410	1091	1642
Liq Mass Density @Std Cond(kg/m3)	1423	3410	1111	1642
Molar Heat Capacity (kJ/kgmole-C)	194.4	10.28	817.1	11.22
Mass Heat Capacity (kJ/kg-C)	13.94	0.5142	39.98	0.9344
Thermal Conductivity (W/m-K)	---	5.703	0.6534	---
Viscosity (cP)	---	0.2123	0.2550	---
Surface Tension (dyne/cm)	---	-0.4070	57.71	---
Molecular Weight	13.95	20.00	20.44	12.01
Z Factor	---	1.909e-004	6.408e-004	2.381e-004

Product 1

	Overall	Vapour Phase	Solid Phase
Vapour/Phase Fraction	0.2299	0.2299	0.7701
Temperature: (C)	505.1	505.1	505.1
Pressure: (kPa)	81.00	81.00	81.00
Molar Flow (kgmole/h)	7.170	1.648	5.522
Mass Flow (kg/h)	100.0	33.68	66.32
Std Ideal Liq Vol Flow (m3/h)	7.103e-002	3.064e-002	4.039e-002
Molar Enthalpy (kJ/kgmole)	2.829e+005	1.206e+006	7372
Mass Enthalpy (kJ/kg)	2.028e+004	5.902e+004	613.8
Molar Entropy (kJ/kgmole-C)	-3258	-1.424e+004	18.93
Mass Entropy (kJ/kg-C)	-233.6	-696.7	1.576
Heat Flow (kJ/h)	2.028e+006	1.988e+006	4.071e+004
Molar Density (kgmole/m3)	6.718e-003	1.544e-003	136.7
Mass Density (kg/m3)	9.369e-002	3.155e-002	1642
Std Ideal Liq Mass Density (kg/m3)	1408	1099	1642
Liq Mass Density @Std Cond(kg/m3)	1423	1127	1642



TEAM LND
Calgary, Alberta
CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3.1\Cases\Furnace Inc

Unit Set: SI

Date/Time: Sun Oct 29 09:56:37 2006

Heater: Furnace (continued)

PROPERTIES

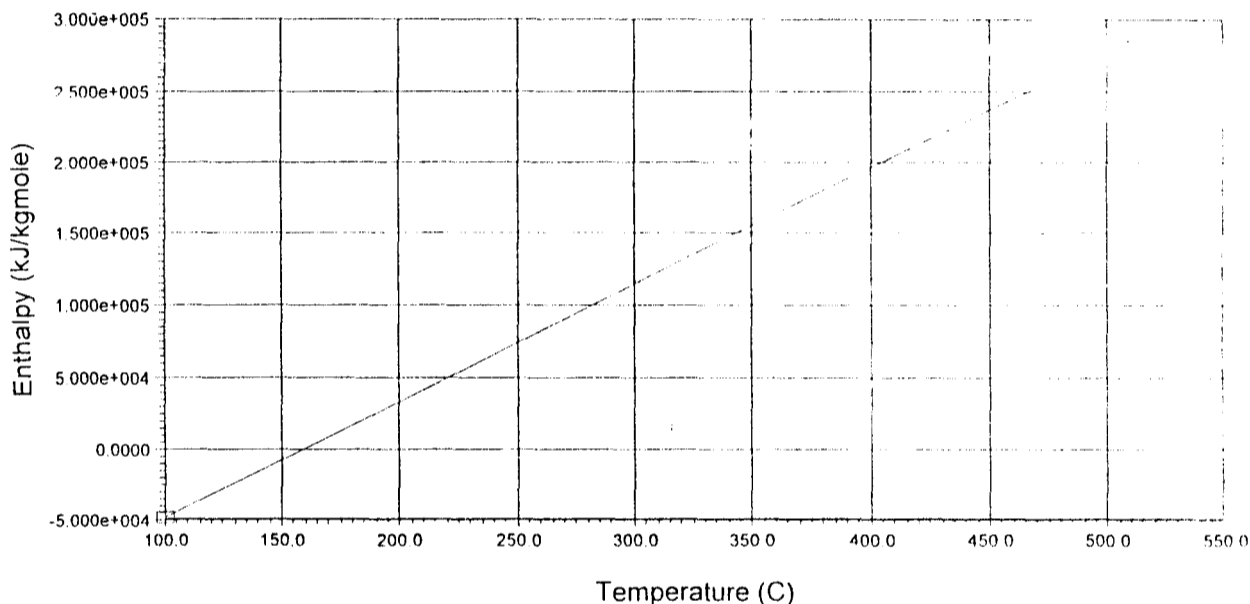
Product 1

	Overall	Vapour Phase	Solid Phase
14 Molar Heat Capacity (kJ/kgmole-C)	1419	6107	19.62
15 Mass Heat Capacity (kJ/kg-C)	101.7	298.9	1.634
16 Thermal Conductivity (W/m-K)	---	4.306	---
17 Viscosity (cP)	---	4.297e-004	---
18 Surface Tension (dyne/cm)	---	---	---
19 Molecular Weight	13.95	20.43	12.01
20 Z Factor	---	8.107	9.156e-005

PERFORMANCE PROFILES

Zone	Pressure (kPa)	Temperature (C)	Vapour Fraction	Enthalpy (kJ/kgmole)
Inlet	101.00	100.00	0.0000	-47663.78
0	81.00	505.12	0.2299	282881.25

PERFORMANCE PLOT



PERFORMANCE TABLE

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)	Vapour Fraction
100.00	101.00	0.00	-47663.78	0.0000
505.12	81.00	2370000.00	282881.25	0.2299

DYNAMICS

Model Details: Supplied Duty

2 Zone	1 *	Delta P (kPa)	20.00
3 Volume (m3)	0.1000 *	Overall K (g/hr/sqrt(kPa-kg/m3))	0.6227 *
4 Duty (kJ/h)	2.370e+006 *		

Holdup Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	0.0000	0.0000	0.0000

Individual Zone Holdups: Zone 0

Delta P Specs and Duties



TEAM LND
Calgary, Alberta
CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3.1\Cases\Furnace.hsc

Unit Jet: 3

Date/Time: Sun Oct 29 09:56:37 2006

Heater: Furnace (continued)

Zone	dP Value (kPa)	dP Option	Duty (k.l/h)
0	20.00	not specified	2.370e+006

Zone Conductance Specifications

Zone	k (kg/hr/sqrt(kPa·kg/m ³))	Specification
0	0.6227	Disabled



TEAM LND
Calgary, Alberta
CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3.1\Cases\Caustic Potash 7.hs

Unit Set: SI

Date/Time: Tue Oct 24 18:14:32 2006

Mixer: MIX-100

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
Product 2 Water	Heat Exchanger E-101

Outlet Stream

STREAM NAME	TO UNIT OPERATION
Product 3	3 Phase Separator V-100

PARAMETERS

User Variables

PROPERTIES

Outlet Stream Properties

	Product 3			
29	Vapour Fraction	0.0000		
30	Temperature (C)	84.92		
31	Pressure (kPa)	61.00		
32	Molar Flow (kgmole/h)	10.06		
33	MassFlow (kg/h)	152.0		
34	Std Ideal Liq Vol Flow (m3/h)	0.1231		
35	Enthalpy (kJ/kgmole)	-1.149e+005		
36	Mass Enthalpy (kJ/kg)	-7604		
37	Entropy (kJ/kgmole-C)	-2693		
38	Mass Entropy (kJ/kg-C)	-178.2		
39	HeatFlow (kJ/h)	-1.156e+006		
40	Molar Density (kgmole/m3)	79.80		
41	Std Ideal Liq Mass Density (kg/m3)	1234		
42	Liq Mass Density @Std Cond(kg/m3)	1251		
43	Molar Heat Capacity (kJ/kgmole-C)	134.0		
44	Mass Heat Capacity (kJ/kg-C)	8.864		
45	Thermal Conductivity (W/m-K)	---		
46	Viscosity (cP)	---		
47	Surface Tension (dyne/cm)	---		
48	Molecular Weight	15.11		
49	Z Factor	---		

