DESIGN OF A PLANT TO PRODUCE 500,000 LITRES PER MONTH OF ETHANOL USING THE DRY MILLING METHOD (SOURCE: CASSAVA)

BY

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2003/15084EH

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NIGER STATE, NIGERIA

NOVEMBER, 2008

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A DESIGN PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE, NIGERIA

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN CHEMICAL ENGINEERING

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DECLARATION

I, Ekeocha Chukwuemeka Donaldson (2003/15084EH), hereby declare that this design project, "Design of a Plant to Produce 500,000 Litres per Month of Ethanol Using the Dry Milling Method (Source: Cassava)", carried out under the supervision of Engr M.S Galadima. and presented in partial fulfilment 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.

Ekeocha Chukwuemeka D.

13/11/08
Date

CERTIFICATION

This is to certify that this design project titled "Design of a Plant to Produce 500,000 Litres per Month of Ethanol Using the Dry Milling Method (Source: Cassava)" was carried out by Ekeocha Chukwuemeka Donaldson. (2003/15084EH) and submitted to the Department of Chemical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Minna, Niger State, in partial fulfilment of the requirement for the award of Bachelor of Engineering (B. Eng.) degree in Chemical Engineering.

M. S. Galadima

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(Project Supervisor)

07-11-08
Date

Dr .M. O.Edoga
(Head of Department)

Date

External Examiner

Date

DEDICATION

This project is dedicated to God my loving parents Mr and Mrs R.J Ekeocha for their efforts towards the success and completion of this work.

ACKNOWLEDGEMENT

My sincere and profound gratitude goes to Almighty God for granting me the opportunity to complete this work successfully.I wish to express my sincere gratitude to my supervisor Engr M. S Galadima. Who despite his tight schedules still found time to supervise and make this work a reality.

Thanks goes to my parents for all their support both financially, morally and spiritually. To my siblings Dozie, Chioma, Onyinye and Onyedikachi I love you guys. To the families of r and Mrs John Anufuro and Mr and Mrs Echefu for their support may God bless your families

This work wil be incomplete if I fail to acknowledge the support of my group members, I love you all then to all my friends Kingsley, Prophet, Momoh, Dowasanta, Buzz, Oga D, U.P, Biano Toyosi Bizzy and finally to Onyinye(2.4)

ABSTRACT

Design of a Plant to Produce 500,000 Litres per Month of Ethanol Using the Dry Milling Method (Source: Cassava) was carried out in this work. In the design of this plant to produce 500,000 Litres per Month of ethanol, 317.75 kmol/day of ethanol was passed into the reactor. The various units involved in the plant such as the storage tank, crusher, liquefaction tank, sacharifying tank, fermentor, distillator, dehydrator, centrifugal separator and dryer were sized. Finally, the economic analysis of the plant showed that fixed capital investment, working capital and total capital investment of the plant were ₦35990000, ₦4679000.73 and ₦ 4067000088. respectively. The plant was found to be economically viable with the rate of return of 75.978% and a pay back period of 1.316 years.

TABLE OF CONTENTS

Title Page i

Declaration ii

Certification iii

Dedication iv

Acknowledgement v

Abstract vi

Table of Contents vii

CHAPTER ONE

1.0 Introduction 1

CHAPTER TWO

2.0 Literature Review 3

CHAPTER THREE

3.0 Material Balances 24

CHAPTER FOUR

4.0 Energy Balances 38

CHAPTER FIVE

5.0 Flow Sheet/Diagram 86

CHAPTER SIX

6.0 Equipment Design 87

CHAPTER SEVEN

7.0 Equipment Optimization 107

CHAPTER EIGHT

8.0 Safety and Quality Control 111

CHAPTER NINE

9.0 Process Control and Instrumentation 117

CHAPTER TEN

10.0 Environmental Acceptability 122

CHAPTER ELEVEN

11.0 Start Up and Shut Down Procedure 124

CHAPTER TWELVE 126

12.0 Site for Plant Location

CHAPTER THIRTEEN

13.0 Economic Analysis 129

CHAPTER FOURTEEN

14.0 Recommendation to the Industrialist 142

References 143

CHAPTER ONE

1.0 INTRODUCTION

Most countries' transport and electricity generation sectors are heavily dependent on petroleum fuels. Finding sustainable alternatives for these two sectors is necessary for the economic development of these Countries. The transportation sector, consumes fuels in two major ways; as petrol (or gasoline) for most small capacity vehicles and as diesel for most of the heavy-duty vehicles and plants. Gasoline (petrol) can be substituted with bioethanol. Diesel on the other hand can be substituted with non-edible vegetable oil, after esterification treatment. In any case, the first ever diesel engine was run with groundnut oil by the German Engineer, Rudolf Diesel in 1893(Crouse & Anglin, I 994).The conventional petrol/diesel engines of the vehicles we have today would not require major modification to use these alternative bio-fuels. Interestingly, our various agricultural waste products, such as corn stalk and comb, millet stalk, rice straw; etc can all be processed to produce bio-ethanol.

Due to the increasing uncertainty regarding the future availability of crude oil, a design of alternative energy sources, preferably from renewable sources. Cassava is a potential producer of ethanol, considering its potentially high yields and low cost. Yet few report concern the industrial application of cassava for ethanol production. This may be because, first, cassava cultivation yields relatively few commercially significant byproducts, compared with, for "'example, sugarcane which yields enormous quantities of bagasse, a valuable source of energy for distillation. Secondly, cassava starch needs to be hydrolyzed

into sugar for bioconversion into ethanol by the common saccharomyces cerevisiae (Lynd, 1996). Ethanol is a colourless water soluble alcohol with the molecular formular CH_3CH_2OH. It is a volatile liquid with a boiling point of 78.3°C; it has a vinous odour and a pungent taste and it is miscible with water and most organic solvents. It burns in air with a flame that is almost colourless. Ethanol is the active principle in alcoholic drinks and it is an important solvent and may be manufactured in three (3) different ways.

It is produced from molasses or cassava starch through fermentation process. Molasses is obtained from sugar industry. It is the spent liquor that has no more economic value. Cassava starch is polysaccharide composing of various proportions of two cellulose polymers: amylase and amylopectin. It occurs naturally in plants especially roots, tubers, seeds fruits as carbohydrate store.

Although ethanol has virtually no direct end use, it has many industrial applications. Its use as a solvent is more prominent; it is used ~1s01vent for organic substances like resins, fats, acids, oil and hydrocarbons. It is also used in the manufacture of acetaldehyde, dyes, pharmaceuticals (drugs), detergents, cosmetics explosives, beverages, antisepsis, adhesives and gasohol which is a blend of ethanol and gasoline used as fuel.

Fermentation is one of the oldest known biological processes, dating back to thousands of years. Though many of the fundamentals of fermentation have been well understood for hundreds of years by brewers, biologist, and wine makers, the kinetics of this biological process can be studied using fundamentals of reaction engineering for non-biological processes (Prescott, 1959).

Therefore in view of the growing concern over the availability of cheap raw material, the ever increasing demand, the future of our fossil fuel and for the fact that life cannot be worthwhile without energy, the importance of this project cannot be over emphasized. The aim of this project is to design a plant to process 2000 tonnes per day of cassava.The project covers design of; a crusher, chemical converter of polysaccharide to ethanol (fermenters), distillation units with heat exchanger. This work also covers, process monitoring control, environmental management system and safety, economic analysis to determine the cost at which a liter of Bio -ethanol and other products of the plant.

CHAPTER TWO

2.0 LITERATURE REVIEW

Ethanol is a liquid alcohol made of oxygen, hydrogen and carbon and is obtained from the fermentation of sugar or converted starch contained in grains and other agricultural or agri-forest feedstocks(www.oee.nrcan.gc.ca). Ethanol (ethyl alcohol, grain alcohol) is a clear, colorless liquid with a characteristic, agreeable odor. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste. Ethanol, is an alcohol, a group of chemical compounds whose molecules contain a hydroxyl group, –OH, bonded to a carbon atom. Ethanol has the molecular formular C_2H_5OH and the following structure.(http//en.wikipedia.org/wiki/ethanol) .

The word alcohol derives from an Arabic word *al-kuhul*, which denotes a fine powder of antimony used asan eye makeup, alcohol originally referred to any fine powder, but medieval chemists later applied the term to the refined products of distillation, and this led to the current usage (Shakhashiri, www.scifun.org). Ethanol melts at –114.1°C, boils at 78.5°C, and has a density of 0.789 g/mL at 20°C. Its low freezing point has made it useful as the fluid in thermometers for temperatures below –40°C, the freezing point of mercury, and for other low-temperature purposes, such as for antifreeze in automobile radiators.

Ethanol has been made since ancient times by the fermentation of sugars. All beverage ethanol and more than half of industrial ethanol is still made by this process. Simple sugars are the raw material. Zymase, an enzyme from yeast, changes the simple sugars into ethanol and carbon dioxide. The fermentation reaction, represented by the simple equation

$$C_6H_{12}O_6 \rightarrow 2\ CH_3CH_2OH + 2\ CO_2$$

is actually very complex, and impure cultures of yeast produce varying amounts of other substances, including glycerine and various organic acids. In the production of beverages, such as whiskey and brandy, the impurities supply the flavor. Starches from potatoes, corn, wheat, and other plants can also be used in the production of ethanol by fermentation. However, the starches must first be broken down into simple sugars. An enzyme released by germinating barley, diastase, converts starches into sugars. Thus, the germination of barley, called malting, is the first step in brewing beer from starchy plants, such as corn and wheat.The ethanol produced by fermentation ranges in concentration from a few percent up to about 14 percent. Above about 14 percent, ethanol destroys the zymase enzyme and fermentation stops. Ethanol is normally concentrated by distillation of aqueous solutions, but the composition of the vapor from aqueous ethanol is 96 percent ethanol and 4 percent water. Therefore, pure ethanol cannot be obtained by distillation.

Commercial ethanol contains 95 percent by volume of ethanol and 5 percent of water. Dehydrating agents can be used to remove the remaining water and produce absolute ethanol.Much ethanol not intended for drinking is now made synthetically, either from acetaldehyde made from acetylene,or from ethylene made from petroleum. Ethanol can be oxidized to form first acetaldehyde and then acetic acid. It can be dehydrated to form ether. Butadiene, used in making synthetic rubber, may be made from ethanol, as can chloroform and many other organic chemicals. Ethanol is used as an automotive fuel by itself and can be mixed with gasoline to form gasohol. Ethanol is miscible in all proportions with water and with most organic solvents. It is useful as a solvent for many substances and in making perfumes, paints, liquor, and explosives. Alcoholic solutions of nonvolatile substances are called tinctures; if the solute is volatile, the solution is called a spirit.

Most industrial ethanol is denatured to prevent its use as a beverage. Denatured ethanol contains small amounts,1 or 2 percent each, of several different unpleasant or poisonous substances. The removal of all these substances would involve a series of treatments more expensive. These denaturants render ethanol unfit for some industrial uses. In such industries undenatured ethanol is used under close supervision.

Ethanol is toxic, and the body begins to dispose of it immediately upon its consumption. Over 90% of it is processed by the liver. In the liver, the alcohol dehydrogenase enzyme converts ethanol into acetaldehyde, which is itself toxic.

$CH3CH2OH \rightarrow CH3\ C\ OH + 2\ H$

Acetaldehyde is destroyed almost immediately by the aldehyde dehydrogenase enzyme, which converts it to acetate ions.

History of ethanol

Ethanol has been used by humans since prehistory as the intoxicating ingredient of alcoholic beverages. Dried residues on 9000-year-old pottery found in China imply that alcoholic beverages were used even among Neolithic people(wikipedia) Its isolation as a relatively pure compound was first achieved by, Persian alchemist, Zakarīya Rāzi (Rhazes), who was renowned for his perfected methods of distillation and extraction. Other chemists who contributed to the development of distillation techniques during the Abbasid caliphate, other than Razi, include Jabir ibn Hayyan (Geber) and Al-Kindi (Alkindus).Writings attributed to Jabir ibn Hayyan mention the flammable vapors of boiled wine. Al-Kindi unambiguously described the distillation of wine (Hassan et al 2008)

In 1796, Johann Tobias Lowitz obtained pure ethanol by filtering distilled ethanol through activated charcoal. Antoine Lavoisier described ethanol as a compound of carbon, hydrogen, and oxygen, and in 1808 Nicolas-Théodore de Saussure determined ethanol's chemical formula(Encyclopedia Britannica). Fifty years later, Archibald Scott Couper published the structural formula of ethanol, which placed ethanol among the first chemical compounds to have their chemical structure determined (Couper, A.S. 1858). Ethanol was first prepared synthetically in 1826 through the independent efforts of Henry

Hennel in Great Britain and S.G. Sérullas in France. In 1828, Michael Faraday prepared ethanol by acid-catalyzed hydration of ethylene, a process similar to that which is used today for industrial ethanol synthesis. (Hennell H, 1828).

Ethanol was used as lamp fuel in the United States as early as 1840, but a tax levied on industrial alcohol during the Civil War made this use uneconomical. This tax was repealed in 1906, and from 1908 onward Ford Model T automobiles could be adapted to run on ethanol. With the advent of Prohibition in 1920 though, sellers of ethanol fuel were accused of being allied with moonshiners and ethanol fuel again fell into disuse until late in the 20th century.(wikipedia)

2.1 Physical and Chemical properties of ethanol.

The physical and chemical properties of ethanol are important factors to be considered when handling the product for a safe and economic production process.

2.1.1 Physical properties

i. Ethanol is a colorless, volatile liquid with a characteristic taste and smell

ii. It is readily soluble in water in all proportions due to the presence of the hydroxyl group.

iii. It has a boiling point of 78.3^0C and freezing point of -114.1^0C.

iv. It has density 0.7893 and flash point 14^0C.

v. Ethanol has a viscosity of 1.200 mPa·s (cP) at 20.0 °C

2.1.2 Chemical properties

The chemical properties of ethanol are:

i. Combustion

Ethanol readily burns in air or oxygen with a pale blue flame, yielding Carbon (iv) oxide.

ii. Oxidation

Ethanol is readily oxidized to ethanal by warming with potassiumheptaoxodichromate (vi) solution which has been acidified with dilute tetraoxosulphate(vi) acid

$$C_2H_5OH_{(aq)} \longrightarrow CH_3CHO_{(g)} + H_2O_{(l)}$$

On further oxidation in the presence of excess tetraoxosulphate (vi) acid, the ethanol is converted to ethanoic acid

$$C_2H_5OH_{(aq)} \longrightarrow CH_3COOH_{(aq)}$$

iii. Esterification

Ethanol reacts reversibly with acids forming ethyl esters.This is known as esterificaton.

Alcohol + Acid = Ester + Water

iv. Dehydration

Strong acid desiccants, such as sulfuric acid, cause ethanol's dehydration to form either diethyl ether or ethylene:

$2\ CH_3CH_2OH \rightarrow CH_3CH_2OCH_2CH_3 + H_2O$

$CH_3CH_2OH \rightarrow H_2C{=}CH_2 + H_2O$

Which product, diethyl ether or ethylene, predominates depends on the precise reaction conditions.

V. Halogenation

Ethanol reacts with hydrogen halides to produce ethyl halides such as ethyl chloride and ethyl bromide:

$CH_3CH_2OH + HCl \rightarrow CH_3CH_2Cl + H_2O$

HCl reaction requires a catalyst such as zinc chloride. Hydrogen chloride in the presence of their respective zinc chloride is known as Lucas reagent.(wikipedia)

$CH_3CH_2OH + HBr \rightarrow CH_3CH_2Br + H_2O$

HBr requires refluxing with a sulfuric acid catalyst.

Ethyl halides can also be produced by reacting ethanol with more specialized halogenation agents, such as thionyl chloride for preparing ethyl chloride, or phosphorus tribromide for preparing ethyl bromide.

$CH_3CH_2OH + SOCl_2 \rightarrow CH_3CH_2Cl + SO_2 + HCl$

Vi Acid-base chemistry

Ethanol's hydroxyl causes the molecule to be slightly basic. It is however, so very slightly basic it is almost neutral, like pure water. The pH of 100% ethanol is 7.33, compared to 7.00 for pure water. Ethanol can be quantitatively converted to its conjugate base, the ethoxide ion (CH3CH2O−), by reaction with an alkali metal such as sodium:

2CH3CH2OH + 2Na → 2CH3CH2ONa + H2

or a very strong base such as sodium hydride:

CH3CH2OH + NaH → CH3CH2ONa + H2

This reaction is not possible in an aqueous solution, as water is more acidic, so that hydroxide is preferred over ethoxide formation.

2.2 Ethanol as fuel

Though not widely used in Africa for this purpose, the science of ethanol as fuel is under intense exploration in developed countries. 100% ethanol is not generally used as motor fuel; instead, a percentage of ethanol is combined with unleaded gasoline. This is beneficial because the ethanol decreases the fuel's cost, increases the fuel's octane rating, and decreases gasoline's harmful emissions (American coalition of ethanol). Fuel ethanol, which is sometimes referred to as "gasohol", has been distilled and dehydrated to create a high-octane, water-free alcohol. All water must be removed because a water-alcohol mixture cannot dissolve in gasoline. Fuel ethanol is made unfit for drinking by adding a small amount of a noxious substance such as gasoline(www.oee. nrcan.gc.ca). Any amount of ethanol can be combined with gasoline, but the most common blends are:

2.2.1 E10

This is a blend of 10% ethanol and 90% unleaded gasoline and it is approved for use in any make or model of vehicle sold in the United States, because of its high performance and clean-burning characteristics its has been recommend by many automakers.

2.2.2 E85

E85 is a bend of 85% ethanol and 15% unleaded gasoline, its an alternative fuel for use in flexible fuel vehicles (FFVs). There are currently more than 6 million FFVs on America's roads today, when E85 is not avaialble, these FFVs can operate on straight gasoline or any ethanol blend up to 85%.

It is important to note that it does not take a special vehicle to run on "ethanol". All vehicles are "ethanol vehicles" and can use up to 10% ethanol with no modifications to the engine. Often people confuse E85 for "ethanol", believing incorrectly that not all vehicles are ethanol-compatible.

2.2.3 Chemistry of Ethanol fuel

In this 3-d diagram of ethanol, the lines represent single block Glucose is created in the plant by photosynthesis.

$$6CO_2 + 6H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2$$

During ethanol fermentation, glucose is decomposed into ethanol and carbon dioxide.

$$C_6H_{12}O_6 \rightarrow 2C_2H_6O + 2CO_2 + \text{heat}$$

During combustion ethanol reacts with oxygen to produce carbon dioxide, water, and heat:

$$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O + \text{heat}$$

After doubling the ethanol combustion reaction because two molecules of ethanol are produced for each glucose molecule, there are equal numbers of each type of molecule on each side of the equation, and the net reaction for the overall production and consumption of ethanol is just:

$$\text{light} \rightarrow \text{heat}$$

The heat of the combustion of ethanol is used to drive the piston in the engine by expanding heated gases. It can be said that sunlight is used to run the engine. Air pollutants are also produced when ethanol is burned in the atmosphere rather than in pure oxygen. Harmful nitrous oxide gases are produced. Nitrogen dioxide is one of the harmful gases as is a major contributor to the formation of "brown smog".

Table 2.1 Fuel properties of ethanol compared to petrol

Fuel Properties	**Ethanol**	**Petrol**
Chemical Formula	C_2H_5OH	C_8H_{15}
Molecular weight[kg/kmol]	46	111

Octane number (RON)	109	97
Octane number (MON)	92	86
Cetane number	11	8
Reid Vapor Pressure[kpa] at 15^{0}C	16.5	75
Density [kg/l] at 15^{0}C	0.8	0.75
Lower Calorific Value[MJ/kg] at 15^{0}C	26.4	41.3
Lower Calorific Value[MJ/l] at 15^{0}C	21.2	31
Stoichiometric air/fuel ratio [kg air/kg fuel]	9.0	14.7
Boiling temperature[^{0}C]	78	30-180

Source: Kroon 1996.

2.2.4 Benefits of Ethanol Fuel

Ethanol is a much cleaner fuel than petrol (gasoline) and has the following benefits

i. It is a renewable fuel made from plants
ii. It is not a fossil-fuel: manufacturing it and burning it does not increase the greenhouse effect
iii. It provides high octane at low cost as an alternative to harmful fuel additives

iv. Ethanol blends can be used in all petrol engines without modifications

v. Ethanol is biodegradable without harmful effects on the environment

vi. It significantly reduces harmful exhaust emissions

vii. Ethanol's high oxygen content reduces carbon monoxide levels more than any other oxygenate: by 25-30%, according to the United States Environmental Protection Agency

viii. Ethanol blends dramatically reduce emissions of hydrocarbons, a major contributor to the depletion of the ozone layer

ix. High-level ethanol blends reduce nitrogen oxide emissions by up to 20%

x. Ethanol can reduce net carbon dioxide emissions by up to 100% on a full life-cycle basis

xi. High-level ethanol blends can reduce emissions of Volatile Organic Compounds (VOCs) by 30% or more (VOCs are major sources of ground-level ozone formation)

xii. As an octane enhancer, ethanol can cut emissions of cancer-causing benzene and butadiene by more than 50%

xiii. Sulphur dioxide and Particulate Matter (PM) emissions are significantly decreased with ethanol.

(source: http://www.Journeytoforever.org)

2.2.5 Aviation grade ethanol (AGE-85)

Aviation Grade Ethanol (AGE-85) is a high-performance, 85 percent ethanol-blended fuel for use in any reciprocating engine aircraft which is beginning to replace 100 octane low lead aviation gasoline (avgas), which has been the standard leaded gasoline for aviation since World War II. Though avgas is the single largest contributor of lead in the atmosphere today, the Environmental Protection Agency has allowed its use until a suitable unleaded replacement can be found. Several millions of gallons of avgas are used each year by the piston engine fleet in aircrafts .

AGE-85 offers a substantial improvement in performance for these aircraft, producing at least 12 percent more horsepower and torque at typical cruising power. Lower operating temperatures are also achieved, with engines tending to run 50 to 100 degrees cooler than similar settings on avgas. Because this fuel causes considerably less buildup of combustion byproducts in the engine, the time between engine overhauls is greater and maintenance costs are lower.

2.2.6 Disadvantages of fuel ethanol

The most important problem with respect to the use of pure ethanol in vehicle engines is that at low temperatures, its evaporation is too slow for use in combustion engines. The ignitability of ethanol can be improved by mixing with addictives (such as petrol) of heating the alcohol with an electrical heating element at the inlet of the engine.

Another difficulty concerns the lower volumetric energy content of ethanol. This entails that larger fuel flows are needed compared to the original engine design to get the same engine performance. Moreover, less oxygen is needed for combustion. This means that the combustion chamber, the valve, the location of the spark plug and the fuel system need to be able to use pure ethanol. The application of ethanol as a transportation fuel requires some adaptations of the petrol distribution infrastructure and refueling facilities.

First of all, the energy content of ethanol is lower, which means larger storage tanks are needed. On board of the vehicle, one can also choose a larger fuel tank. If the same tank volume is used, the vehicle range is reduced. For tankers and storage tanks, the material s used should be compatible with ethanol, just like the engine components. Storage tanks should be water tight because ethanol is soluble in water. Furthermore, they must be equipped with fixed roofs and internal floating covers.

Other infrastructural issues concerns the safety of ethanol handling .For extinguishing an ethanol flame, water can be used. However for mixtures with petrol one should use CO_2 or form instead, because by adding water, the petrol is expelled from the mixture and washed away. As ethanol burns with a visible flame, no special measures have to be taken to improve the luminosity of an ethanol flame (Reith et al, 2001)

2.2.7 Differences between Ethanol and Gasoline

Gasoline is a complex mixture of hydrocarbons substances comprising just hydrogen and carbon atoms. These hydrocarbons can appear in all forms (as a gas, liquid, or solid), but for our purposes, we're concerned with the fuel in its liquid state. To derive various hydrocarbon fuels, the industry merely refines crude oil (made many millions of years ago as a result of geological and biological cycles) and draws off the desired product at a certain temperature and pressure. Hence there are the lighter, gaseous fuels such as butane, propane, and ethane the liquids like octane, pentane, and hexane the heavier,oily liquids such as kerosene and fuel oil and so on the way down through waxes and finally solids.

Gasoline as we know it is a combination of octane, benzene, toluene, various other aromatics, tetraethyl lead, detergents and compounds of sulfur, phosphorus, and boron. Because of this complex mixture of ingredients and because the refineries vary the blend to suit climate, seasonal changes, and altitude it's difficult to choose a "representative" sample of gasoline for comparison purposes. Nonetheless, the figures that are given in the "Properties of Gasoline, Ethanol, and Methanol" chart which follows are fairly typical of average high-test automotive gasoline.

2.2.8 Octane Rating

Actually, when referring to alcohol fuels, the word "octane" does not apply, since octane (in its pure form) is merely the hydrocarbon in gasoline which is assigned the numerical value of 100 for fuel-rating purposes. The octane number given automotive fuels is really an indication of the ability of the fuel to resist premature detonation within the combustion chamber. (Premature detonation, or engine knock, comes about when the fuel/air mixture ignites spontaneously toward the end of the compression stroke because of intense heat and pressure within the combustion chamber. Since the spark plug is supposed to ignite the mixture at a slightly later point in the engine cycle, pre-ignition is undesirable.

Because a high compression ratio in an engine results in more power per stroke, greater efficiency, and better economy, it's easy to see why a fuel that resists pre-ignition even under high compression conditions is especially desirable and alcohol is, on the average, about 16 points higher on the research octane scale than premium gasoline.

2.2.7 Heat value

The heating value of a fuel is a measure of how much energy we can get from it on a per-unit basis, be it pounds or gallons. When comparing alcohol to gasoline using this "measuring stick", it's obvious that ethanol contains only about 63% of the energy that gasoline does mainly because of the presence of oxygen in the alcohol's structure. But since alcohol undergoes different changes as it's vaporized and compressed in an engine, the outright heating value of the ethanol isn't as important when it's used as a motor fuel.

The fact that there's oxygen in the alcohol's structure also means that this fuel will naturally be "leaner" in comparison to gasoline fuel without making any changes to the jets in the carburetor. This is one reason why we must enrich the air/fuel mixture (add more fuel) when burning alcohol by increasing the size of the jets, which we'll discuss further in another section.

2.2.8 Volatility

The volatility of a fuel refers to its ability to be vaporized. This is an important factor, because if vaporization doesn't occur readily, the fuel can't be evenly mixed with air and is of little value in an engine. Some substances that are highly volatile can't easily be used as a motor fuel and others, which have excellent heating value, aren't volatile enough to be used in an engine (such as tars and waxes).

Another point to keep in mind is that a very volatile fuel is potentially dangerous, because of the chance of explosion from heat or sparks. This is one reason why alcohol, with a higher flash point than gasoline, is a much safer automotive fuel especially considering that the average car's storage tank is really quite vulnerable.

2.7.9 Latent heat of vaporization

Latent heat of vaporization is the phenomenon that results in an alcohol-powered engine's running cooler than its gasoline-fueled counterpart. When a substance is about to undergo a change in form (from a liquid to a vapor, in this case), it must absorb a certain amount of additional heat from its surroundings in order for the change to take place. Since alcohol must absorb roughly 2-1/2 times the amount of heat that gasoline does, and the heat naturally is taken from the engine block, the engine should operate at a much lower temperature.

What happens in reality is that the alcohol/air mixture doesn't have time to absorb all the heat it could during its short trip through the engine manifold. So instead of running 2-1/2 times cooler on alcohol than it does on gasoline (which, by the way, would not be desirable since an engine must retain a certain amount of heat to run efficiently), the engine operates at temperatures only slightly cooler - about 20-40°F lower, depending on the specific engine when using alcohol fuel.

2.2.10 Exhaust emissions

When gasoline is burned in an engine, it produces carbon monoxide and other poisonous fumes mostly because of the fact that the fuel never combusts completely, and also because it's subjected to extreme temperatures and pressures. In addition, as we mentioned before, gasoline is a complex mixture of many substances and some of those substances are lead, sulfur, and other noxious materials. These, too, add to the contaminative effects of the engine's exhaustfumes.

Alcohol, on the other hand, burns much cleaner. Even though it, too, never combusts completely, the volume of noxious fumes is drastically reduced in an alcohol-burning engine ... because alcohol contains oxygen in its structure (which means more thorough combustion) but doesn't contain all the other pollutants necessary as additives in gasoline.

2.3 Beverage Ethanol

The production of fuel ethanol and the production of beverage ethanol are closely related. Though the process is now greatly advanced, people have been distilling ethanol for human consumption for centuries. Pure beverage ethanol is often manufactured in the form of Grain Neutral Spirits, not for a final branded product. It is commonly sold in bulk to bottlers or other distillers who blend it or package it as a final product. Familiar products like hard lemonades and iced teas and liquors like vodka generally use grain neutral spirits as the volume of the alcohol content. Ethanol is the principal psychoactive constituent in alcoholic beverages, with depressant effects to the central nervous system. Ethanol is metabolized by the body as an energy-providing carbohydrate nutrient, as it metabolizes into acetyl CoA, an intermediate common with glucose metabolism, that can be used for energy in the citric acid cycle or for biosynthesis.(Wikipedia)

Alcoholic beverages vary considerably in their ethanol content and in the foodstuffs from which they are produced. Most alcoholic beverages can be broadly classified as fermented beverages, beverages made by the action of yeast on sugary foodstuffs, or as distilled beverages, beverages whose preparation involves concentrating the ethanol in fermented beverages by distillation. The ethanol content of a beverage is usually measured in terms of the volume fraction of ethanol in the beverage, expressed either as a percentage or in alcoholic proof units. Fermented beverages can be broadly classified by the foodstuff from which they are fermented. Beers are made from cereal grains or other starchy materials, wines and ciders from fruit juices, and meads from honey. Cultures around the world have made fermented beverages from numerous other foodstuffs, and local and national names for various fermented beverages abound.

Distilled beverages are made by distilling fermented beverages. Broad categories of distilled beverages include whiskeys, distilled from fermented cereal grains; brandies, distilled from fermented fruit juices, and rum, distilled from fermented molasses or sugarcane juice. Vodka and similar neutral grain spirits can be distilled from any fermented material (grain or potatoes are most common); these spirits are so thoroughly distilled that no tastes from the particular starting material remain. Numerous other spirits and liqueurs are prepared by infusing flavors from fruits, herbs, and spices into distilled spirits. A traditional example is gin, which is created by infusing juniper berries into a neutral grain alcohol.

In a few beverages, ethanol is concentrated by means other than distillation. Applejack is traditionally made by freeze distillation, by which water is frozen out of fermented apple cider, leaving a more ethanol-rich liquid behind. Eisbier (more commonly, *eisbock*) is also freeze-distilled, with beer as the base beverage (wikipedia). Fortified wines are prepared by adding brandy or some other distilled spirit to partially-fermented wine. This kills the yeast and conserves some of the sugar in grape juice; such beverages are not only more ethanol-rich, but are often sweeter than other wines. Alcoholic beverages are sometimes used in cooking, not only for their inherent flavors, but also because the alcohol dissolves hydrophobic flavor compounds which water cannot.

2.4 Industrial Ethanol

The personal care products industry is one of the largest users of industrial ethanol, or ethyl alcohol. Products such as hairspray, mouthwash, aftershave, cologne, and perfume all contain large amounts of alcohol by volume. Ethanol is also used in many deodorants, lotions, hand sanitizers, soaps, and shampoos. Industrial alcohols are also used extensively in pharmaceuticals. The characteristics of ethyl alcohol make it a prime carrier for a whole spectrum of medicines including cough treatments, decongestants, iodine solution, and many others. As a solvent for the pharmaceutical industry, ethanol is useful for processing antibiotics, vaccines, tablets, pills, and vitamins.

Many cleaning products contain high volumes of industrial alcohol. A bottle of household disinfectant spray can contain up 80 percent ethanol. Ethanol is also used as a solvent in the manufacture of many other substances including paints, lacquer, and explosives. Industrial ethanol is used as a raw material for the production of vinegar and yeast, and similarly in chemical processing as a chemical intermediate. Food products like extracts, flavorings, and glazes contain large amounts of alcohol. The ethanol is also used in some liquid animal feed products as an energy source.

2.5 Ethanol co-products

2.5.1 Distiller grain

Distillers' grain is an important co-product of dry-mill ethanol production. Dry-mill ethanol production process uses only the starch portion of the, which is about 86% of the dry mass. All the remaining nutrients - protein, fat, fiber, and ash are concentrated into distillers' grain, a valuable feed for livestock. Distillers' grain can be fed to livestock wet or dry. Dried distillers grain (DDG) is the most common variety. Drying the distillers grain increases its shelf life and improves its ability to be transported over longer distances. If a consistent nearby market can be secured, ethanol producers can supply the feed as wet distillers grain (WDG). The wet form is not as easily transportable, but the cost of drying the product is removed.

Dried distillers grain with solubles (DDGS) is the form available to the feed industry. The liquid that is separated from the mash during the distilling process is partially dehydrated into a syrup, then added back onto the dried distillers grain to create DDGS. DDGS is a high quality feedstuff ration for dairy cattle, beef cattle, swine, poultry, and aquaculture. The feed is an economical partial replacement for corn, soybean meal, and di-calcium phosphate in livestock and poultry feeds. DDGS continues to be an excellent, economical feed ingredient for use in ruminant diets.

2.5.2 Carbon dioxide

Carbon dioxide (CO_2) is a co-product of dry-mill ethanol production. Carbon dioxide is present during the fermentation stage of ethanol production, and many ethanol plants collect that carbon dioxide and market it as co-product. The carbon dioxide is cleaned of any residual alcohol, compressed, and sold to other industries. Carbon dioxide is used to carbonate beverages, to manufacture dry ice, and to flash freeze meat. CO_2 is also used by paper mills and other food processors.

2.6 Cassava

The **cassava**, **yuca**, **manioc**, or **mandioca** (*Manihot esculenta*) is a woody shrub of the Euphorbiaceae (spurge family) native to South America that is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root, a major source of carbohydrates(Claude et'al,1990). Indeed, cassava is the third largest source of carbohydrates for human food in the world, with Africa its largest center of production. Though not well known in the temperate region, for most people, cassava is most commonly associated with tapioca. The plant grows tall, sometimes reaching 15ft, with leaves varying in shape and size. The edible part are the tuberous root and leaves. The tuber is somewhat dark brown in colours and grows up to 2ft long. Cassava thrives better in poor soils than major food plant. As a result, fertilization is rarely necessary. However, yields can be increased by planting cuttings on well drained soil with adequate organic matter. Cassava is a heat-loving plant that requires a minimum temperature of 80°F to grow. Since many cultivars are drought resistance, cassava can survive even during the dry season when the moisture is low but humidity is high(www.cassavachips.com/cassava.html)

Around the world, cassava is a vital staple for about many people. Cassava's starchy roots produce more food energy per unit of land than any other staple crop. Its leaves, commonly eaten as a vegetable in parts of Asia and Africa, provide vitamins and protein. Nutritionally, the cassava is comparable to potatoes, except that it has twice the fiber content and a higher level of potassium.

CHAPTER THREE

3.0 MATERIAL BALANCES

Basis: 100.00

Assumptions: The raw material is Cassava	
Composition of the Raw Material (Dried Cassava)	
Components	mass%
Starch	86.30
H_2O	12.60
Fat	0.20
Fibre	0.10
Ash	0.20
Protein	0.60
Total	100.00

Unit 1: Cassava Storage Tank

Operation: Storage of the Cassava

Assumption: No material loss

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	86.30	86.30	0.00	0.00	0.00	0.00	86.30	86.30
H_2O	12.60	12.60	0.00	0.00	0.00	0.00	12.60	12.60
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	0.20	0.20	0.00	0.00	0.00	0.00	0.20	0.20

Protein	0.60	0.60	0.00	0.00	0.00	0.00	0.60	0.60
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.10
Ash	0.20	0.20	0.00	0.00	0.00	0.00	0.20	0.20
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	0.00	0.00	0.00	0.00	100.00	100.00

Unit 2: Crusher

Operation: Size Reduction of the Grain (Grinding)

Assumption: 3% of material loss

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	86.30	86.30	0.00	0.00	2.59	0.00	83.71	86.30
H_2O	12.60	12.60	0.00	0.00	0.38	0.00	12.22	12.60
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	0.20	0.20	0.00	0.00	0.01	0.00	0.19	0.20
Protein	0.60	0.60	0.00	0.00	0.02	0.00	0.58	0.60
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.10
Ash	0.20	0.20	0.00	0.00	0.01	0.00	0.19	0.20
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	0.00	0.00	3.00	0.00	97.00	100.00

Unit 3: Liquefaction Tank

Operation: Liquefaction of Starch with Process Water and Alpha-Amylase, and then Heat is applied. The pH was adjusted to between 6.5-7.0 by addition of NaOH

Assumption: 65kmol/day of NaOH was used to control the pH

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	83.71	86.30	0.00	0.00	0.00	0.00	83.71	51.67
H_2O	12.22	12.60	65.00	81.25	0.00	0.00	77.22	47.67
Alpha Amylase	0.00	0.00	5.00	6.25	5.00	33.33	0.00	0.00
NaOH	0.00	0.00	10.00	12.50	10.00	66.67	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	0.19	0.20	0.00	0.00	0.00	0.00	0.19	0.12
Protein	0.58	0.60	0.00	0.00	0.00	0.00	0.58	0.36
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.06
Ash	0.19	0.20	0.00	0.00	0.00	0.00	0.19	0.12
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	97.00	100.00	80.00	100.00	15.00	100.00	162.00	100.00

Unit 4: Sacharifying Tank

Operation: Sacaharification of Liquified Starch to Fermentable Sugars(Dextrose) by adding of Gluco Amylase: Assumption 10kmol/day of Gluco Amylase is added.

$$\underset{\text{Liquefied Starch}}{(C_6H_{12}O_6)_n} \xrightarrow{\text{Gluco Amylase}} \underset{\text{Sugar}}{nC_6H_{12}O_6}$$

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	83.71	51.67	0.00	0.00	0.00	0.00	0.00	0.00
H_2O	77.22	47.67	0.00	0.00	0.00	0.00	77.22	47.67
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amulase	0.00	0.00	10.00	100.00	10.00	100.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	83.71	51.67
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	0.19	0.12	0.00	0.00	0.00	0.00	0.19	0.12
Protein	0.58	0.36	0.00	0.00	0.00	0.00	0.58	0.36
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.10	0.06	0.00	0.00	0.00	0.00	0.10	0.06
Ash	0.19	0.12	0.00	0.00	0.00	0.00	0.19	0.12
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	162.00	100.00	10.00	100.00	10.00	100.00	162.00	100.00

Unit 5: Fermentor

Operation: Fermentation of the Sugar. Yeast is added to ferment the sugar.
Assumptions: 5kmol/day of yeast added

$$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2C_2H_5OH + 2CO_2$$

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H_2O	77.22	47.67	0.00	0.00	0.00	0.00	77.22	46.38
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amulase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	83.71	51.67	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	42.79	25.70
Fat	0.19	0.12	0.00	0.00	0.00	0.00	0.19	0.12
Protein	0.58	0.36	0.00	0.00	0.00	0.00	0.58	0.35
Yeast	0.00	0.00	5.00	100.00	0.50	100.00	4.50	2.70
Fibre	0.10	0.06	0.00	0.00	0.00	0.00	0.10	0.06
Ash	0.19	0.12	0.00	0.00	0.00	0.00	0.19	0.12
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	40.93	24.58
Total	162.00	100.00	5.00	100.00	0.50	100.00	166.50	100.00

Unit 6: Distillator

Operation: Removal of the Ethanol from the Mash Residue and Water

Assumption: Reflux Ratio of one

	IN				OUT			
	Feed				Distillate		Waste(Stillage)	
Components	kmol/day	mole %			kmol/day	mole %	kmol/day	mole %
Starch	0.00	0.00			0.00	0.00	0.00	0.00
H_2O	77.22	61.49			1.54	3.66	75.68	90.76
Alpha Amylase	0.00	0.00			0.00	0.00	0.00	0.00
NaOH	0.00	0.00			0.00	0.00	0.00	0.00
Gluco Amulase	0.00	0.00			0.00	0.00	0.00	0.00
Sugar	0.00	0.00			0.00	0.00	0.00	0.00
Ethanol	42.79	34.07			40.65	96.34	2.14	2.57
Fat	0.19	0.15			0.00	0.00	0.19	0.23
Protein	0.58	0.46			0.00	0.00	0.58	0.70
Yeast	4.50	3.58			0.00	0.00	4.50	5.40
Fibre	0.10	0.08			0.00	0.00	0.10	0.12

Ash	0.19	0.15			0.00	0.00	0.19	0.23
CO_2	0.00	0.00			0.00	0.00	0.00	0.00
Total	125.57	100.00			42.19	100.00	83.38	100.00

Unit 7: Dehydrator

Operation: Removal of the remaining Water to obtain Anhydrous Ethanol

Assumption: About 95% of the associated water was removed.