Inlet Stream Properties

	Product 2	Water		
53	Vapour Fraction	0.0000	0.0000	
54	Temperature (C)	105.9	30.00	
55	Pressure (kPa)	61.00	101.0	
56	Molar Flow (kgmole/h)	7.170	2.686	
57	MassFlow (kg/h)	100.0	52.00	
58	Std Ideal Liq Vol Flow (m3/h)	7.103e-002	5.210e-002	
59	Enthalpy (kJ/kgmole)	-4.645e+004	-2.850e+005	
60	Mass Enthalpy (kJ/kg)	-3331	-1.582e+004	
61	Entropy (kJ/kgmole-C)	-3783	55.00	
62	Mass Entropy (kJ/kg-C)	-271.3	3.053	
63	HeatFlow (kJ/h)	-3.331e+005	-8.227e+005	
64	Molar Density (kgmole/m3)	98.56	55.71	
65	Std Ideal Liq Mass Density (kg/m3)	1408	998.0	
66	Liq Mass Density @Std Cond(kg/m3)	1423	1015	
67	Molar Heat Capacity (kJ/kgmole-C)	211.3	77.71	
68	Mass Heat Capacity (kJ/kg-C)	15.15	4.313	
69	Thermal Conductivity (W/m-K)	---	0.6182	
70	Viscosity (cP)	---	0.7972	
71	Surface Tension (dyne/cm)	---	71.23	
72	Molecular Weight	13.95	18.02	
73	Z Factor	---	7.193e-004	

DYNAMICS

Pressure Specification: Set Outlet to Lowest Inlet



TEAM LND
Calgary, Alberta
CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3 1\Cases\Caustic Potash 7.hs

Unit Set: SI

Date/Time: Tue Oct 24 18:14:32 2006

Mixer: MIX-100 (continued)

NOTES



TEAM LND
Calgary, Alberta
CANADA

Case Name: D:\Program Files\Hyprotech\HYSYS 3.1\Cases\Causitic Potash 7.hs
Unit Set: SI
Date/Time: Tue Oct 24 18:15:09 2006

3 Phase Separator: V-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
Product 3	Mixer MIX-100

Outlet Stream

Stream Name	To Unit Operation
V	
LL	
HL	Hydrocyclone: X-100

Energy Stream

Stream Name	From Unit Operation

PARAMETERS

Vessel Volume:	2.500 m3	Level SP:	50.00 %	Liquid Volume:	1.250 m3
Vessel Pressure:	61.00 kPa	Pressure Drop:	0.0000 kPa	Duty:	0.0000 kJ/h
				Heat Transfer Mode:	Heating

User Variables

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RATING

Sizing

Cylinder	Vertical	Separator has a Boot:	No
Volume	2.500 m3	Diameter	1.285 m
		Height	1.928

Level Taps: Level Tap Specification

Level Tap	PV High	PV Low	OP High	OP Low

Level Taps: Calculated Level Tap Values

Level Tap	Liquid Level	Aqueous Level

Options

PV Work Term Contribution (%)	100.00
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PROPERTIES

Product 3

	Overall	Liquid Phase	Aqueous Phase	Solid Phase
Vapour/Phase Fraction	0.0000	0.1011	0.3497	0.5491
Temperature: (C)	84.92	84.92	84.92	84.92
Pressure: (kPa)	61.00	61.00	61.00	61.00
Molar Flow (kgmole/h)	10.06	1.017	3.517	5.522
Mass Flow (kg/h)	152.0	22.31	63.36	66.33
Std Ideal Liq Vol Flow (m3/h)	0.1231	1.926e-002	6.349e-002	4.039e-002
Molar Enthalpy (kJ/kgmole)	-1.149e+005	-1.687e+005	-2.807e+005	579.6
Mass Enthalpy (kJ/kg)	-7604	-7690	-1.558e+004	48.26
Molar Entropy (kJ/kgmole-C)	-2693	-2.690e+004	67.65	6.837
Mass Entropy (kJ/kg-C)	-178.2	-1226	3.755	0.5693
Heat Flow (kJ/h)	-1.156e+006	-1.716e+005	-9.874e+005	3201
Molar Density (kgmole/m3)	79.80	51.76	53.31	136.7
Mass Density (kg/m3)	1206	1135	960.4	1642
Std Ideal Liq Mass Density (kg/m3)	1234	1159	998.0	1642
Liq Mass Density @Std Cond(kg/m3)	1251	1194	1015	1642
Molar Heat Capacity (kJ/kgmole-C)	134.0	994.4	78.66	10.70
Mass Heat Capacity (kJ/kg-C)	8.864	45.34	4.366	0.8908
Thermal Conductivity (W/m-K)	---	0.6652	0.6729	---
Viscosity (cP)	---	0.2586	0.3304	---
Surface Tension (dyne/cm)	---	26.85	51.43	---
Molecular Weight	15.11	21.93	18.02	12.01
Z Factor	---	3.959e-004	3.843e-004	1.499e-004

V

	Overall	Liquid Phase	Aqueous Phase	Solid Phase	Vapour Phase
Vapour/Phase Fraction	1.0000	0.0000	0.0000	0.0000	1.0000



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3 Phase Separator: V-100 (continued)

V

		Overall	Liquid Phase	Aqueous Phase	Solid Phase	Vapour Phase
Temperature:	(C)	84.92	84.92	84.92	84.92	84.92
Pressure:	(kPa)	61.00	61.00	61.00	61.00	61.00
Molar Flow	(kgmole/h)	0.0000	0.0000	0.0000	0.0000	0.0000
Mass Flow	(kg/h)	0.0000	0.0000	0.0000	0.0000	0.0000
Std Ideal Liq Vol Flow	(m3/h)	0.0000	0.0000	0.0000	0.0000	0.0000
Molar Enthalpy	(kJ/kgmole)	2.254e+006	-1.687e+005	-2.807e+005	579.6	2.254e+006
Mass Enthalpy	(kJ/kg)	1.127e+005	-7690	-1.558e+004	48.26	1.127e+005
Molar Entropy	(kJ/kgmole-C)	-546.6	-2.690e+004	67.65	6.837	-546.6
Mass Entropy	(kJ/kg-C)	-27.33	-1226	3.755	0.5693	-27.33
Heat Flow	(kJ/h)	0.0000	0.0000	0.0000	0.0000	0.0000
Molar Density	(kgmole/m3)	1.912e-005	51.76	53.31	136.7	1.912e-005
Mass Density	(kg/m3)	3.824e-004	1135	960.4	1642	3.824e-004
Std Ideal Liq Mass Density	(kg/m3)	3410	1159	998.0	1642	3410
Liq Mass Density @Std Cond	(kg/m3)	3410	1194	1015	1642	3410
Molar Heat Capacity	(kJ/kgmole-C)	269.9	994.4	78.66	10.70	269.9
Mass Heat Capacity	(kJ/kg-C)	13.50	45.34	4.366	0.8908	13.50
Thermal Conductivity	(W/m-K)	2.888e-004	0.6652	0.6729	---	2.888e-004
Viscosity	(cP)	-3.826e+006	0.2586	0.3304	---	-3.826e+006
Surface Tension	(dyne/cm)	---	58.83	61.43	---	---
Molecular Weight		20.00	21.93	18.02	12.01	20.00
Z Factor		1072	3.959e-004	3.843e-004	1.499e-004	1072

LL

		Overall	Liquid Phase	Aqueous Phase	Solid Phase	Vapour Phase
Vapour/Phase Fraction		0.0000	1.0000	0.0000	0.0000	0.0000
Temperature:	(C)	84.92	84.92	84.92	84.92	84.92
Pressure:	(kPa)	61.00	61.00	61.00	61.00	61.00
Molar Flow	(kgmole/h)	1.017	1.017	0.0000	0.0000	0.0000
Mass Flow	(kg/h)	22.31	22.31	0.0000	0.0000	0.0000
Std Ideal Liq Vol Flow	(m3/h)	1.926e-002	1.926e-002	0.0000	0.0000	0.0000
Molar Enthalpy	(kJ/kgmole)	-1.687e+005	-1.687e+005	-2.807e+005	579.6	2.254e+006
Mass Enthalpy	(kJ/kg)	-7690	-7690	-1.558e+004	48.26	1.127e+005
Molar Entropy	(kJ/kgmole-C)	-2.690e+004	-2.690e+004	67.65	6.837	-546.6
Mass Entropy	(kJ/kg-C)	-1226	-1226	3.755	0.5693	-27.33
Heat Flow	(kJ/h)	-1.716e+005	-1.716e+005	0.0000	0.0000	0.0000
Molar Density	(kgmole/m3)	51.76	51.76	53.31	136.7	1.912e-005
Mass Density	(kg/m3)	1135	1135	960.4	1642	3.824e-004
Std Ideal Liq Mass Density	(kg/m3)	1159	1159	998.0	1642	3410
Liq Mass Density @Std Cond	(kg/m3)	1194	1194	1015	1642	3410
Molar Heat Capacity	(kJ/kgmole-C)	994.4	994.4	78.66	10.70	269.9
Mass Heat Capacity	(kJ/kg-C)	45.34	45.34	4.366	0.8908	13.50
Thermal Conductivity	(W/m-K)	0.6652	0.6652	0.6729	---	2.888e-004
Viscosity	(cP)	0.2586	0.2586	0.3304	---	-3.826e+006
Surface Tension	(dyne/cm)	58.83	58.83	61.43	---	---
Molecular Weight		21.93	21.93	18.02	12.01	20.00
Z Factor		3.959e-004	3.959e-004	3.843e-004	1.499e-004	1072