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/ day	mole %	kmol/ day	mole %	kmol/ day	mole %	kmol/ day	mole %
Starch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H_2O	1.54	3.66	0.00	0.00	1.47	100.00	0.08	0.19
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	40.65	96.34	0.00	0.00	0.00	0.00	40.65	99.81
Fat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Protein	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	42.19	100.00	0.00	0.00	1.47	0.00	40.72	100.00

Components	Molar mass(kg/kmol)	Density(kg/m^3)
Starch	342.00	945.00
H_2O	18.00	1000.00
NaOH	40.00	2130.00
Sugar	180.00	900.00
Ethanol	46.00	789.30
Fat	280.00	903.00
Protein	262.00	1211.50
Yeast	75.00	1115.00
Fibre	60.00	1032.00
Ash	94.00	550.00
CO_2	44.00	290.80

Conversion factor: 1000.00litres/day =1.00 m^3/day

500000.00 litres/month =**500.00** m^3/month

Operating Time (t) (90-95% of available time in the month)

Time (t) =27.00 day/month

Ethanol production rate =500.00 m^3/month which is equal to **317.75 kmol/day**

The total mass of the components indicates the mass of oil produced from the basis.

So, Ethanol produced from the basis (100kmol/day) =**40.72** kmol/day

The scale-up factor =**7.80**

SCALED MATERIAL BALANCES (Scaling up to Plant Productivity of 500,000litres/month)

Unit 1: Cassava Storage Tank

Operation: Storage of the Cassava

Assumption: No material loss

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	673.37	86.30	0.00	0.00	0.00	0.00	673.37	86.30
H_2O	98.31	12.60	0.00	0.00	0.00	0.00	98.31	12.60
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	1.56	0.20	0.00	0.00	0.00	0.00	1.56	0.20
Protein	4.68	0.60	0.00	0.00	0.00	0.00	4.68	0.60
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.78	0.10	0.00	0.00	0.00	0.00	0.78	0.10
Ash	1.56	0.20	0.00	0.00	0.00	0.00	1.56	0.20
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	780.27	100.00	0.00	0.00	0.00	0.00	780.27	100.00

Unit 2: Crusher

Operation: Size Reduction of the Grain (Grinding)

Assumption: 3% of material loss

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	673.37	86.30	0.00	0.00	20.20	0.00	653.17	86.30
H_2O	98.31	12.60	0.00	0.00	2.95	0.00	95.36	12.60
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	1.56	0.20	0.00	0.00	0.05	0.00	1.51	0.20
Protein	4.68	0.60	0.00	0.00	0.14	0.00	4.54	0.60
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.78	0.10	0.00	0.00	0.02	0.00	0.76	0.10
Ash	1.56	0.20	0.00	0.00	0.05	0.00	1.51	0.20
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	780.27	100.00	0.00	0.00	23.41	0.00	756.86	100.00

Unit 3: Liquefaction Tank

Operation: Liquefaction of the Starch with Process water and Alpha-Amylase, and then Heat is applied The pH was adjusted to between 6.5-7.0 by addition of NaOH

Assumptions: 65kmol/day of Process water and 5kmol/day of Alpha Amylase enzyme were added

10kmol/day of NaOH (Lye) was used to control the pH

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole%	kmol/day	mole%	kmol/day	mole%	kmol/day	mole%
Starch	653.17	86.30	0.00	0.00	0.00	0.00	653.17	51.67
H_2O	95.36	12.60	507.18	81.25	0.00	0.00	602.54	47.67
Alpha Amylase	0.00	0.00	39.01	6.25	39.01	33.33	0.00	0.00
NaOH	0.00	0.00	78.03	12.50	78.03	66.67	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	1.51	0.20	0.00	0.00	0.00	0.00	1.51	0.12
Protein	4.54	0.60	0.00	0.00	0.00	0.00	4.54	0.36
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.76	0.10	0.00	0.00	0.00	0.00	0.76	0.06
Ash	1.51	0.20	0.00	0.00	0.00	0.00	1.51	0.12
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	756.86	100.00	624.22	100.00	117.04	100.00	1264.04	100.00

Unit 4: Sacharifying Tank

Operation: Sacaharification of Liquified Starch to Fermentable Sugars(Dextrose) by adding of Gluco Amylase: Assumption 10kmol/day of Gluco Amylase is added.

$$\underset{\text{Liquefied Starch}}{(C_6H_{12}O_6)_n} \xrightarrow{\text{Gluco Amylase}} \underset{\text{Sugar}}{nC_6H_{12}O_6}$$

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/ day	mole %	kmol/ day	mole %	kmol/ day	mole %	kmol/ day	mole %
Starch	653.17	51.67	0.00	0.00	0.00	0.00	0.00	0.00
H_2O	602.54	47.67	0.00	0.00	0.00	0.00	602.54	47.67
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amulase	0.00	0.00	78.03	100.00	78.03	100.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	653.17	51.67
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	1.51	0.12	0.00	0.00	0.00	0.00	1.51	0.12
Protein	4.54	0.36	0.00	0.00	0.00	0.00	4.54	0.36
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.76	0.06	0.00	0.00	0.00	0.00	0.76	0.06
Ash	1.51	0.12	0.00	0.00	0.00	0.00	1.51	0.12
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1264.04	100.00	78.03	100.00	78.03	100.00	1264.04	100.00

Unit 5: Fermentor

Operation: Fermentation of the Sugar. Yeast is added to ferment the sugar. Assumptions: 5kmol/day of yeast added

$$C_6H_{12}O_6 \xrightarrow{Yeast} 2C_2H_5OH + 2CO_2$$

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole%	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H_2O	602.54	47.67	0.00	0.00	0.00	0.00	602.54	46.38
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amulase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	653.17	51.67	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	333.84	25.70
Fat	1.51	0.12	0.00	0.00	0.00	0.00	1.51	0.12
Protein	4.54	0.36	0.00	0.00	0.00	0.00	4.54	0.35
Yeast	0.00	0.00	39.01	100.00	3.90	100.00	35.11	2.70
Fibre	0.76	0.06	0.00	0.00	0.00	0.00	0.76	0.06
Ash	1.51	0.12	0.00	0.00	0.00	0.00	1.51	0.12
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	319.33	24.58
Total	1264.04	100.00	39.01	100.00	3.90	100.00	1299.15	100.00

Unit 6: Distillator

Operation: Removal of the Ethanol from the Mash Residue and Water. Assumption: Reflux Ratio of one.

	IN				OUT			
	Feed				Distillate		Waste(Stillage)	
Components	kmol/day	mole %			kmol/day	mole %	kmol/day	mole %
Starch	0.00	0.00			0.00	0.00	0.00	0.00
H_2O	602.54	61.49			12.05	3.66	590.49	90.76

Alpha Amylase	0.00	0.00			0.00	0.00	0.00	0.00
NaOH	0.00	0.00			0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00			0.00	0.00	0.00	0.00
Sugar	0.00	0.00			0.00	0.00	0.00	0.00
Ethanol	333.84	34.07			317.15	96.34	16.69	2.57
Fat	1.51	0.15			0.00	0.00	1.51	0.23
Protein	4.54	0.46			0.00	0.00	4.54	0.70
Yeast	35.11	3.58			0.00	0.00	35.11	5.40
Fibre	0.76	0.08			0.00	0.00	0.76	0.12
Ash	1.51	0.15			0.00	0.00	1.51	0.23
CO_2	0.00	0.00			0.00	0.00	0.00	0.00
Total	979.82	100.00			329.20	100.00	650.62	100.00

Unit 7: Dehydrator

Operation: Removal of the remaining Water to obtain Anhydrous Ethanol

Assumption: About 95% of the associated water was removed.

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H_2O	12.05	3.66	0.00	0.00	0.00	0.00	0.60	0.19
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	317.15	96.34	0.00	0.00	0.00	0.00	317.15	99.81
Fat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Protein	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yeast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	329.20	100.00	0.00	0.00	0.00	0.00	**317.75**	100.00

Unit 8: Centrifugal Separator

Operation: Separation of the Stillage from the bottom of the distillation tank. The Stillage is separated into Thin stillage (Liquid with 5-10% solid) and Wet Distillers grain

Assumption: About 95% of the associated water was removed

	IN				OUT			
	Feed(Stillage)				Thin Stillage		WDG(wet distiller's grain)	
Components	kmol/day	mole %			kmol/ day	mole %	kmol/ day	mole %
Starch	0.00	0.00			0.00	0.00	0.00	0.00
H_2O	590.49	90.76			560.96	92.54	29.52	66.41
Alpha Amylase	0.00	0.00			0.00	0.00	0.00	0.00
NaOH	0.00	0.00			0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00			0.00	0.00	0.00	0.00
Sugar	0.00	0.00			0.00	0.00	0.00	0.00
Ethanol	16.69	2.57			16.69	2.75	0.00	0.00
Fat	1.51	0.23			0.08	0.01	1.44	3.23
Protein	4.54	0.70			0.23	0.04	4.31	9.70
Yeast	35.11	5.40			28.09	4.63	7.02	15.80
Fibre	0.76	0.12			0.04	0.01	0.72	1.62
Ash	1.51	0.23			0.08	0.01	1.44	3.23
CO_2	0.00	0.00			0.00	0.00	0.00	0.00
Total	650.62	100.00			606.16	100.00	44.46	100.00

Unit 9: Drying

Operation: Removal of moisture from the WDG

Assumption: 100% of water was removed

	IN				OUT			
	Input		Added		Loss		Output	
Components	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %	kmol/day	mole %
Starch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H_2O	29.52	66.41	0.00	0.00	0.00	0.00	0.00	0.00
Alpha Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NaOH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gluco Amylase	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat	1.44	3.23	0.00	0.00	0.00	0.00	1.44	9.63
Protein	4.31	9.70	0.00	0.00	0.00	0.00	4.31	28.89
Yeast	7.02	15.80	0.00	0.00	0.00	0.00	7.02	47.03
Fibre	0.72	1.62	0.00	0.00	0.00	0.00	0.72	4.82
Ash	1.44	3.23	0.00	0.00	0.00	0.00	1.44	9.63
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	44.46	100.00	0.00	0.00	0.00	0.00	14.93	100.00

CHAPTER FOUR

4.0 ENERGY BALANCES

4.1 THERMODYNAMICS PROPERTIES

4.1.1 HEAT CAPACITY COEFFICIENTS OF THE COMPONENTS

The heat capacity coefficients of the components involved in this project are as outlined below. Their components are: starch, water, ash, yeast, ethanol, Sugar, carbon dioxide, Fibre, protein, and yeast. Denoting the matrix of the heat capacity coefficients by coeff, we have

$$\text{coeff} := \begin{pmatrix} 418.3394 & -0.5973456 \cdot 10^{-2} & 1.331825 \cdot 10^{-8} & 0 \cdot 10^{-9} \\ 18.2964 & 47.212 \cdot 10^{-2} & -133.88 \cdot 10^{-5} & 1314.2 \cdot 10^{-9} \\ 45.44 & 0.5008 \cdot 10^{-2} & -8.732 \cdot 10^{5} & 0 \\ 104.1616 & 0.1580607 & 5.684135 \cdot 10^{-4} & 0 \\ -325.137 & 0.041379 \cdot 10^{-2} & -1403.1 \cdot 10^{-5} & 1.7035 \cdot 10^{-5} \\ 36.11 & 4.233 \cdot 10^{-2} & -2.887 \cdot 10^{-5} & 7.464 \cdot 10^{9} \\ 2950.0 & 727.89 & -1.225 \cdot 10^{-2} & 0 \\ 155.4802 & -0.3265951 & 7.44199 \cdot 10^{-4} & 0 \\ 215.9 & 0 & 0 & 0 \\ 5.26718 \cdot 10^{-7} & -4.27281 \cdot 10^{-1} & 3.96389 \cdot 10^{-3} & -2.3999 \cdot 10^{-6} \end{pmatrix} \quad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

4.1.2 HEAT OF FORMATION OF THE COMPONENTS

Similar to heat capacities, the heat of formation of the components are as outlined below. Denoting the matrix of the heat capacity coefficients by h_f, we have

$$h_f := \begin{pmatrix} -22.08 \cdot 10^{1} \\ -285.840 \cdot 10^{3} \\ 0 \\ 0 \\ -277.63 \cdot 10^{3} \\ -393.51 \cdot 10^{3} \\ -1272.783 \cdot 10^{3} \\ 0 \\ 0 \\ 0 \end{pmatrix} \cdot \frac{\text{kJ}}{\text{kmol}} \quad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

4.2 FORMULATION OF ENERGY BALANCE EQUATION

The equation to be used for the energy balance is given as

$$\Delta H = n \cdot \int_{T_r}^{T_s} c_p \, dT$$

where

H = Enthalpy (kJ)

C_p = Heat capacity (kJ/kgmol K)

T = Temperature (K)

n = Amount (kgmol)

T_r = Reference temperature (K)

T_s = System temperature (K)

If a reaction is involved, the equation becomes

$$\Delta H = n \cdot \int_{T_r}^{T_s} c_p \, dT + h_f$$

where h_f = heat of formation

It should be noted that C_p is given in terms of heat capacity coefficients as

$$C_p = a + b \cdot T + c \cdot T^2 + d \cdot T^3$$

where a, b, c and d are heat capacity coefficients (constants).

So, the energy balance equation will then become

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

Reffering to the table, considering the standard energy balance equation,

$a := coeff^{\langle 1 \rangle}$ $b := coeff^{\langle 2 \rangle}$ $c := coeff^{\langle 3 \rangle}$ $d := coeff^{\langle 4 \rangle}$

As such,

$$a = \begin{pmatrix} 418.339 \\ 18.296 \\ 45.44 \\ 104.162 \\ -325.137 \\ 36.11 \\ 2.95 \times 10^{3} \\ 155.48 \\ 215.9 \\ 5.267 \times 10^{-7} \end{pmatrix} \quad b = \begin{pmatrix} -5.973 \times 10^{-3} \\ 0.472 \\ 5.008 \times 10^{-3} \\ 0.158 \\ 4.138 \times 10^{-4} \\ 0.042 \\ 727.89 \\ -0.327 \\ 0 \\ -0.427 \end{pmatrix} \quad c = \begin{pmatrix} 1.332 \times 10^{-8} \\ -1.339 \times 10^{-3} \\ -8.732 \times 10^{5} \\ 5.684 \times 10^{-4} \\ -0.014 \\ -2.887 \times 10^{-5} \\ -0.012 \\ 7.442 \times 10^{-4} \\ 0 \\ 3.964 \times 10^{-3} \end{pmatrix} \quad d = \begin{pmatrix} 0 \\ 1.314 \times 10^{-6} \\ 0 \\ 0 \\ 1.704 \times 10^{-5} \\ 7.464 \times 10^{9} \\ 0 \\ 0 \\ 0 \\ -2.4 \times 10^{-6} \end{pmatrix}$$

4.3 ENERGY BALANCES CALCULATIONS

4.3.1 ENERGY BALANCES AROUND THE STORAGE TANK

The energy balance around the storage tank is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3 \right) dT$$

4.3.1.1 ENTHALPY OF COMPONENTS ENTERING THE STORAGE TANK

$T_r := 298 \cdot K$ $T_s := 299 \cdot K$

$$T_r := \frac{T_r}{K} \qquad\qquad T_s := \frac{T_s}{K}$$

$$n := \begin{pmatrix} 673.37 \\ 98.31 \\ 1.56 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.78 \\ 4.68 \\ 1.56 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 673.37\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_1 = 2.805\times 10^5 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of H_2O

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$n_2 = 98.31\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_2 = 7.362\times 10^3 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of ash

$n_3 = 1.56\frac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_3 = -1.214\times 10^{11} \frac{kJ}{day}$

Enthalpy of yeast

$n_4 = 0\frac{kmol}{day}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_4 = 0\frac{kJ}{day}$

Enthalpy of EtOH

$n_5 = 0\frac{kmol}{day}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_5 = 0\frac{kJ}{day}$

Enthalpy of CO_2

$n_6 = 0\frac{kmol}{day}$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_6 = 0\frac{kJ}{day}$

Enthalpy of Sugar

$n_7 = 0\frac{kmol}{day}$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_7 = 0\frac{kJ}{day}$

Enthalpy of fibre

$$n_8 = 0.78\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 96.955\frac{\text{kJ}}{\text{day}}$$

Enthalpy of proteins

$$n_9 = 4.68\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 1.01 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.56\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 336.804\frac{\text{kJ}}{\text{day}}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{in} = -1.214 \times 10^{11} \frac{\text{kJ}}{\text{day}}$$

4.3.1.2 ENTHALPY OF COMPONENTS LEAVING THE STORAGE TANK

$$T_r := 298 \cdot \text{K} \qquad T_s := 301 \cdot \text{K}$$

$$n := \begin{pmatrix} 673.37 \\ 98.31 \\ 1.56 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.78 \\ 4.68 \\ 1.56 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 673.37\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_1 = 8.415\times 10^5\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of H_2O

$$n_2 = 98.31\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_2 = 2.209\times 10^4\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of ash

$$n_3 = 1.56\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_3 = -3.666\times 10^{11}\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of yeast

$$n_4 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_4 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_5 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO_2

$$n_6 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_6 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of sugar

$$n_7 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.78\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 291.144\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of protein

$$n_9 = 4.68\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 3.031 \times 10^3\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.56\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 1.01 \times 10^3\,\frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{out} = -3.666 \times 10^{11}\ \frac{kJ}{day}$$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = -2.452 \times 10^{11}\ \frac{kJ}{day}$$

4.3.2 ENERGY BALANCES AROUND THE CRUSHER

The energy balance around the crusher is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

3.3.2.1 ENTHALPY OF COMPONENTS ENTERING THE CRUSHER

$T_r := 298 \cdot K$ $\qquad$ $T_s := 301 \cdot K$

$T_r := \frac{T_r}{K}$ $\qquad$ $T_s := \frac{T_s}{K}$

$$n := \begin{pmatrix} 673.37 \\ 98.31 \\ 1.56 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.78 \\ 4.68 \\ 1.56 \end{pmatrix} \cdot \frac{kmol}{day} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 673.37\frac{kmol}{day}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_1 = 8.415 \times 10^5\ \frac{kJ}{day}$$

Enthalpy of H_2O

$n_2 = 98.31 \frac{kmol}{day}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_2 = 2.209 \times 10^4 \frac{kJ}{day}$

Enthalpy of ash

$n_3 = 1.56 \frac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_3 = -3.666 \times 10^{11} \frac{kJ}{day}$

Enthalpy of yeast

$n_4 = 0 \frac{kmol}{day}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_4 = 0 \frac{kJ}{day}$

Enthalpy of EtOH

$n_5 = 0 \frac{kmol}{day}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_5 = 0 \frac{kJ}{day}$

Enthalpy of CO_2

$n_6 = 0 \frac{kmol}{day}$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_6 = 0 \frac{kJ}{day}$

Enthalpy of Sugar

$$n_7 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.78\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} \qquad \Delta H_8 = 291.144\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of proteins

$$n_9 = 4.68\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 3.031 \times 10^3\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.56\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 1.01 \times 10^3\,\frac{\text{kJ}}{\text{day}}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1}$$

$$\Delta H_{in} = -3.666 \times 10^{11}\,\frac{\text{kJ}}{\text{day}}$$

4.3.2.2 ENTHALPY OF COMPONENTS LEAVING THE CRUSHER

$T_r := 298 \cdot K \qquad T_s := 321 \cdot K$

$T_r := \dfrac{T_r}{K} \qquad T_s := \dfrac{T_s}{K}$

$$n := \begin{pmatrix} 653.17 \\ 95.36 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{kmol}{day} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$n_1 = 653.17 \dfrac{kmol}{day}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_1 = 6.257 \times 10^6 \dfrac{kJ}{day}$

Enthalpy of H_2O

$n_2 = 95.36 \dfrac{kmol}{day}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_2 = 1.648 \times 10^5 \dfrac{kJ}{day}$

Enthalpy of ash

$n_3 = 1.51 \dfrac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_3 = -2.906 \times 10^{12} \dfrac{kJ}{day}$

Enthalpy of yeast

$$n_4 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_4 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_5 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO_2

$$n_6 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} \qquad \Delta H_6 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of sugar

$$n_7 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.76\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 2.198 \times 10^3\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of protein

$$n_9 = 4.54\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 2.254\times 10^4 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.51\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 7.498\times 10^3 \frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{out} = -2.906\times 10^{12} \frac{\text{kJ}}{\text{day}}$$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = -2.54\times 10^{12} \frac{\text{kJ}}{\text{day}}$$

3.3.3 ENERGY BALANCES AROUND THE LIQUEFACTION TANK

The energy balance around the liquefaction tank is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

$$n := \begin{pmatrix} 653.17 \\ 95.36 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

4.3.3.1 ENTHALPY OF COMPONENTS ENTERING THE LIQUEFACTION TANK

$T_r := 298 \cdot K$ $\quad T_s := 321 \cdot K$ $\quad T_r := \frac{T_r}{K}$ $\quad T_s := \frac{T_s}{K}$