HL

		Overall	Liquid Phase	Aqueous Phase	Solid Phase	Vapour Phase
Vapour/Phase Fraction		0.0000	0.0000	0.3891	0.6109	0.0000
Temperature:	(C)	84.92	84.92	84.92	84.92	84.92
Pressure:	(kPa)	61.00	61.00	61.00	61.00	61.00
Molar Flow	(kgmole/h)	9.039	0.0000	3.517	5.522	0.0000
Mass Flow	(kg/h)	129.7	0.0000	63.36	66.33	0.0000
Std Ideal Liq Vol Flow	(m3/h)	0.1039	0.0000	6.349e-002	4.039e-002	0.0000
Molar Enthalpy	(kJ/kgmole)	-1.089e+005	-1.687e+005	-2.807e+005	579.6	2.254e+006
Mass Enthalpy	(kJ/kg)	-7589	-7690	-1.558e+004	48.26	1.127e+005
Molar Entropy	(kJ/kgmole-C)	30.50	-2.690e+004	67.65	6.837	-546.6
Mass Entropy	(kJ/kg-C)	2.126	-1226	3.755	0.5693	-27.33
Heat Flow	(kJ/h)	-9.842e+005	0.0000	-9.874e+005	3201	0.0000
Molar Density	(kgmole/m3)	84.98	51.76	53.31	136.7	1.912e-005
Mass Density	(kg/m3)	1219	1135	960.4	1642	3.824e-004
Std Ideal Liq Mass Density	(kg/m3)	1248	1159	998.0	1642	3410
Liq Mass Density @Std Cond	(kg/m3)	1261	1194	1015	1642	3410
Molar Heat Capacity	(kJ/kgmole-C)	37.14	994.4	78.66	10.70	269.9



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3 Phase Separator: V-100 (continued)

HL

	Overall	Liquid Phase	Aqueous Phase	Solid Phase	Vapour Phase
Mass Heat Capacity (kJ/kg-C)	2.589	45.34	4.366	0.8908	13.50
Thermal Conductivity (W/m-K)	---	0.6652	0.6729	---	2.888e-004
Viscosity (cP)	---	0.2586	0.3304	---	-3.826e+006
Surface Tension (dyne/cm)	---	58.83	61.43	---	---
Molecular Weight	14.35	21.93	18.02	12.01	20.00
Z Factor	---	3.959e-004	3.843e-004	1.499e-004	1072

Inlet Stream

	Product 3
Vapour Fraction	0.0000
Temperature (C)	84.92
Pressure (kPa)	61.00
Molar Flow (kgmole/h)	10.06
MassFlow (kg/h)	152.0
Std Ideal Liq Vol Flow (m3/h)	0.1231
HeatFlow (kJ/h)	-1.156e+006

Outlet Stream

	LL	V	HL
Vapour Fraction	0.0000	1.0000	0.0000
Temperature (C)	84.92	84.92	84.92
Pressure (kPa)	61.00	61.00	61.00
Molar Flow (kgmole/h)	1.017	0.0000	9.039
MassFlow (kg/h)	22.31	0.0000	129.7
Std Ideal Liq Vol Flow (m3/h)	1.926e-002	0.0000	0.1039
HeatFlow (kJ/h)	-1.716e+005	0.0000	-9.842e+005

DYNAMICS

Vessel Parameters: Initialize from Product

Vessel Volume (m3)	2.500	Level Calculator	Vertical cylinder
Vessel Diameter (m)	1.285	Fraction Calculator	Use levels and nozzles
Vessel Height (m)	1.928	Feed Delta P (kPa)	0.0000
Liquid Level Percent (%)	50.00	Vessel Pressure (kPa)	61.00

Holdup: Vessel Levels

Phase	Level (m)	Percent (%)	Volume (m3)
Vapour	---	---	0.0000
Liquid	---	---	0.0000
Aqueous	---	---	0.0000

Holdup: Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	0.0000	0.0000	0.0000



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Case Name: D:\Program Files\Hyprotech\HYSYS 3.1\Cases\Evaporator hsc

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Heater: Evaporator

CONNECTIONS

Inlet Stream

STREAM NAME

FROM UNIT OPERATION

HEF

Outlet Stream

STREAM NAME

TO UNIT OPERATION

HEP

Energy Stream

STREAM NAME

FROM UNIT OPERATION

Q

PARAMETERS

Pressure Drop: 20.00 kPa * Duty: 2.370e+007 kJ/h * Volume: 0.1000 m3
Function: Not Selected Zones: 1

User Variables

PROPERTIES

HEF

	Overall	Vapour Phase	Aqueous Phase
Vapour/Phase Fraction	0.1537	0.1537	0.8463
Temperature (C)	76.85	76.85	76.85
Pressure (kPa)	100.0	100.0	100.0
Molar Flow (kgmole/h)	357.8	55.01	302.8
Mass Flow (kg/h)	8886	3430	5456
Std Ideal Liq Vol Flow (m3/h)	7.181	1.714	5.467
Molar Enthalpy (kJ/kgmole)	-2.521e+005	-9.092e+004	-2.814e+005
Mass Enthalpy (kJ/kg)	-1.015e+004	-1458	-1.562e+004
Molar Entropy (kJ/kgmole-C)	-3.416e+004	-2.226e+005	65.77
Mass Entropy (kJ/kg-C)	-1376	-3570	3.651
Heat Flow (kJ/h)	-9.021e+007	-5.001e+006	-3.521e+007
Molar Density (kgmole/m3)	0.2252	3.475e-002	53.68
Mass Density (kg/m3)	5.593	2.167	967.0
Std Ideal Liq Mass Density (kg/m3)	1237	2001	998.0
Liq Mass Density @Std Cond(kg/m3)	1261	2029	1015
Molar Heat Capacity (kJ/kgmole-C)	1028	6257	78.41
Mass Heat Capacity (kJ/kg-C)	41.41	100.3	4.352
Thermal Conductivity (W/m-K)	---	0.8942	0.6676
Viscosity (cP)	---	1.181e-002	0.3654
Surface Tension (dyne/cm)	---	---	62.91
Molecular Weight	24.83	62.36	18.02
Z Factor	---	0.9890	6.402e-004

HEP

	Overall	Vapour Phase
Vapour/Phase Fraction	1.0000	1.0000
Temperature (C)	100.7	100.7
Pressure (kPa)	80.00	80.00
Molar Flow (kgmole/h)	357.8	357.8
Mass Flow (kg/h)	8886	8886
Std Ideal Liq Vol Flow (m3/h)	7.181	7.181
Molar Enthalpy (kJ/kgmole)	-1.859e+005	-1.859e+005
Mass Enthalpy (kJ/kg)	-7485	-7485
Molar Entropy (kJ/kgmole-C)	-3.398e+004	-3.398e+004
Mass Entropy (kJ/kg-C)	-1368	-1368
Heat Flow (kJ/h)	-6.651e+007	-6.651e+007
Molar Density (kgmole/m3)	2.591e-002	2.591e-002
Mass Density (kg/m3)	0.6433	0.6433
Std Ideal Liq Mass Density (kg/m3)	1237	1237
Liq Mass Density @Std Cond(kg/m3)	1261	1261
Molar Heat Capacity (kJ/kgmole-C)	1581	1581
Mass Heat Capacity (kJ/kg-C)	63.69	63.69
Thermal Conductivity (W/m-K)	0.3362	0.3362

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HYSYS v3.1 (Build 4815)

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Heater: Evaporator (continued)