Enthalpy of starch

$n_1 = 653.17 \frac{kmol}{day}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_1 = 6.257 \times 10^6 \frac{kJ}{day}$

Enthalpy of H_2O

$n_2 = 95.36 \frac{kmol}{day}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_2 = 1.648 \times 10^5 \frac{kJ}{day}$

Enthalpy of ash

$n_3 = 1.51 \frac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_3 = -2.906 \times 10^{12} \frac{kJ}{day}$

Enthalpy of yeast

$n_4 = 0 \frac{kmol}{day}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_4 = 0 \frac{kJ}{day}$

Enthalpy of EtOH

$n_5 = 0 \frac{kmol}{day}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_5 = 0 \frac{kJ}{day}$

Enthalpy of CO_2

$$n_6 = 0 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_6 = 0 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of Sugar

$$n_7 = 0 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.76 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 2.198 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of proteins

$$n_9 = 4.54 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 2.254 \times 10^4 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.51 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 7.498 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{in} = -2.906 \times 10^{12} \frac{\text{kJ}}{\text{day}}$$

4.3.3.2 ENTHALPY OF COMPONENTS LEAVING THE LIQUEFACTION TANK

$T_r := 298 \cdot K$ $\qquad$ $T_s := 373 \cdot K$

$T_r := \frac{T_r}{K}$ $\qquad$ $T_s := \frac{T_s}{K}$

$$n := \begin{pmatrix} 653.17 \\ 602.54 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{kmol}{day} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$n_1 = 653.17\frac{kmol}{day}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_1 = 2.04 \times 10^7 \frac{kJ}{day}$

Enthalpy of H_2O

$n_2 = 602.54\frac{kmol}{day}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_2 = 3.417 \times 10^6 \frac{kJ}{day}$

Enthalpy of ash

$n_3 = 1.51\frac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_3 = -1.118\times 10^{13}\,\frac{kJ}{day}$$

Enthalpy of yeast

$$n_4 = 0\,\frac{kmol}{day}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_4 = 0\,\frac{kJ}{day}$$

Enthalpy of EtOH

$$n_5 = 0\,\frac{kmol}{day}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_5 = 0\,\frac{kJ}{day}$$

Enthalpy of CO$_2$

$$n_6 = 0\,\frac{kmol}{day}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_6 = 0\,\frac{kJ}{day}$$

Enthalpy of sugar

$$n_7 = 0\,\frac{kmol}{day}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{kJ}{kmol} \qquad \Delta H_7 = 0\,\frac{kJ}{day}$$

Enthalpy of fibre

$$n_8 = 0.76\,\frac{kmol}{day}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_8 = 7.411\times 10^{3}\,\frac{kJ}{day}$$

Enthalpy of protein

$n_9 = 4.54 \frac{kmol}{day}$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_9 = 7.351 \times 10^4 \frac{kJ}{day}$

Enthalpy of fat

$n_{10} = 1.51 \frac{kmol}{day}$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_{10} = 2.445 \times 10^4 \frac{kJ}{day}$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$\Delta H_{out} = -1.118 \times 10^{13} \frac{kJ}{day}$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$\Delta H = -8.271 \times 10^{12} \frac{kJ}{day}$

4.3.4 ENERGY BALANCES AROUND THE SACHARIFYING TANK

The energy balance around the sacharifying tank is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

$$n := \begin{pmatrix} 653.17 \\ 602.54 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{kmol}{day} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

.4.1 ENTHALPY OF COMPONENTS ENTERING THE SACHARIFYING TANK

$T_r := 298 \cdot K$ $\quad T_s := 368 \cdot K$ $\quad T_r := \frac{T_r}{K}$ $\quad T_s := \frac{T_s}{K}$

Enthalpy of starch

$n_1 = 653.17 \frac{kmol}{day}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_1 = 1.904 \times 10^7 \frac{kJ}{day}$

Enthalpy of H_2O

$n_2 = 602.54 \frac{kmol}{day}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_2 = 3.187 \times 10^6 \frac{kJ}{day}$

Enthalpy of ash

$n_3 = 1.51 \frac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_3 = -1.027 \times 10^{13} \frac{kJ}{day}$

Enthalpy of yeast

$n_4 = 0 \frac{kmol}{day}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_4 = 0 \frac{kJ}{day}$

Enthalpy of EtOH

$n_5 = 0 \frac{kmol}{day}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_5 = 0 \frac{kJ}{day}$

Enthalpy of CO_2

$n_6 = 0 \frac{kmol}{day}$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_6 = 0 \frac{kJ}{day}$

Enthalpy of Sugar

$n_7 = 0 \frac{kmol}{day}$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_7 = 0 \frac{kJ}{day}$

Enthalpy of fibre

$n_8 = 0.76 \frac{kmol}{day}$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_8 = 6.892 \times 10^3 \frac{kJ}{day}$

Enthalpy of proteins

$n_9 = 4.54 \frac{kmol}{day}$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_9 = 6.861 \times 10^4 \frac{kJ}{day}$

Enthalpy of fat

$n_{10} = 1.51 \frac{kmol}{day}$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_{10} = 2.282 \times 10^4 \frac{kJ}{day}$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$\Delta H_{in} = -1.027 \times 10^{13} \frac{kJ}{day}$

4.3.4.2 ENTHALPY OF COMPONENTS LEAVING THE SACHARIFYING TANK

$T_r := 298 \cdot K$ $\qquad$ $T_s := 308 \cdot K$

$T_r := \frac{T_r}{K}$ $\qquad$ $T_s := \frac{T_s}{K}$

$$n := \begin{pmatrix} 0.00 \\ 602.54 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 653.17 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$n_1 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_1 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of H_2O

$n_2 = 602.54\frac{\text{kmol}}{\text{day}}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_2 = 4.519\times 10^{5}\frac{\text{kJ}}{\text{day}}$

Enthalpy of ash

$n_3 = 1.51\frac{\text{kmol}}{\text{day}}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_3 = -1.211\times 10^{12}\frac{\text{kJ}}{\text{day}}$

Enthalpy of yeast

$$n_4 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_4 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_5 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO_2

$$n_6 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_6 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of sugar

$$n_7 = 653.17\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 1.452 \times 10^9 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.76\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 948.877\frac{\text{kJ}}{\text{day}}$$

Enthalpy of protein

$$n_9 = 4.54\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 9.802 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.51\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 3.26\times 10^{3}\,\frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{out} = -1.209\times 10^{12}\,\frac{\text{kJ}}{\text{day}}$$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = 9.063\times 10^{12}\,\frac{\text{kJ}}{\text{day}}$$

4.3.5 ENERGY BALANCES AROUND THE FERMENTOR

The energy balance around the fermentor is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

3.3.5.1 ENTHALPY OF COMPONENTS ENTERING THE FERMENTOR

$T_r := 298 \cdot K$ $T_r := \frac{T_r}{K}$ $T_s := 308 \cdot K$ $T_s := \frac{T_s}{K}$

$$n := \begin{pmatrix} 0.00 \\ 602.54 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 653.17 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_1 := n_1 \cdot \left[\int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_1}\right]$$

$$\Delta H_1 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of H_2O

$$n_2 = 602.54\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_2 := n_2 \cdot \left[\int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_2}\right]$$

$$\Delta H_2 = -1.718 \times 10^8\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of ash

$$n_3 = 1.51\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_3 := n_3 \cdot \left[\int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_3}\right]$$

$$\Delta H_3 = -1.211 \times 10^{12}\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of yeast

$$n_4 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_1 \cdot \left[\int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_4}\right]$$

$$\Delta H_4 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \left[\int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_5}\right]$$

$$\Delta H_5 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO_2

$$n_6 = 0\,\frac{kmol}{day}$$

$$\Delta H_6 := n_6 \cdot \left[\int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{kJ}{kmol} + h_{f_6}\right]$$

$$\Delta H_6 = 0\,\frac{kJ}{day}$$

Enthalpy of sugar

$$n_7 = 653.17\,\frac{kmol}{day}$$

$$\Delta H_7 := n_7 \cdot \left[\int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{kJ}{kmol} + h_{f_7}\right]$$

$$\Delta H_7 = 6.211 \times 10^8\,\frac{kJ}{day}$$

Enthalpy of fibre

$$n_8 = 0.76\,\frac{kmol}{day}$$

$$\Delta H_8 := n_8 \cdot \left[\int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{kJ}{kmol} + h_{f_8}\right]$$

$$\Delta H_8 = 948.877\,\frac{kJ}{day}$$

Enthalpy of protein

$$n_9 = 4.54\,\frac{kmol}{day}$$

$$\Delta H_9 := n_9 \cdot \left[\int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{kJ}{kmol} + h_{f_9}\right]$$

$$\Delta H_9 = 9.802 \times 10^3\,\frac{kJ}{day}$$

Enthalpy of fat

$$n_{10} = 1.51\,\frac{kmol}{day}$$

$$\Delta H_{10} := n_{10} \cdot \left[\int_{T_r}^{T_s} \left(a_{10} + b_{10} \cdot T + c_{10} \cdot T^2 + d_{10} \cdot T^3\right) dT \cdot \frac{kJ}{kmol} + h_{f_{10}}\right]$$

$$\Delta H_{10} = 2.532 \times 10^3\,\frac{kJ}{day}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{10}$$

$$\Delta H_{in} = -1.21 \times 10^{12} \frac{kJ}{day}$$

4.3.5.2 ENTHALPY OF COMPONENTS LEAVING THE FERMENTOR

$$T_r := 298 \cdot K \qquad T_s := 303 \cdot K$$

$$T_r := \frac{T_r}{K} \qquad T_s := \frac{T_s}{K}$$

$$n := \begin{pmatrix} 0.00 \\ 602.54 \\ 1.51 \\ 35.11 \\ 333.84 \\ 319.33 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{kmol}{day} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 0 \frac{kmol}{day}$$

$$\Delta H_1 := n_1 \cdot \left[\int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3 \right) dT \cdot \frac{kJ}{kmol} + h_{f_1} \right]$$

$$\Delta H_1 = 0 \frac{kJ}{day}$$

Enthalpy of H_2O

$$n_2 = 602.54 \frac{kmol}{day}$$

$$\Delta H_2 := n_2 \cdot \left[\int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3 \right) dT \cdot \frac{kJ}{kmol} + h_{f_2} \right]$$

$$\Delta H_2 = -1.72 \times 10^{8} \frac{kJ}{day}$$

Enthalpy of ash

$$n_3 = 1.51\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_3 := n_3 \cdot \left[\int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_3}\right]$$

$$\Delta H_3 = -5.953 \times 10^{11} \frac{\text{kJ}}{\text{day}}$$

Enthalpy of yeast

$$n_4 = 35.11\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_1 \cdot \left[\int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_4}\right]$$

$$\Delta H_4 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 333.84\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \left[\int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_5}\right]$$

$$\Delta H_5 = -9.457 \times 10^{7} \frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO_2

$$n_6 = 319.33\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \left[\int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_6}\right]$$

$$\Delta H_6 = 3.234 \times 10^{20} \frac{\text{kJ}}{\text{day}}$$

Enthalpy of sugar

$$n_7 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \left[\int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_7}\right]$$

$$\Delta H_7 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.76\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \left[\int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_8}\right]$$

$$\Delta H_8 = 473.257\frac{\text{kJ}}{\text{day}}$$

Enthalpy of protein

$$n_9 = 4.54\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \left[\int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_9}\right]$$

$$\Delta H_9 = 4.901 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.51\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \left[\int_{T_r}^{T_s} \left(a_{10} + b_{10} \cdot T + c_{10} \cdot T^2 + d_{10} \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}} + h_{f_{10}}\right]$$

$$\Delta H_{10} = 1.241 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{10}$$

$$\Delta H_{out} = 3.234 \times 10^{20} \frac{\text{kJ}}{\text{day}}$$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = 3.234 \times 10^{20} \frac{\text{kJ}}{\text{day}}$$

4.3.6 ENERGY BALANCES AROUND THE DISTILLATOR

The energy balance around the distillator is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

3.3.6.1 ENTHALPY OF COMPONENTS ENTERING THE DISTILLATOR

$T_r := 298 \cdot K$ $\qquad$ $T_s := 303 \cdot K$

$T_r := \frac{T_r}{K}$ $\qquad$ $T_s := \frac{T_s}{K}$

$$n := \begin{pmatrix} 0.00 \\ 602.54 \\ 1.51 \\ 35.11 \\ 333.84 \\ 319.33 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$n_1 = 0 \frac{\text{kmol}}{\text{day}}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_1 = 0 \frac{\text{kJ}}{\text{day}}$

Enthalpy of H_2O

$n_2 = 602.54 \frac{\text{kmol}}{\text{day}}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_2 = 2.258 \times 10^5 \frac{\text{kJ}}{\text{day}}$

Enthalpy of ash

$n_3 = 1.51\frac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_3 = -5.953 \times 10^{11} \frac{kJ}{day}$

Enthalpy of yeast

$n_4 = 35.11\frac{kmol}{day}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_4 = 3.563 \times 10^{4} \frac{kJ}{day}$

Enthalpy of EtOH

$n_5 = 333.84\frac{kmol}{day}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_5 = -1.886 \times 10^{6} \frac{kJ}{day}$

Enthalpy of CO_2

$n_6 = 319.33\frac{kmol}{day}$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_6 = 3.234 \times 10^{20} \frac{kJ}{day}$

Enthalpy of Sugar

$n_7 = 0\frac{kmol}{day}$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_7 = 0\frac{kJ}{day}$

Enthalpy of fibre

$n_8 = 0.76\frac{kmol}{day}$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$\Delta H_8 = 473.257\frac{kJ}{day}$

Enthalpy of proteins

$$n_9 = 4.54 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 4.901 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.51 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 1.63 \times 10^3 \frac{\text{kJ}}{\text{day}}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{in} = 3.234 \times 10^{20} \frac{\text{kJ}}{\text{day}}$$

4.3.6.2 ENTHALPY OF COMPONENTS LEAVING THE DISTILLATOR

$$T_r := 298 \cdot \text{K} \qquad T_s := 308 \cdot \text{K}$$

$$n := \begin{pmatrix} 0.00 \\ 12.05 \\ 0.00 \\ 0 \\ 317.15 \\ 0 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 0 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_1 = 0 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of H_2O

$$n_2 = 12.05 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_2 = 9.037\times 10^3 \frac{kJ}{day}$$

Enthalpy of ash

$$n_3 = 0\frac{kmol}{day}$$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_3 = 0\frac{kJ}{day}$$

Enthalpy of yeast

$$n_4 = 0\frac{kmol}{day}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_4 = 0\frac{kJ}{day}$$

Enthalpy of EtOH

$$n_5 = 317.15\frac{kmol}{day}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_5 = -3.613\times 10^6 \frac{kJ}{day}$$

Enthalpy of CO_2

$$n_6 = 0\frac{kmol}{day}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_6 = 0\frac{kJ}{day}$$

Enthalpy of sugar

$$n_7 = 0\frac{kmol}{day}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_7 = 0\frac{kJ}{day}$$

Enthalpy of fibre

$$n_8 = 0\frac{kmol}{day}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_8 = 0\frac{kJ}{day}$$

Enthalpy of protein

$$n_9 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

Enthalpy of fat

$$\Delta H_9 = 0\,\frac{\text{kJ}}{\text{day}}$$

$$n_{10} = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 0\,\frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{out} = -3.604\times 10^{6}\,\frac{\text{kJ}}{\text{day}}$$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = -3.234\times 10^{20}\,\frac{\text{kJ}}{\text{day}}$$

4.3.7 ENERGY BALANCES AROUND THE DEHYDRATOR

The energy balance around the dehydrator is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

4.3.7.1 ENTHALPY OF COMPONENTS ENTERING THE DEHYDRATOR

$$T_r := 298 \cdot K \qquad T_s := 308 \cdot K$$

$$n := \begin{pmatrix} 0.00 \\ 12.05 \\ 0.00 \\ 0 \\ 317.15 \\ 0 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_1 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of H_2O

$$n_2 = 12.05\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_2 = 9.037 \times 10^3\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of ash

$$n_3 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_3 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of yeast

$$n_4 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_4 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 317.15\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_5 = -3.613 \times 10^6\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO_2

$$n_6 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_6 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of Sugar

$$n_7 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of proteins

$$n_9 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 0\,\frac{\text{kJ}}{\text{day}}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1}$$

$$\Delta H_{in} = -3.604 \times 10^6\,\frac{\text{kJ}}{\text{day}}$$

4.3.7.2 ENTHALPY OF COMPONENTS LEAVING THE DEHYDRATOR

$$T_r := 298 \cdot \text{K} \qquad T_s := 348 \cdot \text{K}$$

$$n := \begin{pmatrix} 0.60 \\ 0.00 \\ 0.00 \\ 0 \\ 317.15 \\ 0 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$n_1 = 0.6\frac{\text{kmol}}{\text{day}}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_1 = 1.249 \times 10^4 \frac{\text{kJ}}{\text{day}}$

Enthalpy of water

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_2 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of ash

$n_3 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_3 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of yeast

$n_4 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_4 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of EtOH

$n_5 = 317.15\frac{\text{kmol}}{\text{day}}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_5 = -1.926 \times 10^7 \frac{\text{kJ}}{\text{day}}$

Enthalpy of CO_2

$n_6 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_6 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of sugar

$$n_7 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of protein

$$n_9 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 0\frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1}$$

$$\Delta H_{out} = -1.924 \times 10^7 \frac{\text{kJ}}{\text{day}}$$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = -1.564 \times 10^7 \frac{\text{kJ}}{\text{day}}$$

4.3.8 ENERGY BALANCES AROUND THE CENTRIFUGAL SEPARATOR

The energy balance around the centrifugal separator is given by the equation,

4.3.8.1 ENTHALPY OF COMPONENTS ENTERING THE SEPARATOR

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3\right) dT$$

$T_r := 298 \cdot K$ $\quad$ $T_s := 308 \cdot K$

$T_r := \frac{T_r}{K}$ $\quad$ $T_s := \frac{T_s}{K}$

$$n := \begin{pmatrix} 0.00 \\ 590.49 \\ 1.51 \\ 35.11 \\ 16.69 \\ 0 \\ 0.00 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_1 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of H_2O

$$n_2 = 590.49\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_2 = 4.428 \times 10^5 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of ash

$$n_3 = 1.51\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_3 = -1.211 \times 10^{12} \frac{\text{kJ}}{\text{day}}$$

Enthalpy of yeast

$$n_4 = 35.11\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_4 = 7.171 \times 10^4 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 16.69\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_5 = -1.901\times 10^5 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO2

$$n_6 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_6 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of Sugar

$$n_7 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.76\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 948.877\frac{\text{kJ}}{\text{day}}$$

Enthalpy of proteins

$$n_9 = 4.54\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 9.802\times 10^3 \frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.51\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 3.26\times 10^3 \frac{\text{kJ}}{\text{day}}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{10}$$

$$\Delta H_{in} = -1.211 \times 10^{12} \frac{kJ}{day}$$

4.3.8.2 ENTHALPY OF COMPONENTS LEAVING THE SEPARATOR

$$T_r := 298 \cdot K \qquad T_s := 300 \cdot K$$

$$T_r := \frac{T_r}{K} \qquad T_s := \frac{T_s}{K}$$

$$n := \begin{pmatrix} 0.00 \\ 29.52 \\ 1.44 \\ 7.02 \\ 0.00 \\ 0 \\ 0.00 \\ 0.72 \\ 4.31 \\ 1.44 \end{pmatrix} \cdot \frac{kmol}{day} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 0 \frac{kmol}{day}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_1 = 0 \frac{kJ}{day}$$

Enthalpy of H_2O

$$n_2 = 29.52 \frac{kmol}{day}$$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_2 = 4.422 \times 10^{3} \frac{kJ}{day}$$

Enthalpy of ash

$$n_3 = 1.44 \frac{kmol}{day}$$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_3 = -2.248 \times 10^{11} \frac{kJ}{day}$$

Enthalpy of yeast

$n_4 = 7.02\frac{\text{kmol}}{\text{day}}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_4 = 2.839\times 10^3 \frac{\text{kJ}}{\text{day}}$

Enthalpy of EtOH

$n_5 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_5 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of CO2

$n_6 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_6 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of sugar

$n_7 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_7 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of fibre

$n_8 = 0.72\frac{\text{kmol}}{\text{day}}$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_8 = 179.079\frac{\text{kJ}}{\text{day}}$

Enthalpy of protein

$n_9 = 4.31\frac{\text{kmol}}{\text{day}}$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_9 = 1.861\times 10^3 \frac{\text{kJ}}{\text{day}}$

Enthalpy of fat

$$n_{10} = 1.44 \frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3 \right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 621.792 \frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{out} = -2.248 \times 10^{11} \frac{\text{kJ}}{\text{day}}$$

Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = 9.858 \times 10^{11} \frac{\text{kJ}}{\text{day}}$$

4.3.9 ENERGY BALANCES AROUND THE DRIER

The energy balance around the drier is given by the equation,

$$\Delta H = n \cdot \int_{T_r}^{T_s} \left(a + b \cdot T + c \cdot T^2 + d \cdot T^3 \right) dT$$

4.3.9.1 ENTHALPY OF COMPONENTS ENTERING THE DRIER

$$T_r := 298 \cdot K \qquad T_s := 308 \cdot K$$

$$T_r := \frac{T_r}{K} \qquad T_s := \frac{T_s}{K}$$

$$n := \begin{pmatrix} 0.00 \\ 29.52 \\ 1.44 \\ 7.02 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.72 \\ 4.31 \\ 1.44 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$$n_1 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_1 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of H_2O

$$n_2 = 29.52\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_2 = 2.214\times 10^4\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of ash

$$n_3 = 1.44\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_3 = -1.155\times 10^{12}\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of yeast

$$n_4 = 7.02\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_4 = 1.434\times 10^4\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of EtOH

$$n_5 = 0\,\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_5 = 0\,\frac{\text{kJ}}{\text{day}}$$

Enthalpy of CO_2

$$n_6 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_6 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of Sugar

$$n_7 = 0\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_7 = 0\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fibre

$$n_8 = 0.72\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_8 = 898.936\frac{\text{kJ}}{\text{day}}$$

Enthalpy of proteins

$$n_9 = 4.31\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_9 = 9.305 \times 10^3\frac{\text{kJ}}{\text{day}}$$

Enthalpy of fat

$$n_{10} = 1.44\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 3.109 \times 10^3\frac{\text{kJ}}{\text{day}}$$

The total heat in is given as

$$\Delta H_{in} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1}$$

$$\Delta H_{in} = -1.155 \times 10^{12}\frac{\text{kJ}}{\text{day}}$$

4.3.9.2 ENTHALPY OF COMPONENTS LEAVING THE DRIER

$T_r := 298 \cdot K$ $\qquad$ $T_s := 358 \cdot K$

$T_r := \frac{T_r}{K}$ $\qquad$ $T_s := \frac{T_s}{K}$

$$n := \begin{pmatrix} 0.00 \\ 0.00 \\ 1.44 \\ 7.02 \\ 0.00 \\ 0 \\ 0.00 \\ 0.72 \\ 4.31 \\ 1.44 \end{pmatrix} \cdot \frac{kmol}{day} \qquad \begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix}$$

Enthalpy of starch

$n_1 = 0 \frac{kmol}{day}$

$$\Delta H_1 := n_1 \cdot \int_{T_r}^{T_s} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_1 = 0 \frac{kJ}{day}$$

Enthalpy of H_2O

$n_2 = 0 \frac{kmol}{day}$

$$\Delta H_2 := n_2 \cdot \int_{T_r}^{T_s} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_2 = 0 \frac{kJ}{day}$$

Enthalpy of ash

$n_3 = 1.44 \frac{kmol}{day}$

$$\Delta H_3 := n_3 \cdot \int_{T_r}^{T_s} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \cdot \frac{kJ}{kmol}$$

$$\Delta H_3 = -8.139 \times 10^{12} \frac{kJ}{day}$$

Enthalpy of yeast

$n_4 = 7.02\frac{\text{kmol}}{\text{day}}$

$$\Delta H_4 := n_4 \cdot \int_{T_r}^{T_s} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_4 = 9.154\times 10^4 \frac{\text{kJ}}{\text{day}}$

Enthalpy of EtOH

$n_5 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_5 := n_5 \cdot \int_{T_r}^{T_s} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_5 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of CO_2

$n_6 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_6 := n_6 \cdot \int_{T_r}^{T_s} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_6 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of sugar

$n_7 = 0\frac{\text{kmol}}{\text{day}}$

$$\Delta H_7 := n_7 \cdot \int_{T_r}^{T_s} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_7 = 0\frac{\text{kJ}}{\text{day}}$

Enthalpy of fibre

$n_8 = 0.72\frac{\text{kmol}}{\text{day}}$

$$\Delta H_8 := n_8 \cdot \int_{T_r}^{T_s} \left(a_8 + b_8 \cdot T + c_8 \cdot T^2 + d_8 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_8 = 5.557\times 10^3 \frac{\text{kJ}}{\text{day}}$

Enthalpy of protein

$n_9 = 4.31\frac{\text{kmol}}{\text{day}}$

$$\Delta H_9 := n_9 \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$\Delta H_9 = 5.583\times 10^4 \frac{\text{kJ}}{\text{day}}$

Enthalpy of fat

$$n_{10} = 1.44\frac{\text{kmol}}{\text{day}}$$

$$\Delta H_{10} := n_{10} \cdot \int_{T_r}^{T_s} \left(a_9 + b_9 \cdot T + c_9 \cdot T^2 + d_9 \cdot T^3\right) dT \cdot \frac{\text{kJ}}{\text{kmol}}$$

$$\Delta H_{10} = 1.865\times 10^{4}\frac{\text{kJ}}{\text{day}}$$

The total heat out is given as

$$\Delta H_{out} := \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6 + \Delta H_7 + \Delta H_8 + \Delta H_9 + \Delta H_{1(}$$

$$\Delta H_{out} = -8.139\times 10^{12}\frac{\text{kJ}}{\text{day}}$$

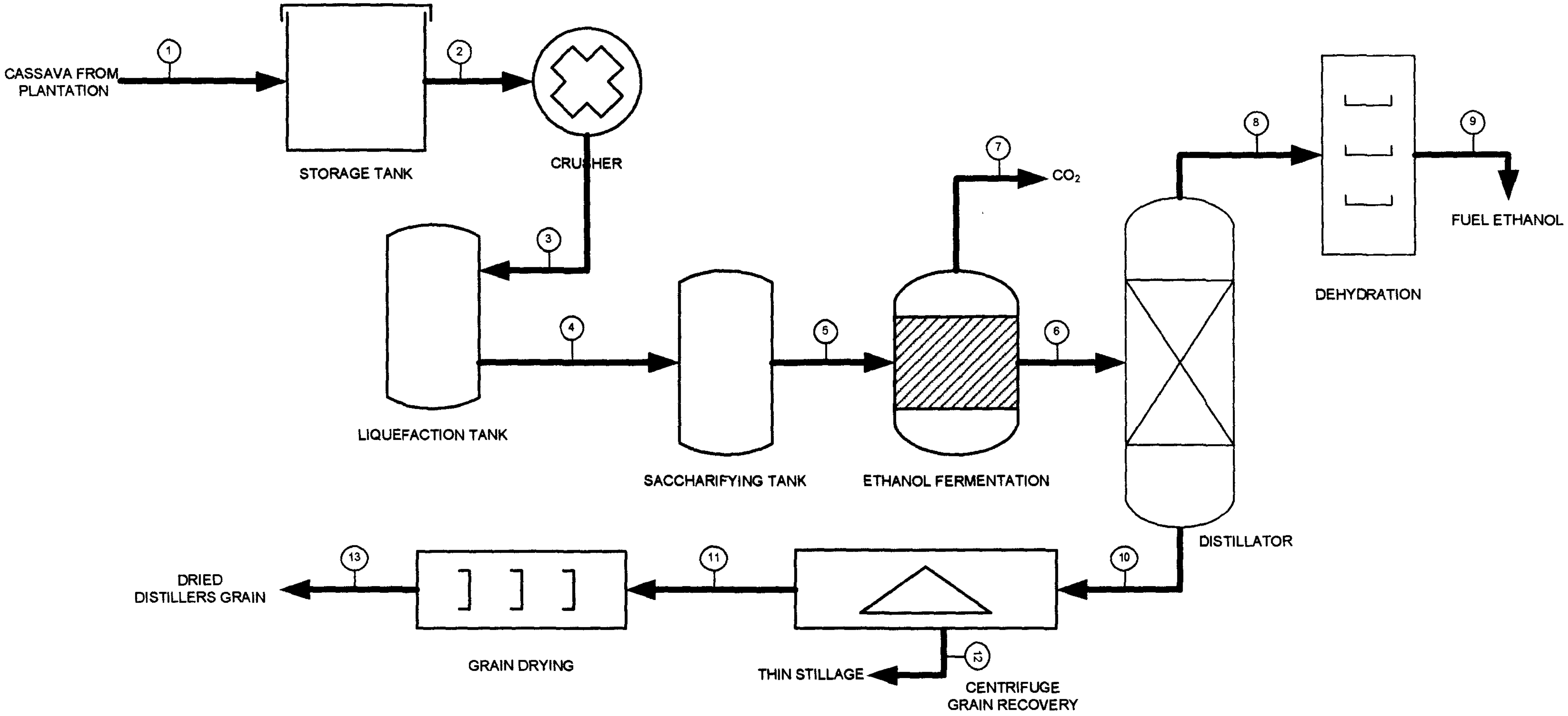
Heat load is thus

$$\Delta H := \Delta H_{out} - \Delta H_{in}$$

$$\Delta H = -6.985\times 10^{12}\frac{\text{kJ}}{\text{day}}$$

CHAPTER FIVE

5.0 FLOWDIAGRAM/FLOWSHEETING



PROCESS FLOW DIAGRAM OF ETHANOL PRODUCTION PLANT

CHAPTER SIX

6.0 SIZING OF EQUIPMENTS

6.1 CHEMICAL ENGINEERING SELECTION OF EQUIPMENTS

6.1.1 SIZING OF THE STORAGE TANK

Considering the balances around the storage tank, denoting the amount in moles by n; the molecular weight by mol_wt; and the density by , the molecular weight, the Densities and the amount in moles of the components in the tank are given as

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} \quad mol\_wt := \begin{pmatrix} 342.00 \\ 18.00 \\ 94.00 \\ 75.00 \\ 46.00 \\ 44.00 \\ 180.00 \\ 60.00 \\ 262.00 \\ 280.00 \end{pmatrix} \cdot \frac{kg}{kmol} \quad \rho := \begin{pmatrix} 945.00 \\ 1000.00 \\ 550 \\ 1115.00 \\ 789.30 \\ 290.80 \\ 900.00 \\ 1032.00 \\ 1211.50 \\ 903.00 \end{pmatrix} \cdot \frac{kg}{m^3} \quad n := \begin{pmatrix} 673.37 \\ 98.31 \\ 1.56 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.78 \\ 4.68 \\ 1.56 \end{pmatrix} \cdot \frac{kmol}{day}$$

The average density of the components is then calculated thus;

$$\rho_{av} := \frac{\begin{pmatrix} n_1 \cdot mol\_wt_1 \cdot \rho_1 + n_2 \cdot mol\_wt_2 \cdot \rho_2 + n_3 \cdot mol\_wt_3 \cdot \rho_3 + n_4 \cdot mol\_wt_4 \cdot \rho_4 \ldots \\ + n_5 \cdot mol\_wt_5 \cdot \rho_5 + n_6 \cdot mol\_wt_6 \cdot \rho_6 + n_7 \cdot mol\_wt_7 \cdot \rho_7 \end{pmatrix} \ldots \\ + n_8 \cdot mol\_wt_8 \cdot \rho_8 + n_9 \cdot mol\_wt_9 \cdot \rho_9 + n_{10} \cdot mol\_wt_{10} \cdot \rho_{10}}{\begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}}$$

$$\rho_{av} = 946.504 \frac{kg}{m^3}$$

The total mass of the materials in the storage tank is given as

$$m_{storage\_tank} = \sum_{i=1}^{10} \left(n_i \cdot mol\_wt_i \right)$$

$$m_{storage\_tank} := \begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \dots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}$$

$$m_{storage\_tank} := m_{storage\_tank} \cdot day$$

$$m_{storage\_tank} = 2.339 \times 10^5 kg$$

The total mass of the material in the storage tank is estimated to be $m_{storage\_tank} = 2.339 \times 10^5 kg$

$$V_{storage\_tank} := \frac{m_{storage\_tank}}{\rho_{av}} \qquad V_{storage\_tank} = 247.139 m^3$$

On the assumption that the dilution tank is cylindrical and making H = 1.5D

$$V_{storage\_tank} = \pi \cdot r^2 \cdot H$$

$$V_{storage\_tank} = \pi \cdot \left(\frac{D}{2}\right)^2 \cdot H$$

$$V_{storage\_tank} = \pi \cdot \frac{D^2}{4} \cdot H$$

Substituting for H,

$$V_{storage\_tank} = \pi \cdot \frac{D^2}{4} \cdot 1.5 \cdot D$$

$$4 \cdot V_{storage\_tank} = 1.5 \cdot \pi \cdot D^3$$

Making D the subject of the formular

$$D = \sqrt[3]{\left(\frac{4 \cdot V_{storage\_tank}}{1.5 \cdot \pi}\right)}$$

Given the parameters $V_{dillution\_tank}$ and to be

$$V_{storage\_tank} = 247.139 m^3$$

$$\pi = 3.142$$

$$D_{storage\_tank} := \left(\frac{4 \cdot V_{storage\_tank}}{1.5 \cdot \pi}\right)^{\frac{1}{3}}$$

$$D_{storage\_tank} = 5.942 m$$

With reference to the former assumption that H = 1.95D,

$$H_{storage\_tank} := 1.5 \cdot D_{storage\_tank}$$

$$H_{storage\_tank} = 8.913 m$$

The area of the storage tank is therefore,

$$A_{storage\_tank} = 221.83 m^2$$

$$A_{storage\_tank} := \pi \cdot D_{storage\_tank} \cdot H_{storage\_tank} + 2\pi \cdot \left(\frac{D_{storage\_tank}}{2}\right)^2$$

6.1.3 SIZING OF THE LIQUEFACTION TANK

Considering the balances around the liquefaction tank, denoting the amount in moles

By n; the molecular weight by mol_wt; and the density by , the molecular weight, the densities and the amount in moles of the components in the tank are given as

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} mol\_wt := \begin{pmatrix} 342.00 \\ 18.00 \\ 94.00 \\ 75.00 \\ 46.00 \\ 44.00 \\ 180.00 \\ 60.00 \\ 262.00 \\ 280.00 \end{pmatrix} \cdot \frac{kg}{kmol} \quad \rho := \begin{pmatrix} 945.00 \\ 1000.00 \\ 550 \\ 1115.00 \\ 789.30 \\ 290.80 \\ 900.00 \\ 1032.00 \\ 1211.50 \\ 903.00 \end{pmatrix} \cdot \frac{kg}{m^3} \quad n := \begin{pmatrix} 653.17 \\ 95.36 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{kmol}{day}$$

The average density of the components in liquefaction tank is then calculated thus;

$$\rho_{av} := \frac{\begin{pmatrix} n_1 \cdot mol\_wt_1 \cdot \rho_1 + n_2 \cdot mol\_wt_2 \cdot \rho_2 + n_3 \cdot mol\_wt_3 \cdot \rho_3 + n_4 \cdot mol\_wt_4 \cdot \rho_4 \ldots \\ + n_5 \cdot mol\_wt_5 \cdot \rho_5 + n_6 \cdot mol\_wt_6 \cdot \rho_6 + n_7 \cdot mol\_wt_7 \cdot \rho_7 \end{pmatrix} \ldots \\ + n_8 \cdot mol\_wt_8 \cdot \rho_8 + n_9 \cdot mol\_wt_9 \cdot \rho_9 + n_{10} \cdot mol\_wt_{10} \cdot \rho_{10}}{\begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}}$$

$$\rho_{av} = 946.505 \frac{kg}{m^3}$$

The total mass of the materials in the liquefaction tank is given as

$$m_{liquefaction\_tank} = \sum_{i=1}^{10} \left(n_i \cdot mol\_wt_i\right)$$

$$m_{liquefaction\_tank} := \begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}$$

$$m_{liquefaction\_tank} := m_{liquefaction\_tank} \cdot day$$

$$m_{liquefaction\_tank} = 2.269 \times 10^5 \, kg$$

The total mass of the material in the liquefaction tank is estimated to be $m_{storage\_tank} = 2.339\times 10^{5}\,kg$

$$V_{liquefaction\_tank} := \frac{m_{liquefaction\_tank}}{\rho_{av}} \qquad V_{liquefaction\_tank} = 239.724m^{3}$$

On the assumption that the liquefaction tank is cylindrical and making H = 1.5D

$$V_{liquefaction\_tank} = \pi \cdot r^{2} \cdot H$$

$$V_{liquefaction\_tank} = \pi \cdot \left(\frac{D}{2}\right)^{2} \cdot H$$

$$V_{liquefaction\_tank} = \pi \cdot \frac{D^{2}}{4} \cdot H$$

substituting for H,

$$V_{liquefaction\_tank} = \pi \cdot \frac{D^{2}}{4} \cdot 1.5 \cdot D$$

$$4 \cdot V_{liquefaction\_tank} = 1.5 \cdot \pi \cdot D^{3}$$

Making D the subject of the formular

$$D = \sqrt[3]{\left(\frac{4 \cdot V_{liquefaction\_tank}}{1.5 \cdot \pi}\right)}$$

Given the parameters $V_{liquefaction\_tank}$ and to be

$$V_{liquefaction\_tank} = 239.724m^{3} \qquad \pi = 3.142$$

$$D_{liquefaction\_tank} := \left(\frac{4 \cdot V_{liquefaction\_tank}}{1.5 \cdot \pi}\right)^{\frac{1}{3}}$$

$$D_{liquefaction\_tank} = 5.882m$$

With reference to the former assumption that H = 1.5D,

$$H_{liquefaction\_tank} := 1.5 \cdot D_{liquefaction\_tanl}$$

$$H_{liquefaction\_tank} = 8.823m$$

The area of the liquefaction tank is therefore,

$$A_{liquefaction\_tank} := \pi \cdot D_{liquefaction\_tank} \cdot H_{liquefaction\_tank} + 2\pi \cdot \left(\frac{D_{liquefaction\_tank}}{2}\right)^{2}$$

$$A_{liquefaction\_tank} = 217.371m^{2}$$

6.1.4 SIZING OF THE SACHARIFYING TANK

Considering the balances around the sacharifying tank, denoting the amount in moles by n; the molecular weight by mol_wt; and the density by , the molecular weight, the densities and the amount in moles of the components in the tank are given as

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} \quad mol\_wt := \begin{pmatrix} 342.00 \\ 18.00 \\ 94.00 \\ 75.00 \\ 46.00 \\ 44.00 \\ 180.00 \\ 60.00 \\ 262.00 \\ 280.00 \end{pmatrix} \cdot \frac{kg}{kmol} \quad \rho := \begin{pmatrix} 945.00 \\ 1000.00 \\ 550 \\ 1115.00 \\ 789.30 \\ 290.80 \\ 900.00 \\ 1032.00 \\ 1211.50 \\ 903.00 \end{pmatrix} \cdot \frac{kg}{m^3} \quad n := \begin{pmatrix} 653.17 \\ 602.54 \\ 1.51 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{kmol}{day}$$

The average density of the components in sacharifying tank is then calculated thus;

$$\rho_{av} := \frac{\begin{pmatrix} n_1 \cdot mol\_wt_1 \cdot \rho_1 + n_2 \cdot mol\_wt_2 \cdot \rho_2 + n_3 \cdot mol\_wt_3 \cdot \rho_3 + n_4 \cdot mol\_wt_4 \cdot \rho_4 \ldots \\ + n_5 \cdot mol\_wt_5 \cdot \rho_5 + n_6 \cdot mol\_wt_6 \cdot \rho_6 + n_7 \cdot mol\_wt_7 \cdot \rho_7 \end{pmatrix} \ldots \\ + n_8 \cdot mol\_wt_8 \cdot \rho_8 + n_9 \cdot mol\_wt_9 \cdot \rho_9 + n_{10} \cdot mol\_wt_{10} \cdot \rho_{10}}{\begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}}$$

$$\rho_{av} = 948.574 \frac{kg}{m^3}$$

The total mass of the materials in the sacharifying tank is given as

$$m_{sacharifying\_tank} = \sum_{i=1}^{10} \left(n_i \cdot mol\_wt_i\right)$$

$$m_{sacharifying\_tank} := \begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}$$

$$m_{sacharifying\_tank} := m_{sacharifying\_tank} \cdot day$$

$$m_{sacharifying\_tank} = 2.36 \times 10^5 \, kg$$

The total mass of the material in the sacharifying tank is estimated to be $m_{sacharifying\_tank} = 2.36\times 10^{5}\,kg$

$$V_{sacharifying\_tank} := \frac{m_{sacharifying\_tank}}{\rho_{av}} \qquad V_{sacharifying\_tank} = 248.826m^{3}$$

On the assumption that the liquefaction tank is cylindrical and making H = 1.5D

$$V_{sacharifying\_tank} = \pi \cdot r^{2} \cdot H$$

$$V_{sacharifying\_tank} = \pi \cdot \left(\frac{D}{2}\right)^{2} \cdot H$$

$$V_{sacharifying\_tank} = \pi \cdot \frac{D^{2}}{4} \cdot H$$

Substituting for H,

$$V_{sacharifying\_tank} = \pi \cdot \frac{D^{2}}{4} \cdot 1.5 \cdot D$$

$$4 \cdot V_{liquefaction\_tank} = 1.5 \cdot \pi \cdot D^{3}$$

Making D the subject of the formular

$$D = \sqrt[3]{\left(\frac{4 \cdot V_{sacharifying\_tank}}{1.5 \cdot \pi}\right)}$$

Given the parameters $V_{sacharifying\_tanl}$ and to be

$$V_{sacharifying\_tank} = 248.826m^{3} \qquad \pi = 3.142$$

$$D_{sacharifying\_tank} := \left(\frac{4 \cdot V_{sacharifying\_tank}}{1.5 \cdot \pi}\right)^{\frac{1}{3}} \qquad D_{sacharifying\_tank} = 5.955m$$

With reference to the former assumption that H = 1.5D,

$$H_{sacharifying\_tank} := 1.5 \cdot D_{sacharifying\_tanl}$$

$$H_{sacharifying\_tank} = 8.933m$$

The area of the sacharifying tank is therefore,

$$A_{sacharifying\_tank} := \pi \cdot D_{sacharifying\_tank} \cdot H_{sacharifying\_tank} + 2\pi \cdot \left(\frac{D_{sacharifying\_tank}}{2}\right)^{2}$$

$$A_{sacharifying\_tank} = 222.838m^{2}$$

6.1.2 SIZING OF THE CRUSHER

Type: Jaw crusher

Material of construction: Steel

The crusher is used to reduce the size of the cassava with the aid of the crushing ability it possesses. The crushing ability of the crusher is carried by the rolls inside the crusher. Therefore, the sizing of the crusher will take the space of the rolls into account so as not to underestimate the capacity of the crusher.