PROPERTIES

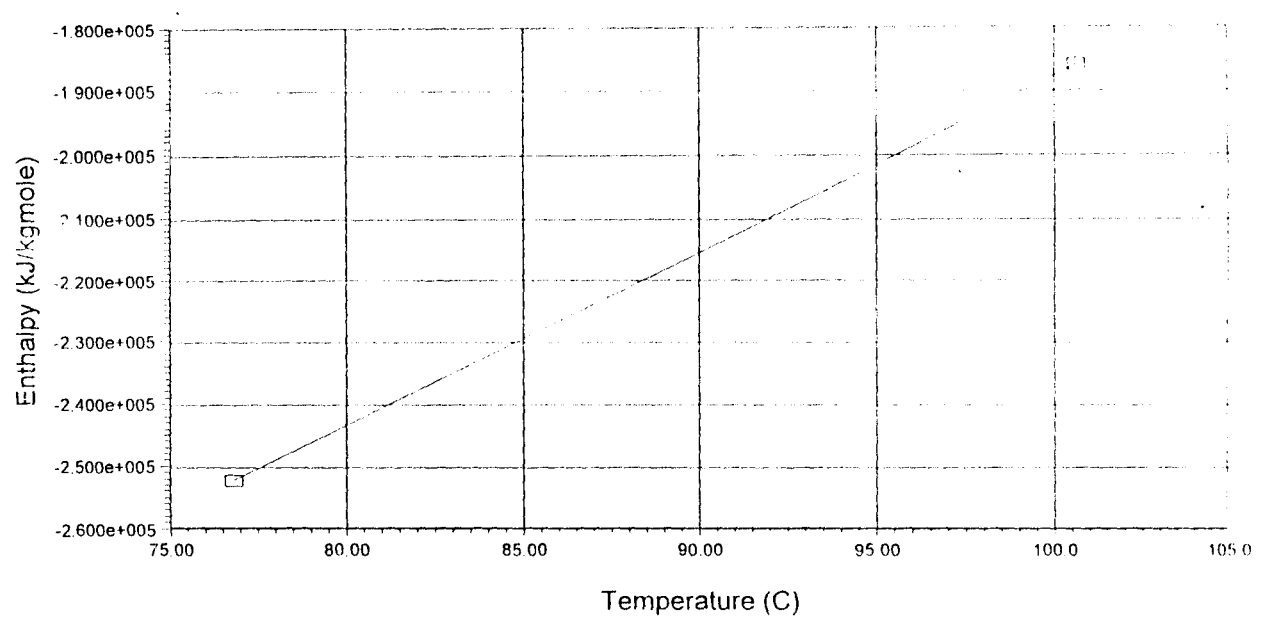
HEP

	Overall	Vapour Phase
Viscosity (cP)	9.481e-003	9.481e-003
Surface Tension (dyne/cm)	---	---
Molecular Weight	24.83	24.83
Z Factor	0.9936	0.9936

PERFORMANCE PROFILES

Zone	Pressure (kPa)	Temperature (C)	Vapour Fraction	Enthalpy (kJ/kgmole)
Inlet	100.00	76.85	0.1537	252091.93
0	80.00	100.68	1.0000	-185862.57

PERFORMANCE PLOT



PERFORMANCE TABLE

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)	Vapour Fraction
76.85	100.00	0.00	-252091.93	0.1537
100.68	80.00	23700000.00	-185862.57	1.0000

DYNAMICS

Model Details: Supplied Duty

Zone	1	Delta P (kPa)	20.00
Volume (m3)	0.1000	Overall K (j/hr/sqrt(kPa·kg/m3))	858.5
Duty (kJ/h)	2.370e+007		

Holdup Details

Phase	Accumulation (kgmole/h)	Moles (kgmole)	Volume (m3)
Vapour	0.0000	0.0000	0.0000
Liquid	0.0000	0.0000	0.0000
Aqueous	0.0000	0.0000	0.0000
Total	0.0000	0.0000	0.0000

Individual Zone Holdups: Zone 0

Delta P Specs and Duties

Zone	dP Value (kPa)	dP Option	Duty (kJ/h)
0	20.00	not specified	2.370e+007

1
2
3
4
5
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Heater: Evaporator (continued)

Zone Conductance Specifications

Zone	k (kg/hr/sqrt(kPa·kg/m3))	Specification
0	858.5	Disabled

CHAPTER SEVEN

7.0 EQUIPMENT OPTIMIZATION

7.1 Optimization of furnace

In optimizing, the first step is clearly to define the objective; that is, the criterion to be used to judge the performance of the system. In engineering design, the objective of optimizing any equipment must be an economical one. This is because for any chemical plant set up, the primary objective is to maximize the profit. This can be approached based on the fact that, in order to minimize cost of construction, the dimensions (Volume and Area) of the equipment must be kept at minimum. For the furnace, the total surface area is given as

$$A_{\text{furnace}} = 2 \cdot \pi \cdot R_{\text{furnace}}^2 + 2 \cdot \pi \cdot R_{\text{furnace}} \cdot H_{\text{furnace}}$$

$$\text{and } R_{\text{furnace}} = \frac{D_{\text{furnace}}}{2}$$

where R_{furnace} = "radius of the furnace tube"

D_{furnace} = "diameter of the furnace"

H_{furnace} = "height of the furnace"

π = "pie, a constant"

So, the formula becomes

$$A_{\text{furnace}} = 2 \cdot \pi \cdot \left(\frac{D_{\text{furnace}}}{2} \right)^2 + 2\pi \cdot \frac{D_{\text{furnace}}}{2} \cdot H_{\text{furnace}}$$

$$A_{\text{furnace}} = 2 \cdot \pi \cdot \frac{D_{\text{furnace}}^2}{4} + 2 \cdot \pi \cdot \frac{D_{\text{furnace}}}{2} \cdot H_{\text{furnace}}$$

$$A_{\text{furnace}} = \pi \cdot \frac{D_{\text{furnace}}^2}{2} + \pi \cdot D_{\text{furnace}} \cdot H_{\text{furnace}}$$

At this point, it is clear that area of the equipment is a function of the diameter and length

of the equipment. Mathematically,

$$A_{\text{furnace}} = f(D_{\text{furnace}}, H_{\text{furnace}})$$

where the objective function is

$$A_{\text{furnace}} = \pi \cdot \frac{D_{\text{furnace}}^2}{2} + \pi \cdot D_{\text{furnace}} \cdot H_{\text{furnace}}$$

and the constraints are

$$D \geq D_{\text{minimum}} \quad \text{and} \quad H \geq H_{\text{minimum}}$$

so that the equation of A_{furnace} becomes

$$f(D_{\text{furnace}}, H_{\text{furnace}}) = \pi \cdot \frac{D_{\text{furnace}}^2}{2} + \pi \cdot D_{\text{furnace}} \cdot H_{\text{furnace}}$$

Noting that the volume of the equipment is given as

$$V_{\text{furnace}} = \pi \cdot R_{\text{furnace}}^2 \cdot H_{\text{furnace}}$$

$$\text{with } R_{\text{furnace}} = \frac{D_{\text{furnace}}}{2}$$

$$V_{\text{furnace}} = \pi \cdot \left(\frac{D_{\text{furnace}}}{2}\right)^2 \cdot H_{\text{furnace}}$$

$$V_{\text{furnace}} = \pi \cdot \frac{D_{\text{furnace}}^2}{4} \cdot H_{\text{furnace}}$$

Making the height of the equipment the subject of the formula in the above equation,

$$H_{\text{furnace}} = \frac{4 \cdot V_{\text{furnace}}}{\pi \cdot D_{\text{furnace}}^2}$$

So,

$$f(D_{\text{furnace}}, H_{\text{furnace}}) = \pi \cdot \frac{D_{\text{furnace}}^2}{2} + \pi \cdot D_{\text{furnace}} \cdot \frac{4 \cdot V_{\text{furnace}}}{\pi \cdot D_{\text{furnace}}^2}$$

Simplifying,

$$f(d_{\text{furnace}}, h_{\text{furnace}}) = \pi \cdot \frac{D_{\text{furnace}}^2}{2} + \pi \cdot \frac{4 \cdot V_{\text{furnace}}}{\pi \cdot D_{\text{furnace}}}$$

It can now be observed from the above equation that the area is a function of the diameter if the volume is kept constant.

$$f(D_{\text{furnace}}) = \pi \cdot \frac{D_{\text{furnace}}^2}{2} + \pi \cdot \frac{4 \cdot V_{\text{furnace}}}{\pi \cdot D_{\text{furnace}}}$$

Differentiating the above equation yields,

$$\frac{d}{d(D_{\text{furnace}})} f(D_{\text{furnace}}) = \pi \cdot D_{\text{furnace}} - \frac{4}{D_{\text{furnace}}^2} \cdot V_{\text{furnace}}$$

At optimum point, the derivative is equated to zero. That is,

$$\frac{d}{dd_{\text{furnace}}} f(D_{\text{furnace}}) = \pi \cdot D_{\text{furnace}} - \frac{4}{D_{\text{furnace}}^2} \cdot V_{\text{furnace}} = 0$$

Taking the last two expressions,

$$\pi \cdot D_{\text{furnace}} - \frac{4}{D_{\text{furnace}}^2} \cdot V_{\text{furnace}} = 0$$

$$\pi \cdot D_{\text{furnace}} = \frac{4}{D_{\text{furnace}}^2} \cdot V_{\text{furnace}}$$

$$D_{\text{furnace}}^2 \cdot D_{\text{furnace}} = \frac{4 \cdot V_{\text{furnace}}}{\pi}$$

$$D_{\text{furnace}}^3 = \frac{4 \cdot V_{\text{furnace}}}{\pi}$$

$$D_{\text{furnace}} = \sqrt[3]{\frac{4 \cdot V_{\text{furnace}}}{\pi}}$$

The above expression is now the optimized diameter of the equipment.

From,

$$H_{\text{furnace}} = \frac{4 \cdot V_{\text{furnace}}}{\pi \cdot D_{\text{furnace}}^2}$$

Substituting for D_{furnace} in this expression yields

$$H_{\text{furnace}} = \frac{4 \cdot V_{\text{furnace}}}{\pi \cdot \left(\frac{4 \cdot V_{\text{furnace}}}{\pi} \right)^{2/3}}$$

Simplifying,

$$H_{\text{furnace}} = \frac{V_{\text{furnace}}}{\pi} \cdot \sqrt[3]{2^2}$$

Numerically, with

$$V_{\text{furnace}} := 2.272 \cdot \frac{\text{m}^3}{\text{day}}$$

$$D_{\text{furnace}} := \sqrt[3]{\frac{4 \cdot V_{\text{furnace}} \cdot \text{day}}{\pi}}$$

$$D_{\text{furnace}} = 1.425 \text{ m}$$

$$H_{\text{furnace}} := \frac{(V_{\text{furnace}} \cdot \text{day})}{\pi} \cdot \sqrt[3]{2^2}$$

$$H_{\text{furnace}} = 1.425 \text{ m}$$

It, therefore, means that the optimum diameter and height of the equipment are $D_{\text{furnace}} = 1.425 \text{ m}$ and $H_{\text{furnace}} = 1.425 \text{ m}$.

CHAPTER EIGHT

8.0 SAFETY AND QUALITY CONTROL

8.1 Safety

Safety is an area of engineering and public health that deals with the protection of workers' health, through control of the work environment to reduce or eliminate hazards. Industrial accidents and unsafe working conditions can result in temporary or permanent injury, illness, or even death. They also take a toll in reduced efficiency and loss of productivity. (Encarta, 2004)

8.1.1 General Safety Rules

Follow relevant instructions

- a) Before attempting to operate the plant, all relevant manufacturers' instructions and local regulations should be understood and implemented.
- b) It is irresponsible and dangerous to misuse equipment or ignore instructions, regulations or warnings.
- c) The specified maximum operating conditions must not be exceeded. (Odigure, 1998)

Operation

- a) It must be ensured that all staff must be fully aware of the potential hazards when the plant is being operated.
- b) Serious injury can result from touching apparently stationary equipment or rotating belt.
- c) No metallic object should be allowed into the plant. Otherwise, the gear motor of the affected conveyor must be set in the reverse direction and the entrained materials should be discharged. (Odigure, 1998)

Maintenance

- a) A badly maintained plant is a potential hazard. It must be ensured that competent members of staff is responsible for organizing maintenance and repairs on a planned basis.
- b) Faulty equipment must be permitted to be operated. Repairs must be carried out competently and the operation must be checked. (Odigure, 1998)

Using electricity

- a) At least once a month, the electrical cables should be checked to ensure that they are operating normally.
- b) Electricity is the commonest cause of accidents in the factory, it must be respected.
- c) It must be ensured that electricity supply has been disconnected from the equipment before attempting repairs or adjustment.
- d) It must be known that water and electricity are not compatible and can cause serious injury if they come into contact.
- e) The plant must always be disconnected from electricity when not in use.
(Odigure, 1998)

Avoiding fire or explosion

- a) It must be ensured that the factory is provided with adequate fire extinguishers appropriate to the potential dangers.
- b) It must be known that empty vessels having inflammable liquids can contain vapours and explode if ignited.

Handling poisons or toxic materials

- a) Food must not be allowed to be brought into or consumed in the factory.
- b) Smoking should not be allowed in the factory premises. Notices should be so displayed and enforced. (Odigure, 1998)

Avoiding cuts and burns

- a) Care must be taken when handling sharp edged components. Undue force must not be exerted on glass or fragile items.
- b) Hot surfaces cannot, in most cases, be totally shielded and can produce severe burns even when not "visibly hot". Common sense must be used always!

Eye protection

- a) Facilities for eye irritation should always be available

Ear protection

- a) Ear protectors must be worn when operating the plant.

Guard and safety devices

- a) Guards and safety devices must be installed on the plant to protect the operators. The equipment must not be operated with such devices removed.
- b) Safety gauges, cut-out and other safety devices must be set to protect the equipment. Interference with these devices may create a potential hazard.
- c) It is impossible to guard the operator against all contingencies. Common sense must be used.

- d) Before starting a machine, it must be ensured that the members of staff are aware of how it (the machine) should be stopped in an emergency. (Odigure, 1998)

First aid

- a) It is essential that first aid equipment is available and that the supervisor knows how to use it.
- b) A notice giving details of a proficient first aider should be prominently displayed. (Odigure, 1998)

8.2 Quality Control

Quality simply means “fitness for use”. But, according to the International Standard Organisation (ISO), quality is defined as the totality of the characteristics of an entity that bear on its ability to satisfy stated and intended needs. It is more costly to exceed a specification than to meet it. Therefore, there is the need to get quality goal or target for effective quality control.

Maintaining product quality in accordance with acceptable standard has been a major role for industrial instrumentation since its inception decades ago. With the ever-increasing interest in speeding up production, one becomes aware of the fact that rejectable as well as acceptable products can be produced at high rates.

8.2.1 Quality assurance

Quality assurance is defined by ISO as all the planned and systematic activities implemented within the quality system and demonstration is needed to provide adequate confidence on entity will fulfil requirement for quality.

8.2.1.1 Principles of quality assurance

The principles of quality assurance include the following:

- i. Management involvements and objective (management) involvement is very essential to ensure quality.
- ii. Programming and planning.
- iii. Application of quality control principles.
- iv. Design and specification control.
- v. Purchasing control and vendor appraisal.
- vi. Production control.
- vii. Marketing and service quality functions.
- viii. Proper documentation.
- ix. Non-conformance control.
- x. Remedial action.
- xi. Defect and failure analysis.

8.2.1.2 Quality management

Quality management involves all activities of the overall management functions that determine the quality policy, objective and responsibilities and implement them by means, such as quality planning control assurance and improvement within the quality system. Responsibility of quality lies at all level of all. To successfully implement quality management, the organisation structure, procedure process and resources are requisite.

CHAPTER NINE

9.0 PROCESS CONTROL AND INSTRUMENTATION

It is proposed that most of the plant equipments in this plant are to be operated using automatic control with the indicating instruments being located in a control room. This is the general practice for a plant of this type which is not labour intensive. With the exception of the reactor system, the plant operates at atmospheric pressure and therefore the process control and instrumentation will be based upon temperature, flow and level measurements. Measurements of these parameters will be made using thermocouples, orifice plates and float type indicators respectively. (Austin & Jeffrey, 1991)

9.1 Types of control instruments

The control instruments are of four major categories

- a) Temperature controllers (TC)
- b) Pressure controller (PC)
- c) Flow controller (FC)
- d) Level controller (LC)

9.2 Control Mechanism

The pneumatic control hardware is recommended for this process it will be powered by instrument air supplies.

The control mechanism for this process consist of a sensor to detect the process variables; a transmitter to convert the sensor into an equivalent "signal" a

controller that compares this process signal with a desired set point value and produces an appropriate controller output signal and a final control element (pneumatic activator) that changes the manipulated variable with the use of a mechanical action.

9.3 Control Sensors

The devices to be used for the on-line measurement of the process variables are:

- 1) Flow sensor: The orifice meter can be employed in the process since it is simple and of low cost.
- 2) Temperature sensor: The recommended temperature sensors are resistance thermometer detectors (RTDS) and Thermocouples. The 100v pt (-2000C to 850C) and type N (0-13000) are both sufficient for RTDS and thermocouples respectively.
- 3) Pressure sensors: Bourdon – Tube pressure gauge can be used.
- 4) Level sensor: float activated devices are sufficient.

Alarms are to be employed to alert the process operator to a process that requires immediate action and attention. Instead of individually issuing point alarms, all alarms associated with a certain aspect of the process are to be simply wired to give a single trouble alarm.

9.4 Transmitters, Controllers and Control Valves

The transmitter is the inter-phase between the process and its control system. The transmitter converts the sensors signal into a control signal. The pilot – acting

controllers should be employed in the process. The pilot – acting controllers are capable of greater degree of sensitivity since they eliminate of the lags which would be inherent in sel – acting mechanism activated by the force of a large volume of fluid. The fluid control element is an automatic control which throttles the flow of the manipulated variable.

CHAPTER TEN

10.0 ENVIRONMENTAL ACCEPTABILITY

10.1 Identification of possible pollutants

The main atmospheric pollution problem encountered in caustic potash production plant is from the combustibles when discharged into the air.

Another source of pollution is from the tanks if they are leaking. This is because caustic potash, if allowed to flow into the river body, can harm the aquatic animals in the water.