Given the the amount of materials in the crusher to be:

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} \quad \text{mol\_wt} := \begin{pmatrix} 342.00 \\ 18.00 \\ 94.00 \\ 75.00 \\ 46.00 \\ 44.00 \\ 180.00 \\ 60.00 \\ 262.00 \\ 280.00 \end{pmatrix} \cdot \frac{\text{kg}}{\text{kmol}} \quad \rho := \begin{pmatrix} 945.00 \\ 1000.00 \\ 550 \\ 1115.00 \\ 789.30 \\ 290.80 \\ 900.00 \\ 1032.00 \\ 1211.50 \\ 903.00 \end{pmatrix} \cdot \frac{\text{kg}}{\text{m}^3} \quad n := \begin{pmatrix} 673.37 \\ 98.31 \\ 1.56 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.78 \\ 4.68 \\ 1.56 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}}$$

The average density of the materials in the crusher can be calculated as;

$$\rho_{av} := \frac{\begin{pmatrix} n_1 \cdot \text{mol\_wt}_1 \cdot \rho_1 + n_2 \cdot \text{mol\_wt}_2 \cdot \rho_2 + n_3 \cdot \text{mol\_wt}_3 \cdot \rho_3 + n_4 \cdot \text{mol\_wt}_4 \cdot \rho_4 \ldots \\ + n_5 \cdot \text{mol\_wt}_5 \cdot \rho_5 + n_6 \cdot \text{mol\_wt}_6 \cdot \rho_6 + n_7 \cdot \text{mol\_wt}_7 \cdot \rho_7 \end{pmatrix} \ldots \\ + n_8 \cdot \text{mol\_wt}_8 \cdot \rho_8 + n_9 \cdot \text{mol\_wt}_9 \cdot \rho_9 + n_{10} \cdot \text{mol\_wt}_{10} \cdot \rho_{10}}{\begin{pmatrix} n_1 \cdot \text{mol\_wt}_1 + n_2 \cdot \text{mol\_wt}_2 + n_3 \cdot \text{mol\_wt}_3 + n_4 \cdot \text{mol\_wt}_4 + n_5 \cdot \text{mol\_wt}_5 \ldots \\ + n_6 \cdot \text{mol\_wt}_6 + n_7 \cdot \text{mol\_wt}_7 + n_8 \cdot \text{mol\_wt}_8 + n_9 \cdot \text{mol\_wt}_9 + n_{10} \cdot \text{mol\_wt}_{10} \end{pmatrix}}$$

$$\rho_{av} = 946.504 \frac{\text{kg}}{\text{m}^3}$$

The total mass of the materials in the crusher is given as

$$m_{crusher} = \sum_{i=1}^{10} \left(n_i \cdot mol\_wt_i\right)$$

$$m_{crusher} := \left(\begin{array}{l} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{array}\right)$$

$$m_{crusher} := m_{crusher} \cdot day \qquad m_{crusher} = 2.339 \times 10^5\, kg$$

The total mass of the material in the crusher is estimated to be $m_{crusher} = 2.339 \times 10^5\, kg$

So, the volume is calculated to be

$$V_{crusher} := \frac{m_{crusher}}{\rho_{av}} \qquad V_{crusher} = 247.139\, m^3$$

The volume of the occupied by the rolls can be given as

$$Q = \frac{d \cdot L \cdot s}{2.96}$$

Where

Q is the capacity of the crusher occupied by the rolls in

d is the distance between the rolls

L is the length of rolls

s is the peripheral speed

Given that,

$d := 1.33 \cdot cm \qquad d = 0.013 m$

$L := 1.15 \cdot cm \qquad L = 0.012 m$

$s' := 7 \cdot \frac{cm}{min} \qquad s' = 1.167 \times 10^{-3} \frac{m}{s}$

The total volume of the crusher is thus

$$V_{Tcrusher} := V_{crusher} + Q_{crusher}$$

$$Q_{crusher} := \frac{(d \cdot L \cdot s')}{2.96} \qquad Q_{crusher} := Q_{crusher} \cdot day$$

$$Q_{crusher} = 5.209 \times 10^{-3}\, m^3$$

$$V_{Tcrusher} = 247.145\, m^3$$

The volume of the crusher is given as:

$$V = \pi \cdot r^2 \cdot h$$

and, since

$$r = \frac{d}{2}$$

$$V = \pi \cdot \left(\frac{d}{2}\right)^2 \cdot h$$

$$V = \pi \cdot \frac{d^2}{4} \cdot h$$

Let h = kd, where k is a constant

substituting for h,

$$V = \pi \cdot \frac{d^2}{4} \cdot (k \cdot d)$$

$$4 \cdot V = k \cdot \pi \cdot d^3$$

Making d the subject of the formular

$$d = \left(\frac{4 \cdot V}{k \cdot \pi}\right)^{\frac{1}{3}}$$

assuming that $k := 1.7$

$$d_{crusher} := \left(\frac{4 \cdot V_{Tcrusher}}{k \cdot \pi}\right)^{\frac{1}{3}}$$

$$d_{crusher} = 5.644m$$

From

$$h_{crusher} := k \cdot d_{crusher}$$

$$h_{crusher} = 9.877m$$

The area of the crusher is therefore,

$$A := 2\pi \cdot \frac{d_{crusher}}{2} \cdot h_{crusher} + 2\pi \cdot \left(\frac{d_{crusher}}{2}\right)^2$$

$$A = 225.189m^2$$

The net power to drive a roll ball was found to be

$$E = [(1.64 \cdot L - 1) \cdot K + 1](1.64 \cdot D)^{2.5} \cdot E_2$$

where

E is the net power to drive a roll

L is the inside length of the crusher, m

D is the mean inside diameter of the crusher,
m

E_2 is the net power used by a 0.6 - 0.6-m roll under similar operating conditions K is a constant which is 0.9 for rolls less than 1.5m long and 0.85 for crushers over 1.5m long

Now, choosing

$L = 0.012\mathrm{m}$

$K_r := 0.9$

$D := d_{crusher}$

$E_2 := 9.5 \cdot W$ (Ernest, 1995)

So, the net power used by the roll is

$$E_{roll} := \left[(1.64 \cdot L - 1 \cdot m) \cdot K_r + 1m\right](1.64 \cdot D)^{2.5} \cdot E_2 \cdot m^{-3.5} \qquad E_{roll} = 289.696W$$

6.1.5 SIZING OF THE FERMENTOR

The fermentor is like a batch reactor where the fermentation reaction takes place.

The design equation of a batch reactor is

Data:

Number of moles of materials in the reactor, $N_{A0} := 1264.04 \cdot \mathrm{kmol}$

Conversion, $X_A := 0.9$

Final concentration of sugar, $C_A := 0.01 \cdot \frac{\mathrm{kmol}}{\mathrm{m}^3}$

$$C_A = \frac{N_A}{V}$$

$$V = \frac{N_A}{C_A}$$

And $N_A = N_{A0} \cdot (1 - X_A)$

So,

$$V = \frac{N_{A0} \cdot (1 - X_A)}{C_A}$$

Imputing the data,

$N_{A0} = 1.264 \times 10^3 \mathrm{kmol}$

$X_A = 0.99$

$C_A = 0.01 \frac{\mathrm{kmol}}{\mathrm{m}^3}$

$$V_{fermentor} := \frac{N_{A0} \cdot (1 - X_A)}{C_A}$$

$N_{A0} = 1.264 \times 10^3 \mathrm{kmol}$

$V_{fermentor} = 1.264 \times 10^3 \mathrm{m}^3$

The volume of the fermentor is therefore, $V_{fermentor} = 1.264 \times 10^3 \mathrm{m}^3$

Assuming that the the height of the fermentor is given as H = 1.5D

$V_{fermentor} = \pi \cdot r^2 \cdot H$ $V_{fermentor} = \pi \cdot \left(\frac{D}{2}\right)^2 \cdot H$ $V_{fermentor} = \pi \cdot \frac{D^2}{4} \cdot H$

Substituting for H,

$$V_{fermentor} = \pi \cdot \frac{D^2}{4} \cdot 1.5 \cdot D$$

$$4 \cdot V_{fermentor} = 1.5 \cdot \pi \cdot D^3$$

Making D the subject of the formular

$$D = \sqrt[3]{\left(\frac{4 \cdot V_{fermentor}}{1.5 \cdot \pi}\right)}$$

Given the parameters $V_{fermentor}$ and to be

$$V_{fermentor} = 1.264 \times 10^3 \, m^3$$

$$\pi = 3.142$$

$$D_{fermentor} := \left(\frac{4 \cdot V_{fermentor}}{1.5 \cdot \pi}\right)^{\frac{1}{3}} \qquad D_{fermentor} = 10.237m$$

With reference to the former assumption that H = 1.5D,

$$H_{fermentor} := 1.5 \cdot D_{fermentor}$$

$$H_{fermentor} = 15.356m$$

The area of the fermentor is therefore,

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

$$A_{fermentor} = 658.516m^2$$

The time of the reaction is obtained from the relationship,

$$-\ln(1 - X_A) = k \cdot t$$

Where $k := \frac{1.3}{hr}$

From the formula,

$$-\ln(1 - X_A) = k \cdot t$$

Making t the subject of the formula,

$$t := \frac{-\ln(1 - X_A)}{k} \qquad t = 3.542hr$$

6.1.6 SIZING OF DISTILLATOR

Given the amount of materials in the distillator to be

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} \qquad n := \begin{pmatrix} 0.00 \\ 602.54 \\ 1.51 \\ 35.11 \\ 333.84 \\ 0.00 \\ 0.00 \\ 0.76 \\ 4.54 \\ 1.51 \end{pmatrix} \cdot \frac{kmol}{day}$$

The average density of the components is then calculated thus;

$$\rho_{av} := \frac{\begin{pmatrix} n_1 \cdot mol\_wt_1 \cdot \rho_1 + n_2 \cdot mol\_wt_2 \cdot \rho_2 + n_3 \cdot mol\_wt_3 \cdot \rho_3 + n_4 \cdot mol\_wt_4 \cdot \rho_4 \ldots \\ + n_5 \cdot mol\_wt_5 \cdot \rho_5 + n_6 \cdot mol\_wt_6 \cdot \rho_6 + n_7 \cdot mol\_wt_7 \cdot \rho_7 \end{pmatrix} \ldots \\ + n_8 \cdot mol\_wt_8 \cdot \rho_8 + n_9 \cdot mol\_wt_9 \cdot \rho_9 + n_{10} \cdot mol\_wt_{10} \cdot \rho_{10}}{\begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}}$$

$$\rho_{av} = 909.103 \frac{kg}{m^3}$$

The total mass of the materials in the distillator is given as

$$m_{dist} = \sum_{i=1}^{10} \left(n_i \cdot mol\_wt_i \right)$$

$$m_{dist} := \begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}$$

$$m_{dist} := m_{dist} \cdot day \qquad m_{dist} = 3.064 \times 10^4 \, kg$$

Knowing that the total mass of the material in the distillator is equal to $m_{dist} = 3.064 \times 10^4 \, kg$

$$V_{dist} := \frac{m_{dist}}{\rho_{av}} \qquad V_{dist} = 33.699 m^3$$

On the assumption that the distillator is cylindrical and making $H = 1.19D$

$$V_{dist} = \pi \cdot r^2 \cdot H$$

$$V_{dist} = \pi \cdot \left(\frac{D}{2} \right)^2 \cdot H$$

$$V_{dist} = \pi \cdot \frac{D^2}{4} \cdot H$$

Substituting for H,

$$V_{dist} = \pi \cdot \frac{D^2}{4} \cdot 1.19 \cdot D$$

$$4 \cdot V_{dist} = 1.19 \cdot \pi \cdot D^3$$

Making D the subject of the formular

$$D_{dist} := \left(\frac{4 \cdot V_{dist}}{1.19 \cdot \pi} \right)^{\frac{1}{3}} \qquad D = \sqrt[3]{\left(\frac{4 \cdot V_{dist}}{1.19 \cdot \pi} \right)}$$

$$\pi = 3.142 \qquad D_{dist} = 3.304 m$$

Given the parameters $V_{distillator}$ and to be

$$V_{dist} = 33.699 m^3$$

With reference to the former assumption that H = 1.19D,

$$H_{dist} := 1.19 \cdot D_{dist}$$

$$H_{dist} = 3.931\text{m}$$

The area of the distillator is therefore,

$$A_{dist} := \pi \cdot D_{dist} \cdot H_{dist} + 2\pi \cdot \left(\frac{D_{dist}}{2}\right)^2 \qquad A_{dist} = 57.945\text{m}^2$$

6.1.7 SIZING OF THE DEHYDRATOR

Given the amount of materials in the dehydrator to be

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} \qquad n := \begin{pmatrix} 0.00 \\ 12.05 \\ 0.00 \\ 0.00 \\ 317.5 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}}$$

The average density of the components is then calculated thus;

$$\rho_{av} := \frac{\begin{pmatrix} n_1 \cdot mol\_wt_1 \cdot \rho_1 + n_2 \cdot mol\_wt_2 \cdot \rho_2 + n_3 \cdot mol\_wt_3 \cdot \rho_3 + n_4 \cdot mol\_wt_4 \cdot \rho_4 \dots \\ + n_5 \cdot mol\_wt_5 \cdot \rho_5 + n_6 \cdot mol\_wt_6 \cdot \rho_6 + n_7 \cdot mol\_wt_7 \cdot \rho_7 \end{pmatrix} \dots \\ + n_8 \cdot mol\_wt_8 \cdot \rho_8 + n_9 \cdot mol\_wt_9 \cdot \rho_9 + n_{10} \cdot mol\_wt_{10} \cdot \rho_{10}}{\begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \dots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}}$$

$$\rho_{av} = 792.383\frac{\text{kg}}{\text{m}^3}$$

The total mass of the materials in the dehydrator is given as

$$m_{dehyd} = \sum_{i=1}^{10} \left(n_i \cdot mol\_wt_i\right)$$

$$m_{dehyd} := \begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \dots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}$$

Knowing that the total mass of the species in the concentrator is equal to $m_{conc} := 107059.37 \cdot \text{kg}$

$$V_{dehyd} := \frac{m_{dehyd}}{\rho_{av}} \qquad m_{dehyd} := m_{dehyd} \cdot \text{day} \qquad m_{dehyd} = 1.482 \times 10^4 \text{kg}$$

$$V_{dehyd} = 18.705\text{m}^3$$

On the assumption that the dehydrator is cylindrical and making H = 1.71D

$$V_{dehyd} = \pi \cdot r^2 \cdot H$$

$$V_{dehyd} = \pi \cdot \left(\frac{D}{2}\right)^2 \cdot H$$

$$V_{dehyd} = \pi \cdot \frac{D^2}{4} \cdot H$$

Substituting for H,

$$V_{dehyd} = \pi \cdot \frac{D^2}{4} \cdot 1.71 \cdot D$$

$$4 \cdot V_{dehyd} = 1.71 \cdot \pi \cdot D^3$$

Making D the subject of the formular

$$D = \sqrt[3]{\left(\frac{4 \cdot V_{dehyd}}{1.71 \cdot \pi}\right)}$$

Given the parameters $V_{dehydrator}$ and to be

$V_{dehyd} = 18.705m^3$ $\pi = 3.142$

$$D_{dehyd} := \left(\frac{4 \cdot V_{dehyd}}{1.71 \cdot \pi}\right)^{\frac{1}{3}} \qquad D_{dehyd} = 2.406m$$

With reference to the former assumption that H = 1.71D,

$$H_{dehyd} := 1.71 \cdot D_{dehyd} \qquad H_{dehyd} = 4.114m$$

The area of the dehydrator is therefore,

$$A_{dehyd} := \pi \cdot D_{dehyd} \cdot H_{dehyd} + 2\pi \cdot \left(\frac{D_{dehyd}}{2}\right)^2 \qquad A_{dehyd} = 40.191m^2$$

6.1.8 SIZING OF THE CENTRIFUGAL SEPARATOR

The centrifugal separator is used to separate the stillage from the bottom of the distillator which contains solids from the grain and added yeast as well as liquid from the water added during the process. This is separated into thin stillage and wet distiller grain (WDG)

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} \qquad n := \begin{pmatrix} 0.00 \\ 12.05 \\ 0.00 \\ 0.00 \\ 317.5 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{\text{kmol}}{\text{day}}$$

The average density of the components is then calculated thus;

$$\rho_{av} := \frac{\begin{pmatrix} n_1 \cdot mol\_wt_1 \cdot \rho_1 + n_2 \cdot mol\_wt_2 \cdot \rho_2 + n_3 \cdot mol\_wt_3 \cdot \rho_3 + n_4 \cdot mol\_wt_4 \cdot \rho_4 \ldots \\ + n_5 \cdot mol\_wt_5 \cdot \rho_5 + n_6 \cdot mol\_wt_6 \cdot \rho_6 + n_7 \cdot mol\_wt_7 \cdot \rho_7 \end{pmatrix} \ldots \\ + n_8 \cdot mol\_wt_8 \cdot \rho_8 + n_9 \cdot mol\_wt_9 \cdot \rho_9 + n_{10} \cdot mol\_wt_{10} \cdot \rho_{10}}{\begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}}$$

$$\rho_{av} = 792.383\frac{kg}{m^3}$$

The total mass of the materials in the centrifugal separator is given as

$$m_{sep} = \sum_{i=1}^{10} \left(n_i \cdot mol\_wt_i\right)$$

$$m_{sep} := \begin{pmatrix} n_1 \cdot mol\_wt_1 + n_2 \cdot mol\_wt_2 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \\ + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \end{pmatrix}$$

$$m_{sep} := m_{sep} \cdot day \qquad m_{sep} = 1.482\times 10^4 kg$$

Knowing that the total mass of the species in the concentrator is equal to $m_{conc} := 107059.37 \cdot kg$

$$V_{sep} := \frac{m_{sep}}{\rho_{av}} \qquad V_{sep} = 18.705m^3$$

On the assumption that the centrifugal separator is conical in shape and making H = 1.5D

$$V_{sep} = \frac{1}{3}\pi \cdot r^2 \cdot H \qquad V_{sep} = \frac{1}{3}\pi \cdot \left(\frac{D}{2}\right)^2 \cdot H \qquad V_{sep} = \frac{1}{3}\pi \cdot \frac{D^2}{4} \cdot H$$

Substituting for H,

$$V_{sep} = \frac{1}{3}\pi \cdot \frac{D^2}{4} \cdot 1.5 \cdot D$$

$$4 \cdot V_{sep} = \frac{1.5}{3} \cdot \pi \cdot D^3$$

Making D the subject of the formular

$$D = \sqrt[3]{\left(\frac{12 \cdot V_{sep}}{1.5 \cdot \pi}\right)}$$

Given the parameters $V_{separator}$ and to be

$V_{sep} = 18.705m^3$ $\pi = 3.142$

$$D_{sep} := \left(\frac{12 \cdot V_{sep}}{1.5 \cdot \pi}\right)^{\frac{1}{3}}$$ $D_{sep} = 3.625m$

With reference to the former assumption that H = 1.5D,

$H_{sep} := 1.71 \cdot D_{sep}$ $H_{sep} = 6.199m$

The area of the centrifugal separator is calculated from the relation,

$$A_{sep} = \pi \cdot r_{sep} \cdot L_{sep} + \pi \cdot r_{sep}^2$$

Where L_{sep} = length_of_centrifuge_separator

Assuming that L_{sep} is $1.2H_{sep}$

$L_{sep} := 1.2H_{sep}$

The area of the centrifugal separator is therefore,

$$A_{sep} := \pi \cdot D_{sep} \cdot L_{sep} + \pi \cdot \left(\frac{D_{sep}}{2}\right)^2$$ $A_{sep} = 95.03m^2$

6.1.9 SIZING OF THE DRYER

The vacuum drier forms an important part of the plant. The drier has a capability of removing the moisture associated with the WDG. The drier is a counter current drier, with air as the heating medium. The Relative Humidity (RH) of the air entering is 15%. The air entering is heated to a temperature of 170°C.