10.2 Suggestions on treatment of such pollutants

The method suggested for the treatment and control of the pollution encountered in the caustic potash production plant are:

- a. all the combustible material suspected to be harmful should be converted to harmless substances before discharged into the atmosphere.
- b. all the tanks should be well tight.
- c. effluent from the plant should also be treated before discharged into water body.

CHAPTER ELEVEN

11.0 START UP AND SHUT DOWN PROCEDURE

Start up time may be defined as the time span between end of construction and the beginning of normal operations. Start up and shut down procedure must proceed safely and be flexible enough to be carried out in various ways. In other words, the start up and shut down of the caustic potash plant should be such that it can be easily and safely operated. The operating limits of the plant should not be exceeded and dangerous mixtures must not be formed as a result of abnormal states of concentration, composition, temperature, phase, pressure, reactants and products.

It should be noted that some items of actions must be completed before even the start up of the plant in order to prepare the plant for the start up operation. The items of actions are:

- i. All scaffolds and temporary piping and supports should be removed.
- ii. Lines and equipment should be flushed out.
- iii. Pumps, motors/turbines and compressors should be run.
- iv. Hydrostatic or pneumatic lines and equipment should be tested.
- v. Laboratory and sampling schedule should be prepared.
- vi. All instruments should be inspected and tested.

11.1 Start Up Procedures

For the caustic potash plant designed, the following are the start up procedures:

- i. The dryer should be started up.
- ii. The furnace should be heated up and maintained at their operating temperatures and pressures.
- iii. The inlet and outlet valves of the units should be opened up.

- iv. The compressor valve to supply air at a regulated pressure should be opened.
- v. All the inlet and outlet valves to the furnace should be shut as soon as the feed enters the furnace in order to achieve maximum conversion.
- vi. The outlet valve of the furnace should be opened for the evacuation of the reactor contents.
- vii. The outlet valve of the furnace should be locked before opening the inlet valve before further entering of the feed into the reactor.

11.2 Shut Down Procedures

The shut down procedures for the caustic potash plant are as outlined below

- i. The supply of cocoa pod husk into the dryer should be stopped
- ii. The supply of the hot air to the dryer should be cut off.
- iii. The water supply into the leaching tank should also be terminated.

12.1.2 Raw materials

The availability and price of suitable raw materials will often determine the site location. Plants producing bulk chemical as the formaldehyde plant are best located close to the source of the major raw materials (which is methanol); where this is also close to the marketing area.

12.1.3 Transport

The transport of materials and products to and from the plant will be an overriding consideration for site selection.

If practicable, a site should be selected that is close to at least two major forms of transport: road, rail, waterway (canal or river), or a sea port. Road transport is being increasingly used, and is suitable for local distribution from a central warehouse. Rail transport will be cheaper for the long-distance transport of bulk chemicals.

Air transport is convenient and efficient for the movement of personnel and essential equipment and supplies, and the proximity of the site to a major airport should be considered.

12.1.4 Availability of labour

Labour will be needed for construction of the plant and its operation. Skilled construction workers will usually be brought in from outside the site area, but there should be an adequate pool of unskilled labour available locally; and labour suitable for training to operate the plant. Skilled tradesmen will be needed for plant maintenance. Local trade union customs and restrictive practices will have to be considered when assessing the availability and suitability of the local labour for recruitment and training.

12.1.5 Utilities (Services)

Chemical processes invariably require large quantities of water for cooling and general process use, and the plant must be located near a source of water of suitable quality. Process water may be drawn from a river, from wells, or purchased from a local authority.

At some sites, the cooling water required can be taken from a river or lake, or from the sea; at other locations cooling towers will be needed. Electrical power will be needed at all sites.

12.1.6 Environmental impact and effluent disposal

All industrial processes produce waste products, and full consideration must be given to the difficulties and cost of their disposal. The disposal of toxic and harmful effluents will be covered by local regulations, and the appropriate authorities must be consulted during the initial site survey to determine the standards that must be met.

12.1.7 Local community considerations

The proposed plant must be fit in with and be acceptable to the local community. Full consideration must be given to the safe location of the plant so that it does not impose a significant additional risk to the community.

On a new site, the local community must be able to provide adequate facilities for the plant personnel: schools, banks, housing, and recreational and cultural facilities.

12.1.8 Availability of suitable land

Sufficient suitable land must be available for the proposed plant and for future expansion. The land should be ideally flat, well drained and have suitable load

bearing capacity. A full site evaluation should be made to determine the need for piling or other special foundations. It should also be available at low cost.

12.1.9 Climate

Adverse climatic conditions at a site will increase costs. Abnormally low temperatures will require the provision of additional insulation & special heating for equipment & pipe runs. Stronger structures will be needed at locations subject to high winds or earthquakes.

12.1.10 Political and strategic consideration

Capital grants, tax concessions and other incentives provided by governments to direct new investment to preferred locations, such as areas of high un-employment should be the overriding considerations in the site selection.

12.2 Selection of Site

Careful consideration of the factors for the site selection outlined above reveals that the best site for this project is Akure in Ondo State, Nigeria.

12.3 Justification of the Selected Site

Actually, the site selected based on the fact that it satisfied more than 95% of the factors considered. For instance, it is close to the source and market apart from having good road network.

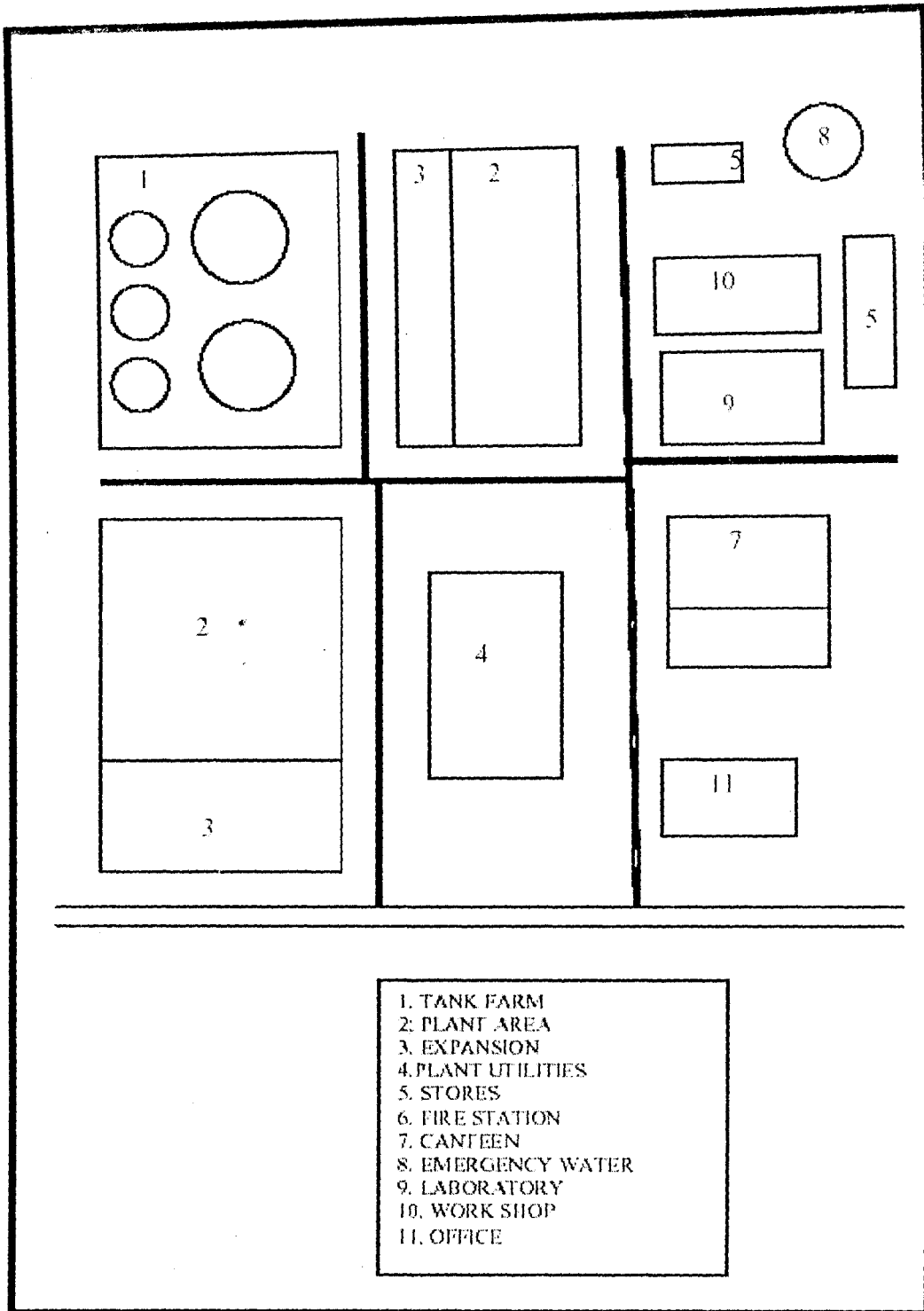


Fig. 12.1: Plant layout

CHAPTER THIRTEEN

13.0 ECONOMIC ANALYSIS

13.1 Purchased Equipment Cost

The purchased equipment cost can be obtained from the cost of existing plant using the relationship

which is given as:

$$C_2 = C_1 \cdot \left(\frac{S_2}{S_1}\right)^n \quad (\text{Sinnot, 1999})$$

where C_2 = capital cost of the project with capacity S_2

C_1 = capital cost of the project with capacity S_1

$$C_1 := 238718475.34 \cdot \text{Naira}$$

$$S_1 := 10 \cdot \frac{\text{tonne}}{\text{day}}$$

$$S_2 := 3 \cdot \frac{\text{tonne}}{\text{day}}$$

$$n := 0.6 \quad (\text{Sinnot, 1999})$$

$$C_2 := C_1 \cdot \left(\frac{S_2}{S_1}\right)^n \quad C_2 = 1.159 \times 10^8 \text{ Naira}$$