Given the amount of materials in the dryer to be

$$\begin{pmatrix} \text{Starch} \\ H_2O \\ \text{Ash} \\ \text{Yeast} \\ \text{EtOH} \\ CO_2 \\ \text{Sugar} \\ \text{Fibre} \\ \text{Protein} \\ \text{Fat} \end{pmatrix} \qquad n := \begin{pmatrix} 0.00 \\ 29.52 \\ 1.44 \\ 7.02 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.72 \\ 4.31 \\ 1.44 \end{pmatrix} \cdot \frac{kmol}{day} \qquad mol\_wt := \begin{pmatrix} 342.00 \\ 18.00 \\ 94.00 \\ 75.00 \\ 46.00 \\ 44.00 \\ 180.00 \\ 60.00 \\ 262.00 \\ 280.00 \end{pmatrix} \cdot \frac{kg}{kmol}$$

Amount of water in dryer feed is calculated thus,

$$W_f := n_2 \cdot mol\_wt_2$$

Hence the amount of water in dryer feed, $W_f = 531.36 \frac{kg}{day}$

Dry solid in dryer feed is calculated as average of remaining component,

$$S_f := \left(n_1 \cdot mol\_wt_1 + n_3 \cdot mol\_wt_3 + n_4 \cdot mol\_wt_4 + n_5 \cdot mol\_wt_5 \ldots \atop + n_6 \cdot mol\_wt_6 + n_7 \cdot mol\_wt_7 + n_8 \cdot mol\_wt_8 + n_9 \cdot mol\_wt_9 + n_{10} \cdot mol\_wt_{10} \right)$$

Dry solid in dryer feed, $S_f = 2.237 \times 10^3 \frac{kg}{day}$

Water content in dryer output, $W_p := 0 \cdot \frac{kg}{day}$

Hence, water removed by the dryer is

$$W_d := W_f - W_p$$

$$W_d = 531.36 \frac{kg}{day}$$

Inlet temperature of feed, $T_{if} := (35 + 273) \cdot K$

Outlet air temperature, $T_{oa} := (90 + 273) \cdot K$

Inlet air temperature, $T_{ia} := (170 + 273) \cdot K$

Discharge temperature, $T_d := (80 + 273) \cdot K$

The temperature of the air leaving the dryer should be selected on the basis of an economic balance between dryer and fuel cost. It has been observed that dryers are most economically operated when the total Number of Transfer Units (NTU) range from 1.0 to 2.0. Assuming that

So, assuming that

$$NTU := 1.1$$

Knowing that,

$$NTU = \ln\left[\frac{(t_{g1} - t_w)}{t_{g2} - t_w}\right]$$

$$t_{g1} := T_{ia}$$

$$t_w := T_d$$

$$t_{g2} := \frac{(\exp(NTU) \cdot t_w + t_{g1} - t_w)}{\exp(NTU)} \qquad t_{g2} = 382.958\,K$$

The heat balance of the dryer has revealed that the total heat required to raise the product to the discharge temperature is

$$Q_t := -6.985 \times 10^{12} \cdot \frac{kJ}{day} \qquad Q_t = -6.985 \times 10^{12} \frac{kJ}{day}$$

The Log Mean Temperature Difference (LMTD) across the dryer, T_m is

$$\Delta T_m := \left| \frac{[(T_{ia} - T_{if}) - (T_d - T_{oa})]}{\ln\left[\frac{(T_{ia} - T_{if})}{(T_d - T_{oa})}\right]} \right|$$

$$\Delta T_m = 35.542\,K$$

The minimum velocity of air is set based on the particle size. Air flow rate of

$v_{air} := 23 \times 10^5 \cdot \frac{kg}{hr \cdot m^2}$ is sufficient for WDG. Hence this will be used in application.

The minimum velocity is used since it gives the smallest possible size of dryer.

where A_{dryer} is the area of dryer; R_{dryer} is the radius of dryer

Denoting the diameter of the dryer as D_{dryer}

Amount of air required is calculated using the relationship

$$Q_t = M \cdot C_p \cdot \Delta T$$

$$A_{dryer} = \pi \cdot \left(\frac{D_{dryer}}{2}\right)^2$$

$$M = \frac{|Q_t|}{(C_p \cdot \Delta T)}$$

Given that

$$|Q_t| = 2.91 \times 10^{11}\,\frac{kJ}{hr}$$

$$C_p := 4.187 \cdot \frac{kJ}{kg \cdot K}$$

So,

Length of transfer unit has been related to mass velocity and diameter by the following relation,

$$\Delta T := T_{ia} - T_{oa}$$

$$LTU = 0.000064 \cdot C_p \cdot (G)^{0.84} \cdot d_{dryer}$$

$$M_{air} := \frac{|Q_t|}{(C_p \cdot \Delta T)}$$

where G is the mass velocity which is equal to $G := v_{air}$, that is,

$$G = 2.3 \times 10^{6}\,\frac{kg}{m^2 hr}$$

$$M_{air} = 8.689 \times 10^{8}\,\frac{kg}{hr}$$

Area of dryer is thus calculated to be

So,

$$A_{dryer} := \frac{M_{air}}{G}$$

$$LTU := 0.000064 \cdot \frac{C_p}{\frac{kJ}{kg \cdot K}} \cdot \left(\frac{G}{\frac{kg}{day \cdot m^2}}\right)^{0.4} \cdot D_{dryer}$$

$$A_{dryer} = 377.776\,m^2$$

Using the formula for the area of dryer which is

$$LTU = 0.34\,m$$

$$A_{dryer} = \pi \cdot R_{dryer}^2$$

Length of the dryer is given as

$$L_{dryer} := LTU \cdot NTU$$

$$A_{dryer} = \pi \cdot \frac{D_{dryer}^2}{4}$$

$$L_{dryer} = 8.078\,m$$

$$4 \cdot A_{dryer} = \pi \cdot D_{dryer}^2$$

$$D_{dryer}^2 = \frac{4 \cdot D_{dryer}}{\pi}$$

The diameter of dryer is thus equal to

$$D_{dryer} := \sqrt{\frac{4 \cdot A_{dryer}}{\pi}}$$

$$D_{dryer} = 21.932\,m$$

CHAPTER SEVEN

7.0 OPTIMIZATION OF PROCESS EQUIPMENT

7.1 Introduction

The problem of optimizing cassava-based bioethanol plants is addressed through the use of heat integration and mathematical programming techniques. The goal is to reduce the operating costs of the plant. Capital cost, energy usage, and yields all contribute to production cost. Yield and energy-use also influence the viability of cassava-based ethanol as a sustainable fuel.

A limited superstructure is first proposed comprising alternative designs including the various process units and utility streams involved in ethanol production. The objective is to determine the connections in the network and the flow in each stream in the network such that the energy requirement of the overall plant is minimized. This is accomplished through the formulation of a mixed integer nonlinear programming problem involving mass and energy balances for all the units in the system, where the model is solved through two nonlinear programming subproblems. a heat integration study is then performed on the resulting flowsheet; the modified flowsheet includes multieffect distillation columns and further reduces energy consumption. The results indicate that it is possible to reduce the current steam consumption required in the transformation of cassava into fuel grade ethanol by more than 40% compared to initial basic design.

7.2 The Optimization Principle

7.2.1 Ethanol Process technology

In this process, cassava grains are used as feed, and are first washed and then ground. The resulting ground cassava undergoes cooking and liquefaction to produce cassava slurry, which is then enzymatically saccharified to produce glucose. The mash is then fed to the fermentor where ethanol is produced from glucose. After the fermentation, a stripping column known as 'beer column' separates the solids and some water from the ethanol-water mixture.

The column overhead stream contains 80–90% ethanol and is further rectified in a distillation tower to obtain an azeotropic mixture of ethanol and ether. This azeotropic mixture then passes over a molecular sieve made of zeolite to produce anhydrous or fuel grade ethanol at the outlet.

The wet solids from the bottom of the beer column go to a centrifuge, which separates the mixture into solids (relatively wet) and a liquid mixture. These wet solids from the bottom of the centrifuge are combined with the proteins obtained by evaporating the water from the centrifuge and are dried. This material (Distillers Dried Grains with Solubles, or, DDGS) is sold as cattle feed.

7.2.2 Optimization Principles

The improvement of the design and the energy efficiency of the dry-grind ethanol plants can be achieved through process synthesis and mathematical optimization techniques. A limited superstructure optimization approach is propose where a flowsheet is first constructed embedding the various process units involved in ethanol production, and then considering alternatives for some of the processes. These units are interconnected to each other through network flows and other utility streams.

The goal is to optimize the structure minimizing the energy input in the ethanol production process. The optimization of the system is formulated as a mixed integer nonlinear programming (MINLP) problem, where the model involves a set of constraints representing mass and energy balances for all the units in the system. This problem is solved through two nonlinear programming (NLP) subproblems.

Heat integration analysis of the resulting process is then performed. The heat recovery network, together with a modified distillation column design, further reduces the energy consumption in the plant and this decreased the unit production cost of ethanol.

7.2.3 Superstructure of the Design Alternatives

In this section, alternatives are introduced for some of the processes in the standard flowsheet. This yields a superstructure of design alternatives that is optimized using nonlinear programs to minimize energy consumption in the plant

A superstructure of the operations involved in the transformation of cassava to fuel ethanol is proposed by considering a number of different design alternatives.

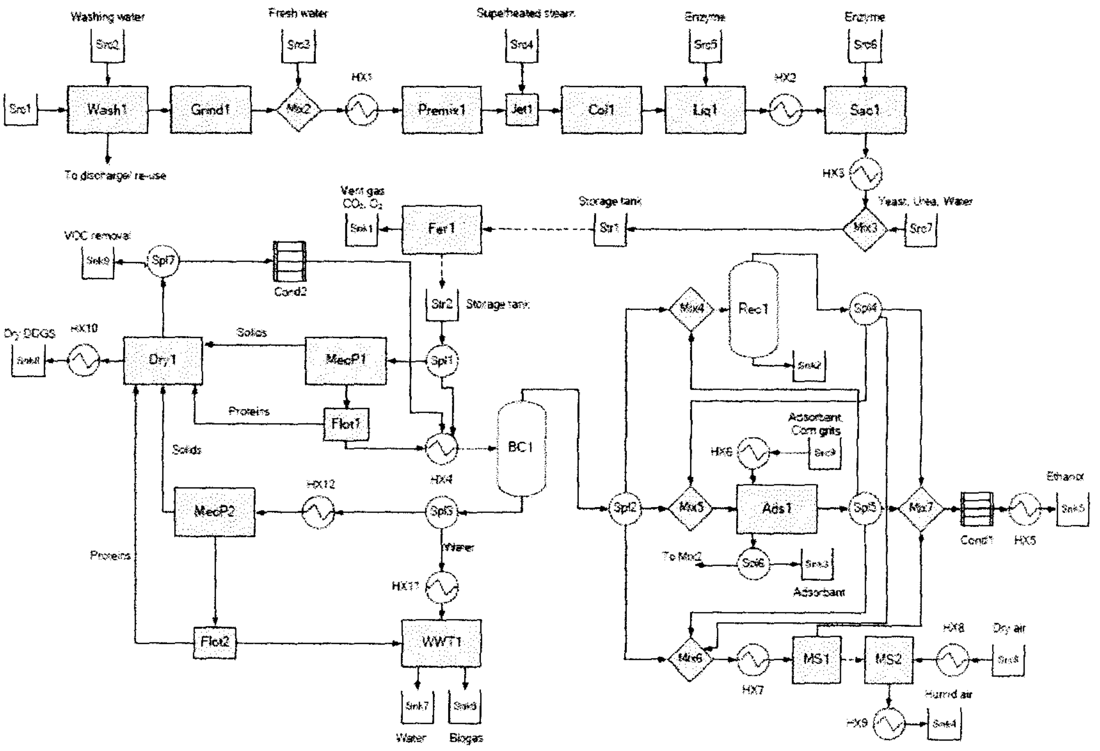


Fig 7.1 Superstructure of a cassava based ethanol plant

As can be seen from Fig. 7.1, the superstructure has three specific sub-structures.

These pertain to:

(i) Feed preparation and enzymatic hydrolysis – These are operations which are necessary for the production of ethanol, including cassava washing and grinding, jet cooking, liquefaction, saccharification and fermentation.

(ii) Ethanol purification – This involves operations required for the purification of ethanol as obtained from the fermentor to fuel grade ethanol. This part consists of the distillation columns, cassava bed adsorbers and molecular sieves.

(iii) Solids drying – These operations are for separating and drying the solids from the fermentor to be used as cattle feed. This part of the network includes the mechanical press, the flotation unit, and the dryer.

Cassava grains are used as feedstock in this fuel ethanol production process. The cassava grains consist primarily of starch. Other components include free sugars proteins, hemicellulose, cellulose, oils and ash. It is assumed that the sugars are only glucose. The cellulose and hemicellulose are mainly part of the fiber. The moisture content of the cassava is taken to be 15%. The feedstock is converted into the required product, which is nearly anhydrous ethanol following a series of steps. There exist a number of different design alternatives in the superstructure. For instance, we have two different routes for separating the solids and liquids coming out of the fermentor as seen in Fig. 7.1. We can have a mechanical press (separator) placed at the outlet of the fermentor so that the solid-liquid separation takes place before the beer column. Alternatively, the separator can be placed after the bottoms of the distillation column, in which case the distillation process also provides the main solid-liquid separation. In the former separation route the solid loading to the distillation column is lower, while in the latter case the solid loading to the distillation column is higher.

For purifying the ethanol-water mixture coming out at the top of the beer column, we can use one or a combination of the following (see Fig. 7.1):

(a) Rectification column (distillation column that gives an azeotropic mixture of ethanol and water at the top).

CHAPTER EIGHT

8.0 SAFETY AND QUALITY CONTROL

8.1 Introduction

In designing a plant, safety is one of the major criteria for selection of the best alternative along with economic viability. This is because value is placed on the operating personnel and the equipment handled. Operating conditions and equipment in operation are normally dangerous and could lead to serious injury or major damage to the plant as well as disability or death for the victim.

Safety becomes even more pertinent when the materials involved are hazardous. This is the case in the design of the Ethanol plant. Fuel ethanol presents some challenges. It is corrosive, and materials that normally would not be affected by low percentage ethanol blends, have been found to dissolve in the presence of higher ethanol concentrations. Dedicated ethanol vehicles must use unplated steel, stainless steel, black iron or bronze, which have all shown acceptable resistance to ethanol corrosion, or they have to use non-metallic materials such as thermoset reinforced fiberglass or neoprene rubber

Also siting of any process plant should be far from the public to avoid environmental pollution.

8.1 Safety

Safety is the area of engineering and public health which 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.

8.1.1 General Safety Rules

Relevant Instructions

a) Before attempting to operate the Ethanol 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)

a) It must be ensured that all staff must be fully aware of the potential hazards when the Ethanol 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 Ethanol plant. Otherwise, the gear motor of the affected equipment must be set in the reverse direction and the entrained materials should be discharged. (Odigure, 1998)

Operational Instructions

d) All materials of construction should be well selected on the basis of corrosion resistance and structural strength. This is to avoid the collapse of any equipment or structures.

e) All pipelines carrying flammable materials must be installed with flame traps.

f) Relief valves should be installed along all lines carrying gases and vapour.

g) Automatic controllers should be installed to control temperature, pressure, and flow rates of the material or equipment involved.

h) A badly maintained plant is a potential hazard. Ensure that a competent staff is responsible for recognizing maintenance and repairs on a planned basis.

i) Signs and placards warning of the hazardous materials should be placed all over the plant.

j) Foam fire extinguishers or those using carbon dioxide should be widely and easily available and ready for immediate use at all times.

Maintenance

a) A badly maintained Ethanol 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 not 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 Ethanol 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 Ethanol plant e.g. while operating the crusher.

Guard and safety devices

a) Guards and safety devices must be installed on the Ethanol 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 muse 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.

8.3 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.

8.3.1 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.

8.3.2 Quality management

Quality management involves all activities of the overall management functions that determine the quality policy, objective and responsibilities and implement then 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.

General Quality Control Measures

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

The concept of quality control analysis has been greatly achieved by statistically quality control (SQC) method. The general intent of SQC is that of sampling units and parts being produced and essentially determining trends in deviation from production as continuously (affordable and achievable) as possible.

There are many important statistical tests, which could be used to determine the quality of products, among the techniques is the t-test hypothesis.

However, before a statistical test is applied, the level of significance is generally selected. It is customary to prescribe significance 0f 95% or more before rejecting a specific hypothesis.

CHAPTER NINE

9.0 PROCESS CONTROL AND INSTRUMENTATION

9.1 INTRODUCTION

In the design of an industrial plant, the methods, which will be used, for plant operation and control help determine many of design variables, for example, the extent of instrumentation can be a factor in choosing the type of process and setting the labor requirements. It should be remembered that maintenance work would be necessary to keep the installed equipment and facilities in good operating condition. The importance of such factors which are directly related to plant operation and control must be recognized and take into proper account during the development of a design project.

Processes may be controlled more precisely to give more uniform and higher – quality products by the application of automatic control, often leading to higher profits. Therefore, any process with an input and output which may be flow, pressure, liquid level, temperature, composition or any other inventory, environmental or quality variable that is to be held at a desired value must have some measure of control applied to it.

Change in output may occur:

1. Randomly as caused by changes in weather or raw material quality.
2. Diurnally with ambient temperature
3. Manually when operators change production rate.
4. Stepwise when equipment is switched in or out of service, or
5. Cyclically as a result of oscillations in other control loops.

Variation in any of the ways stated above would drive the output (controlled variable) further away from the set point (desired value) thus requiring a corresponding variable to bring it back (manipulative variable).

9.2 Instrumentation and Control Objectives

The key objectives adhered to in the specification of the instrumentation and control schemes are:

1. Safe plant operation
    - i. To keep the process variables within known safe operations limits.
    - ii. To defect dangerous situations as they develop and to provide alarms and automatic shut – down systems
    - iii. To provide interlocks and alarms to prevent dangerous operation procedures
2. Production rate. To achieve the design producer output
3. Product quality. To maintain the product composition within the specific quality standards
4. Cost. They operate at the lowest production cost, but not to the detriment of the product quality.

In the plant design some of the variables needed to be monitored and controlled are, the flow rate, temperature, pressure and composition.

- i. **Flow rates/feed ratio control**: a feed ratio controller is applied between the methane stream and the oxygen stream with the aim of maintaining a complete conversion of methane to the desired products. This is necessary to avoid excess oxygen being built up in the reactor.
- ii. **Temperature control reaction**: temperature is controlled by regulating the flow rate of the reaction into it. This can also be controlled by heat transfer. The reaction is exothermic. It produces heat, which tends to raise reaction temperature thereby increasing reaction rate and producing more heat. This positive feedback is countered by negative feedback in the cooling system, which removes more heat as reactor temperature rises.

The temperature controller, which in turn operates the coolant value, to counter the rise or drop in temperature in the sector.

iii. **Pressure control**: pressure sensing is quite straightforward with the aid of pneumatic instrumentation such as Bourdon gauge, diaphragms and bellows. These sensors measure absolute pressure and pressure differences between two levels. Therefore, pressure control is achieved by manipulating the airflow rate in the compressor to avoid deviation from set point.

iv. **Composition control**: first requirement here is to establish proper stoichiometry of the reactants in propositions needed to satisfy the reaction chemistry and also the desired output product. This is achieved by setting input flow rates in ratio to one another, or a composition measurement (analyzer) can be used to trim the ratios to the right proportion

9.3 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) tat changes the manipulated variable with the use of a mechanical action.