Cost index in the year 2005, $n_{2005} := 250.5$

Cost index in the year 2006, $n_{2006} := 270.9$

$$\text{PEC}_{\text{current}} := C_2 \cdot \frac{n_{2006}}{n_{2005}} \quad \text{PEC}_{\text{current}} = 1.254 \times 10^8 \text{ Naira}$$

Estimation of Total Capital Investment

I. Direct Costs

A. Equipment + installation + instrumentation + piping + electrical + insulation + painting

1. Purchased equipment cost (PEC), 15-40% of fixed capital investment

As calculated,

$$\text{PEC} := \text{PEC}_{\text{current}}$$

$$\text{PEC} = 1.254 \times 10^8 \text{ Naira}$$

2. Installation, including insulation and painting, 25-55% of purchased equipment cost

Assuming $Insta := 40\% \cdot PEC$ $Insta = 5.014 \times 10^7$ Naira

3. Instrumentation and controls, installed, 6-30% of purchased equipment cost

Assume $Instr := 11\% \cdot PEC$ $Instr = 1.379 \times 10^7$ Naira

4. Piping installed, 10-80% of purchased equipment cost

Assume $Pip := 30\% \cdot PEC$ $Pip = 3.761 \times 10^7$ Naira

5. Electrical, installed, 10-40% of purchased equipment cost

Assume $Elect := 15\% \cdot PEC$ $Elect = 1.88 \times 10^7$ Naira

So, the cost of equipment, installation, instrumentation, piping, electrical, insulation and painting is given as

$CA := PEC + Insta + Instr + Pip + Elect$ $CA = 2.457 \times 10^8$ Naira

B. Buildings, process and auxiliary, 10-70% of purchased equipment cost

Assume $Build := 20\% \cdot PEC$ $Build = 2.507 \times 10^7$ Naira

C. Service facilities and yard improvements, 40-100% of purchased equipment cost

Assuming $Servi := 50\% \cdot PEC$ $Servi = 6.268 \times 10^7$ Naira

D. Land, 1-2% of fixed capital investment or 4-8% of purchased equipment cost)

Assuming $Lan := 5\% \cdot PEC$ $Lan = 6.268 \times 10^6$ Naira

Thus, the direct cost is equal to

$Direct_Cost := CA + Build + Servi + Lan$ $Direct_Cost = 3.397 \times 10^8$ Naira

II. Indirect costs: expenses which are not directly involved with material and labour of

actual installation of complete facility (15-30% of fixed capital investment)

A. Engineering and supervision, 5-30% of direct cost

Assuming $Engin := 13\% \cdot Direct_Cost$ $Engin = 4.416 \times 10^7$ Naira

B. Construction expense and contractor's fee, 6-30% of direct cost

Assuming $\text{Const} := 15\% \cdot \text{Direct_Cost}$ $\text{Const} = 5.096 \times 10^7 \text{ Naira}$

C. Contingency, 5-15% of direct cost

Assuming $\text{Conti} := 7\% \cdot \text{Direct_Cost}$ $\text{Conti} = 2.378 \times 10^7 \text{ Naira}$

Thus, indirect cost is equal to

$$\text{Indirect_Cost} := \text{Engin} + \text{Const} + \text{Conti} \quad \text{Indirect_Cost} = 1.189 \times 10^8 \text{ Naira}$$

III. Fixed Capital Investment:

Fixed capital investment = Direct cost + Indirect cost

$$\text{Fixed_CI} := \text{Direct_Cost} + \text{Indirect_Cost} \quad \text{Fixed_CI} = 4.586 \times 10^8 \text{ Naira}$$

IV. Working Capital, 11-20% of fixed capital investment

Assuming $\text{Working_C} := 11\% \cdot \text{Fixed_CI}$ $\text{Working_C} = 5.045 \times 10^7 \text{ Naira}$

13.1 V. Total Capital Investment (TCI):

Total capital investment to be Fixed capital investment + Working capital

Assuming $\text{TCI} := \text{Fixed_CI} + \text{Working_C}$ $\text{TCI} = 5.091 \times 10^8 \text{ Naira}$

Estimation of Total Product Cost:

I. Manufacturing Cost = Direct production cost + Fixed charges + Plant overhead cost

A. Fixed Charges, 10-20% of total product cost)

i. **Depreciation**, This depends on life period, salvage value and method of calculation

- about 13% of FCI for machinery and equipment and 2-3% of building value for

~~Assuming~~ ^{buildings} $\text{Depre} := 10\% \cdot \text{Fixed_CI} + 3\% \cdot \text{Build}$ $\text{Depre} = 4.662 \times 10^7 \text{ Naira}$

ii. **Local Taxes**, 1-4% of fixed capital investment

Assuming $\text{Tax} := 3.5\% \cdot \text{Fixed_CI}$ $\text{Tax} = 1.605 \times 10^7 \text{ Naira}$

iii. **Insurance**, 0.4-1% of fixed capital investment)

Assuming $\text{Insur} := 0.6\% \cdot \text{Fixed_CI}$ $\text{Insur} = 2.752 \times 10^6 \text{ Naira}$

iv. Rent, 8-12% of value of fixed capital investment

Assuming $\text{Ren} := 10\% \cdot \text{Fixed_CI}$ $\text{Ren} = 4.586 \times 10^7 \text{ Naira}$

Thus, fixed charges is given as

$\text{Fixed_Charges} := \text{Depre} + \text{Tax} + \text{Insur} + \text{Ren}$ $\text{Fixed_Charges} = 1.113 \times 10^8 \text{ Naira}$

13.2 B. Direct Production Cost (Operating Cost):

Fixed charges is 10-20% of total product cost

Assuming $\text{Fixed_Charges} = 15\% \cdot \text{TPC}$

making total product cost, TPC, the subject of the formula,

$$\text{TPC} = \frac{\text{FC}}{15\%}$$

$$\text{TPC} := \frac{\text{Fixed_Charges}}{15\%} \quad \text{TPC} = 7.419 \times 10^8 \text{ Naira}$$

i. Raw materials, 10-50% of total product cost)

Assuming

$\text{Raw_mat} := 15\% \cdot \text{TPC}$ $\text{Raw_mat} = 1.113 \times 10^8 \text{ Naira}$

ii. Operating Labour (OL), 10-20% of total product cost

Assuming

$\text{OperL} := 10\% \cdot \text{TPC}$ $\text{OperL} = 7.419 \times 10^7 \text{ Naira}$

iii. Direct Supervisory and Clerical Labour (DS & CL), 10-25% of OL

Assuming

$\text{DireS} := 15\% \cdot \text{OperL}$ $\text{DireS} = 1.113 \times 10^7 \text{ Naira}$

iv. Utilities, 10-20% of total product cost

Assuming

$\text{Util} := 12.5\% \cdot \text{TPC}$ $\text{Util} = 9.274 \times 10^7 \text{ Naira}$

v. Maintenance and repairs (M & R), 2-10% of fixed capital investment

Assuming

$\text{Maint} := 3.7\% \cdot \text{Fixed_CI}$ $\text{Maint} = 1.697 \times 10^7 \text{ Naira}$

vi. Operating Supplies, 10-20% of M & R or 0.5-1% of FCI

Assuming

$\text{OperS} := 17\% \cdot \text{Maint}$ $\text{OperS} = 2.885 \times 10^6 \text{ Naira}$

vii. Laboratory Charges, 10-20% of OL

Assuming $\text{Lab} := 15\% \cdot \text{OperS}$ $\text{Lab} = 4.327 \times 10^5 \text{ Naira}$

viii. Patent and Royalties, 0-6% of total product cost

Assuming $\text{Paten} := 4.5\% \cdot \text{TPC}$ $\text{Paten} = 3.338 \times 10^7 \text{ Naira}$

Thus, direct production cost is

$$\text{DPC} := \text{Raw_mat} + \text{OperL} + \text{DireS} + \text{Util} + \text{Maint} + \text{OperS} + \text{Lab} + \text{Paten}$$
$$\text{DPC} = 3.43 \times 10^8 \text{ Naira}$$

C. Plant Overhead Costs, 50-70% of operating labour, supervision, and maintenance or 5-15% of total product cost); includes for the following: general plant upkeep and overhead, payroll overhead, packaging, medical services, safety and protection, restaurants, salvage, laboratories, and storage facilities.

Considering the plant overhead cost to be 55% of OL, DS & CL and M & R

Therefore,

$$\text{Plant_Overhead} := 55\% \cdot (\text{OperL} + \text{DireS} + \text{Maint}) \quad \text{Plant_Overhead} = 5.626 \times 10^7 \text{ Naira}$$

Manufacture cost = Direct production cost + Fixed charges + Plant overhead cost

$$\text{Manuf} := \text{DPC} + \text{Fixed_Charges} + \text{Plant_Overhead} \quad \text{Manuf} = 5.105 \times 10^8 \text{ Naira}$$

II. General Expenses = Administrative costs + distribution and selling costs + research

and development costs

A. Administrative costs, 2-6% of total product cost

Assuming $\text{Admin} := 3\% \cdot \text{TPC}$ $\text{Admin} = 2.226 \times 10^7 \text{ Naira}$

B. Distribution and Selling Costs, 2-20% of total product cost; includes costs for sales offices, salesmen, shipping, and advertising.

Assuming $\text{Distr} := 11\% \cdot \text{TPC}$ $\text{Distr} = 8.161 \times 10^7 \text{ Naira}$

C. Research and Development Costs, about 5% of total product cost

Assuming $\text{Resea} := 5\% \cdot \text{TPC}$ $\text{Resea} = 3.709 \times 10^7 \text{ Naira}$

D. Financing (Interest), 0 - 10% of total capital investment

$$\text{Assuming} \quad \text{Interest} := 5\% \cdot \text{TCI} \quad \text{Interest} = 2.545 \times 10^7 \text{ Naira}$$

Thus, general expenses,

$$\text{Gener} := \text{Admin} + \text{Distr} + \text{Resea} + \text{Interest} \quad \text{Gener} = 1.664 \times 10^8 \text{ Naira}$$

III. Total Product Cost = Manufacture Cost + General Expenses

$$\text{TProdC} := \text{Manuf} + \text{Gener} \quad \text{TProdC} = 6.77 \times 10^8 \text{ Naira}$$

13.3 V. Gross Earnings/Income (Revenue Expectations):

The selling price of the product is

$$\text{Selling_price} := 716 \cdot \frac{\text{Naira}}{\text{kg}}$$

$$\text{Quantity_Produced} := 3048.1800 \cdot \frac{\text{kg}}{\text{day}}$$

Assuming that the attainment is $\text{Attainment} := 341 \cdot \text{day}$

Total income = Selling price x quantity of product manufactured

$$\text{Assume Total_income} := \text{Selling_price} \cdot \text{Quantity_Produced} \cdot \text{Attainment}$$

$$\text{Total_income} = 7.442 \times 10^8 \text{ Naira}$$

Gross income = Total income - Total Product Cost

$$\text{That is,} \quad \text{Gross_income} := \text{Total_income} - \text{TPC} \quad \text{Gross_income} = 2.35 \times 10^6 \text{ Naira}$$

Tax rate = 45% of gross income, $\text{Tax_rate} := 45\%$

$$\text{Taxes} := 45\% \cdot \text{Gross_income} \quad \text{Taxes} = 1.058 \times 10^6 \text{ Naira}$$

Net profit = Gross income - Taxes

$$\text{Net_profit} := \text{Gross_income} - \text{Taxes} \quad \text{Net_profit} = 1.293 \times 10^6 \text{ Naira}$$

Calculation of Rate of Return:

$$\text{Rate_of_return} = \frac{\text{Net_profit}}{\text{Total_CI}} \cdot 100$$

Therefore,

$$\text{Rate_of_return} := \frac{\text{Net_profit}}{\text{TCI}} \cdot 100 \quad \text{Rate_of_return} = 25.393 \%$$

13.4 Cash Flow

Cash flow is the difference between the amount earned and the amount expended.

$$\text{Cash_Flow} := \text{Total_income} - \text{TProdC} \qquad \text{Cash_Flow} = 6.728 \times 10^7 \text{ Naira}$$

13.5 Pay-Back Period

The pay-back period is calculated as the reciprocal of the rate of return.

Therefore,

$$\text{Pay_back_period} := \frac{1}{\text{Rate_of_return}} \cdot \text{yr} \qquad \text{Pay_back_period} = 3.94 \text{ yr}$$

13.6 Discounted Cash Flow Rate or Return

The discounted cash flow is the interest rate that will make the condition given as

$$\text{DCF} = \sum_{i=1}^n \frac{\text{Cash_Flow}}{(1+r)^i} = 0$$

Using trial-and-error calculations as suggested by Sinnott R. K. (Coulson and Richardson's

Chemical Engineering, 3rd Edition, pg 277,

$$r := 53 \cdot \% \qquad n := 61 \qquad \text{DCFRR} := r$$

$$\text{DCF} := \sum_{i=1}^n \frac{\text{Cash_Flow}}{(1+r)^i} \qquad \text{DCF} = 0$$

Therefore, the Discounted Cash Flow Rate of Return (DCFRR) is equal to DCFRR = 53%.

13.7 Return on Investment

This is calculated as given thus.

Return on investment (ROI) is given by the expression,

$$\text{ROI} = \frac{\text{Total_profit_less_depreciation}}{\text{Total_investment}}$$

That is,

$$\text{ROI} := \frac{\text{Total_income} - \text{Depre}}{\text{Total_income}} \cdot 100\% \qquad \text{ROI} = 93.736 \%$$

13.8 Project Income and Expenses Statement for 2006-2009

It is expected that the performance of the plant should increase every year. The projected income

and expenses for four consecutive years are as shown below.

Table 13.1: Projected income and expenses statement for the year 2006 to 2009

DESCRIPTION	YEARS			
	2006	2007	2008	2009
kg/day	3048.18	3483.63	3919.09	4354.54
Capacity (%)	70	80	90	100
REVENUE	AMOUNT IN NAIRA			
Net sales	744231436.08	850550212.66	956868989.25	1063187765.83
EXPENDITURE				
Raw material	111282159.73	127179611.12	143077062.51	158974513.90
Factory labour	74188106.49	84786407.42	95384708.34	105983009.27
Depreciation	46615231.52	53274550.31	59933869.10	66593187.89
Overhead	56257112.03	64293842.32	72330572.61	80367302.90
TOTAL	288342609.77	329534411.17	370726212.56	411918013.96
PROFIT				
Before tax	455888826.31	521015801.50	586142776.68	651269751.87
Tax	1057667.05	1208762.34	1359857.64	1510952.93
Net profit	454831159.26	519807039.15	584782919.05	649758798.94

13.9 Conclusion on the Economic Viability of the Project

The total capital investment of the plant which is $TCI = 5.091 \times 10^8$ Naira and a net profit of $Net_profit = 1.293 \times 10^6$ Naira have revealed that the project is economically viable with a pay back period of $Pay_back_period = 3.938$ yr.

CHAPTER FOURTEEN

14.0 RECOMMENDATIONS TO THE INDUSTRIALIST

14.1 General Recommendations

Based on the design work carried out, the following recommendations are made to the industrialists to be noted during the construction, start-up and operating phases of the work:

- i. Personnel should undergo routine training about new work ethic and equipments to improve their knowledge of the plant operation and increase overall plant productivity.
- ii. The safety of workers, equipments and infrastructures should be highly evaluated during the design implementation stage of the design.
- iii. Adequate data and technological parameters should be at the possession of the plant operations at all time to forestall any unwanted accident.
- iv. Routine turn around plant maintenance should be of paramount importance in the design. An articulate and organised maintenance team should safeguard quick plant shut down and ensure equipment salvage value. This will also take care of schedule, slippage, cost over-run and possible re-work.
- v. Procurement of raw materials and equipments should be based on strict regulation of specification and maximum quality.
- vi. The implementation of this design work must be adequately supervised by the experts.
- vii. Alternative sources of energy should be available at all times to avoid plant failure and possible sources of failure.
- viii. The water and air around the plant should monitored regularly to ensure compliance with the Environmental Protection Agency Standards.

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