Types of control instruments

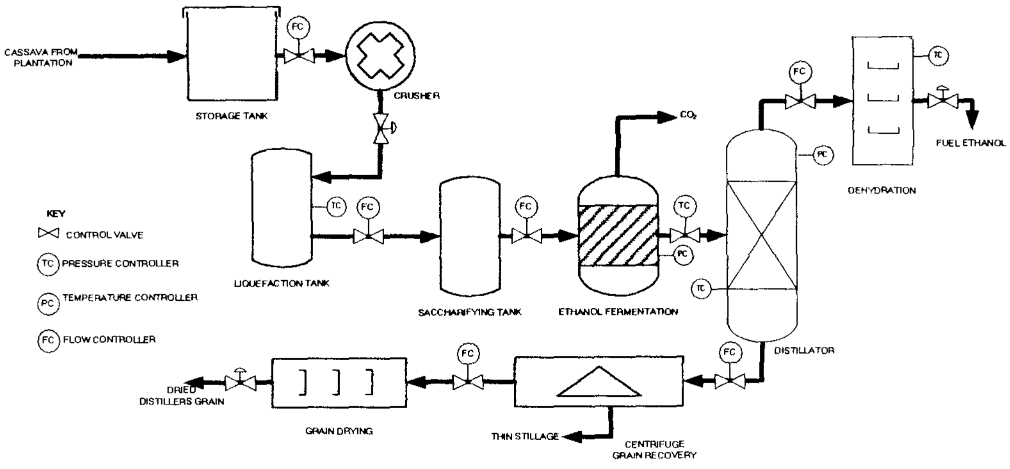
The control instruments are of four major categories

a) Temperature controllers (TC)

b) Pressure controller (PC)

c) Flow controller (FC)

d) Level controller (LC)



PROCESS CONTROL AND INSTRUMENTATION DIAGRAM OF ETHANOL PRODUCTION PLANT

9.3.1 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.

9.3.2 Transmitters, Controllers and Control Valves

The transmitter is the interface between the process and it's 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 self – 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

Any project involving new technology or hazardous material such as ethanol production plant requires a rational approach of assessing the methodology in order to identify systematically all possible pollutants. Suitability or acceptability of any process plant depends on its impact to the life, properties and environment.

Solvent emissions arise from several sources within ethanol production plants. There are potential solvent emissions from the transfer and storage of ethanol from factory, as well as potential leaks of solvent from piping and tanks. Small quantities of solvent (up to 0.15 percent by volume of solvent) are present in the ethanol even after solvent recovery by distillation stripper and the dehydrator. Trace quantities of solvent also are present in the waste water collected from direct contact steam in the distillation stripper. Adequate emission data from waste water also are not available.

Vents are another source of emissions. Solvent emissions are discharged from three vents: the main vent from the solvent recovery section, the vent from the dehydrator, and the vent from the centrifuge. The dehydrator typically vents to the atmosphere.

Solvent retained after the desolventizer-toaster is a fugitive emission source.

In addition, trace heavy metal particulate emissions have been identified at cassava grain mills at the seed cleaners and linter cyclones. Heavy metals detected were cadmium, chromium, copper, lead, manganese, nickel, zinc, and mercury; all of these metals are hazardous air pollutants. These emissions may be the result of the metals naturally present in soil and may occur in particulate emissions from other ethanol mills.

10.2 Treatments of Possible Pollutants

Therefore to make this process suitable and acceptable to the environment, there is need for these pollutants to be controlled. Some of the solvent (thin stillage) is routed back to the cook/slurry tanks as make up water, reducing the amount of fresh water required by the cook process. Condensers and mineral oil scrubbers are used together to recover hexane from exhaust streams. The most efficient recovery or control device is a mineral oil scrubber (MOS). Mineral oil scrubbers used to recover CO_2 from the main vent gases are approximately 95 percent efficient. However, over half of solvent loss may occur as a result of fugitive emissions from tanks, piping, and equipment shutdowns and breakdowns requiring extraction equipment to be opened. Process controls to reduce breakdowns and leaks can be used to effectively reduce emissions.

10.3 Waste Water Treatment

This is carried out by using both physical and chemical treatments. The physical treatment involves the removal of large floating or suspended particles from the waste water. This is achieved by gravity settling. This is further processed by filtration to clarify the effluents. The next stage is the chemical treatment. It involves the Ethanol of acids and alkali, conversion of ions to poorly soluble compounds, co-precipitation of inorganic substances, oxidation, Electrolysis, catalytic oxidation, etc. these methods are mainly used to deactivate and remove the impurities of inorganic compounds.

10.4 Thermal Pollution Control

The waste heat should be reclaimed by raising the thermal potentials of the gas, by setting up cogeneration technology; the water heat could be converted to mechanical power.

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 ethanol 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.

11.1 Start-Up

1. Put all the valves in manual position
2. Air-purge all the equipment and the process line with compressed air.
3. steam purge all steam bearing lines to debris which must have been contacted during construction
4. Adjust controls to set point.
5. Start water into the tanks with enough water to run for about 2 hours, and commission all the pumps.
6. Fill entire fermentor with sugar and start burner
7. Start cooling water to heat exchangers, and start steam to boilers.
8. Read all indicators and ensure process is in control
9. Turn all valves to automatic position

11.2 Shut-Down

1. Turn all valves to manual position
2. Isolate all pumps, and stop cooling water and steam supply to heat exchangers and boilers respectively.

3. Discharge reactors content.

4. Flush all line with air to inert the system

CHAPTER TWELVE

12.0 PLANT LAYOUT

The choice of site for plant has a long lasting effect on the cost of production and distribution room for expansion and safe living condition for plant operations. The following factors should be considered when sitting a plant.

1 **Availability of raw materials**: Ethanol production plant should be sited near its raw material such as cassava farmlands; so as to cut down the cost of transporting and storing raw materials

2 **Market Area**: The plant should be located close to its market in order to reduce cost of transporting products and time of delivery

3 **Availability of energy**: Power and steam requirements are high in the ethanol plant. Hence, it should be sited where there is constant supply of energy.

4 **Climate**: Excessive humidity or extremes of hot or cold weather can have serious effect on the economic operation of a plant. Therefore, this factor should not be neglected during site consideration.

5 **Water Supply**: water, in ethanol plant, is required for cooling, washing, steam generation and also as a raw material. The plant therefore must be located where a dependable supply of water is available.

6 **Transportation**: The plant should be sited where it's accessible to roads, railways and waterways for effective transportation of raw materials and product.

7 **Waste Disposal**: The site chosen for the plant should have adequate capacity and facilities for correct waste disposal.

8 **Labour Supply**: The type of supply of labour available in vicinity of a proposed site must be examined. Skilled labour could be brought from outside site area. But there should be adequate pool of unskilled labour in the area.

9 **Land considerations**: The topography of land must be evaluated. The land should be relatively flat, well drained and have suitable load bearing characteristics. It should also have allowance for real estate expansion.

10 **Political and strategic considerations**: Capital grants and other inducements are often given by government to direct new investment to area or locations such as a high unemployment prone zone. The availability of such grants can be overriding considerations in site selection.

11 **Community factors**: The character and facilities of a community such as churches, libraries, schools, civic theatres concert association, etc for satisfactory living of plant personnel should be considered when choosing a site.

12.1 BUILDING LAYOUT

The ethanol production plant and auxiliary buildings should be laid out to give the most economical flow of materials and personnel around the site. Consideration must also be given to the future expansion of the plant. The auxiliary buildings and services buildings and services required on the site in addition to the processing units (buildings) include:

1. Storage for raw materials and products
2. Materials workshop
3. Stores for maintenance and operating supplies
4. Laboratory for process control

5. Fire station and other emergency services
6. Effluent disposal plant
7. Offices for general administration
8. Canteen, car park, security post, etc.

Building layout is arranged in such a way that its processing steps from raw material to the final product and location of auxiliary buildings should be in a way that minimum time is spent by personnel in traveling between buildings.

CHAPTER THIRTEEN

13.0 ECONOMICS ANALYSIS

Chemical plants are built to make a profit, and an estimate of the investment required and the cost of production are needed before the profitability of a project can be assessed.For any industrial plant to be put into operation, huge sum of money must have been invested in it to purchase and install the necessary machinery and equipment. Land and service facilities must be obtained and the plant must be erected complete with the piping, controls, and service. In addition to all these cost, it is necessary to have money available for the payment of expenses involved in plant operation.

The capital requires to have the necessary manufacturing and plant facilities is called the fixed capital investment. That which is necessary for operation of the plant is termed the working capital. The sum of the fixed investment and the working capital is the total capital equipment

13.1 METHOD OF COSTING

The method of costing used in this project is **Marshall and Smith Method.**

13.2 ESTIMATION OF PURCHASED EQUIPMENT COSTS

The cost analysis of equipments in the plant is carried out using the cost equation of each process equipment as proposed by Marshall and Smith.

13.2.1 COST OF STORAGE TANK

The cost of storage tank is given as

$$PC_{storage\_tank} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where D = diameter

H = height

$F_c = F_m \cdot F_p$

and M_S = "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the storage tank,

$D_{storage\_tank} := 5.942m$

$H_{storage\_tank} := 8.913m$

Choosing carbon steel for the storage tank,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{storage\_tank} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{storage\_tank}}{m}\right)^{1.066} \left(\frac{H_{storage\_tank}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{storage\_tank} = 2.01 \times 10^6$ Naira

13.2.2 COST OF CRUSHER

The cost of crusher is given as

$$PC_{crusher} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where D = diameter

H = height

$F_c = F_m \cdot F_p$

and M_S = "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the crusher,

$D_{crusher} := 5.644m$

$H_{crusher} := 9.877m$

Choosing carbon steel for the crusher,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{crusher} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{crusher}}{m}\right)^{1.066} \left(\frac{H_{crusher}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{crusher} = 2.066 \times 10^6$ Naira

13.2.3 COST OF LIQUEFACTION TANK

The cost of liquefaction tank is given as

$$PC_{liquefaction\_tank} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where D = diameter

H = height

$F_c = F_m \cdot F_p$

and M_S = "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the liquefaction tank,

$D_{liquefaction\_tank} := 5.882m$

$H_{liquefaction\_tank} := 8.823m$

Choosing carbon steel for the liquefaction tank,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{liquefaction\_tank} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{liquefaction\_tank}}{m}\right)^{1.066} \left(\frac{H_{liquefaction\_tank}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{liquefaction\_tank} = 1.973 \times 10^6$ Naira

13.2.4 COST OF SACHARIFYING TANK

The cost of sacharifying tank is given as

$$PC_{sacharifying\_tank} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where D = diameter

H = height

$F_c = F_m \cdot F_p$

and M_S = "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the sacharifying tank,

$D_{sacharifying\_tank} := 5.955m$

$H_{sacharifying\_tank} := 8.933m$

Choosing carbon steel for the sacharifying tank,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{sacharifying\_tank} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{sacharifying\_tank}}{m}\right)^{1.066} \left(\frac{H_{sacharifying\_tank}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{sacharifying\_tank} = 2.019 \times 10^6$ Naira

13.2.5 COST OF FERMENTOR

The cost of fermentor is given as

$$PC_{fermentor} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where $D = \text{diameter}$

$H = \text{height}$

$F_c = F_m \cdot F_p$

and $M\_S =$ "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the fermentor,

$D_{fermentor} := 10.237m$

$H_{fermentor} := 15.356m$

Choosing carbon steel for the fermentor,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{fermentor} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{fermentor}}{m}\right)^{1.066} \left(\frac{H_{fermentor}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{fermentor} = 5.554 \times 10^6$ Naira

13.2.6 COST OF DISTILLATOR

The cost of distillator is given as

$$PC_{distillator} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where $D = \text{diameter}$

$H = \text{height}$

$F_c = F_m \cdot F_p$

and $M\_S =$ "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the distillator,

$D_{distillator} := 3.304m$

$H_{distillator} := 3.931m$

Choosing carbon steel for the distillator,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{distillator} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{distillator}}{m}\right)^{1.066} \left(\frac{H_{distillator}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{distillator} = 5.578 \times 10^5$ Naira

13.2.7 COST OF DEHYDRATOR

The cost of dehydrator is given as

$$PC_{dehydrator} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where D = diameter

H = height

$F_c = F_m \cdot F_p$

and M_S = "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the distillator,

$D_{dehydrator} := 2.406m$

$H_{dehydrator} := 4.114m$

Choosing carbon steel for the dehydrator,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{dehydrator} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{dehydrator}}{m}\right)^{1.066} \left(\frac{H_{dehydrator}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{dehydrator} = 4.125 \times 10^5$ Naira

13.2.8 COST OF CENTRIFUGAL SEPARATOR

The cost of centrifugal separator is given as

$$PC_{separator} = \frac{M\_S}{280} \cdot \left(101.9 \cdot D^{1.066} H^{0.802} \cdot F_c\right)$$

where D = diameter

H = height

$F_c = F_m \cdot F_p$

and M_S = "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the separator,

$D_{separator} := 3.625m$

$H_{separator} := 6.199m$

Choosing carbon steel for the separator,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{separator} := \frac{M\_S}{280} \cdot \left[101.9 \cdot \left(\frac{D_{separator}}{m}\right)^{1.066} \left(\frac{H_{separator}}{m}\right)^{0.802} \cdot F_c\right]$$

$PC_{separator} = 8.872 \times 10^{5}$ Naira

13.2.9 COST OF THE DRYER

The cost of dryer is given as

$$PC_{dryer} = \frac{M\_S}{280} \cdot \left(101.3 \cdot A^{0.65} \cdot F_c\right)$$

where D = diameter

H = height

$F_c = F_m \cdot F_p$

and M_S = "Marshall and Smith index and has a numerial value of"

$M\_S := 1100$

For the dryer

$A_{dryer} := 377.776m^2$

$D_{dryer} := 21.932m$

Choosing carbon steel for the dryer,

$F_m := 1$

$F_p := 1$

$F_c := F_m \cdot F_p$

$F_c = 1$

So, from

$$PC_{dryer} := \frac{M\_S}{280} \cdot \left[101.3 \cdot \left(\frac{A_{dryer}}{m^2}\right)^{0.65} \cdot F_c\right]$$

$PC_{dryer} = 2.449 \times 10^{6}$ Naira

13.3 Summary of the Purchased Equipment Cost

$$\begin{pmatrix} PC_{storage\_tank} \\ PC_{crusher} \\ PC_{liquefaction\_tank} \\ PC_{sacharifying\_tank} \\ PC_{fermentor} \\ PC_{distillator} \\ PC_{dehydrator} \\ PC_{separator} \\ PC_{dryer} \end{pmatrix} = \begin{pmatrix} 2.01 \times 10^{6} \\ 2.066 \times 10^{6} \\ 1.973 \times 10^{6} \\ 2.019 \times 10^{6} \\ 5.554 \times 10^{6} \\ 5.578 \times 10^{5} \\ 4.125 \times 10^{5} \\ 8.872 \times 10^{5} \\ 2.449 \times 10^{6} \end{pmatrix} \text{Naira}$$

The total purchased cost of equipments is calculated,

$$PC_T := \sum \begin{pmatrix} PC_{storage\_tank} \\ PC_{crusher} \\ PC_{liquefaction\_tank} \\ PC_{sacharifying\_tank} \\ PC_{fermentor} \\ PC_{distillator} \\ PC_{dehydrator} \\ PC_{separator} \\ PC_{dryer} \end{pmatrix}$$

total purchased cost of equipments is therefore,

$PC_T = 1.793\times 10^7$ Naira

Assuming that the initial fixed capital investment for the plant is the total purchased cost of

equipments, the initial fixed capital investment is then equal to

$FCI := PC_T$

$FCI = 1.793\times 10^7$ Naira

13.4 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

Assuming

$PEC := 33\% \cdot FCI$

$PEC = 5.916\times 10^6$ Naira

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

equipment cost

Assume

$Insta := 40.9\% \cdot PEC$

$Insta = 2.42\times 10^6$ Naira

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

Assuming

$Instr := 27\% \cdot PEC$

$Instr = 1.597\times 10^6$ Naira

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

Assuming

$Pip := 60\% \cdot PEC$

$Pip = 3.55\times 10^6$ Naira

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

$Elect := 30\% \cdot PEC$

$Elect = 1.775\times 10^6$ Naira

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

$CA := PEC + Insta + Instr + Pip + Elect$

$CA = 1.526\times 10^7$ Naira

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

$Build := 60\% \cdot PEC$

$Build = 3.55\times 10^6$ Naira

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

$Servi := 50\% \cdot PEC$

$Servi = 2.958\times 10^6$ Naira

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

$Lan := 5.3\% \cdot PEC$

$Lan = 3.136\times 10^5$ Naira

Thus, the direct cost is equal to

$Direct\_Cost := CA + Build + Servi + Lan$

$Direct\_Cost = 2.208\times 10^7$ 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

$Engin := 23\% \cdot Direct\_Cost$

$Engin = 5.078\times 10^6$ Naira

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

$Const := 30\% \cdot Direct\_Cost$

$Const = 6.624\times 10^6$ Naira

C. Contingency, 5-15% of direct cost
Assuming

$Conti := 10\% \cdot Direct\_Cost$

$Conti = 2.208\times 10^6$ Naira

Thus, indirect cost is equal to

$Indirect\_Cost := Engin + Const + Conti$

$Indirect\_Cost = 1.391\times 10^7$ Naira

III. Fixed Capital Investment:

Fixed capital investment to be Direct cost + Indirect cost

$Fixed\_CI := Direct\_Cost + Indirect\_Cost$

$Fixed\_CI = 3.599\times 10^7$ Naira

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

Assuming

$Working\_C := 13\% \cdot Fixed\_CI$

$Working\_C = 4.679\times 10^{6}$ Naira

V. Total Capital Investment (TCI):

Total capital investment to be Fixed capital investment + Working capital

Assuming

$Total\_CI := Fixed\_CI + Working\_C$

$Total\_CI = 4.067\times 10^{7}$ Naira

13.5 Estimation of Total Product Cost

I. Manufacturing Cost to be Direct production + 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 equiupment and 2-3% of building value for buildings

Assuming

$Depre := 13\% \cdot Fixed\_CI + 3\% \cdot Build$

$Depre = 4.785\times 10^{6}$ Naira

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

Assuming

$Tax := 2.9\% \cdot Fixed\_CI$

$Tax = 1.044\times 10^{6}$ Naira

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

Assuming

$Insur := 0.5\% \cdot Fixed\_CI$

$Insur = 1.8\times 10^{5}$ Naira

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

Assuming

$Ren := 9\% \cdot Fixed\_CI$

$Ren = 3.239\times 10^{6}$ Naira

Thus, fixed charges is given as

$Fixed := Depre + Tax + Insur + Ren$

$Fixed = 9.248\times 10^{6}$ Naira

Assuming

$Fixed\_C = 15\% \cdot TPC$

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

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

$$TPC := \frac{Fixed}{15\%}$$

$TPC = 6.165\times 10^{7}$ Naira

B. Direct Production Cost:

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

Assuming

$Raw\_mat := 40\% \cdot TPC$

$Raw\_mat = 2.466\times 10^{7}$ Naira

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

Assuming

$OperL := 13\% \cdot TPC$

$OperL = 8.015\times 10^{6}$ Naira

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

Assuming

$DireS := 22.5\% \cdot OperL$

$DireS = 1.803\times 10^{6}$ Naira

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

Assuming

$Util := 16\% \cdot TPC$

$Util = 9.865\times 10^{6}$ Naira

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

Assuming

$Maint := 9\% \cdot Fixed\_CI$

$Maint = 3.239\times 10^{6}$ Naira

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

Assuming

$OperS := 17\% \cdot Maint$

$OperS = 5.507\times 10^{5}$ Naira

vii. Laboratory Charges, 10-20% of OL

Assuming

$Lab := 15\% \cdot OperL$

$Lab = 1.202\times 10^{6}$ Naira

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

Assuming

$Paten := 5\% \cdot TPC$

$Paten = 3.083\times 10^{6}$ Naira

Thus, direct production cost is

$DPC := Raw\_mat + OperL + DireS + Util + Maint + OperS + Lab + Paten$

$DPC = 5.242\times 10^{7}$ 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,

$Plant := 55\% \cdot (OperL + DireS + Maint)$

$Plant = 7.182\times 10^{6}$ Naira

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

$Manuf := DPC + Fixed + Plant$

$Manuf = 6.885\times 10^{7}$ Naira

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

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

Assuming

$Admin := 5\% \cdot TPC$

$Admin = 3.083\times 10^{6}$ Naira

B. Distribution and Selling Costs, 2-20% of total product cost; includes costs for

sales offices, salesmen, shipping, and advertising.

Assuming

$\text{Distr} := 19\% \cdot \text{TPC}$

$\text{Distr} = 1.171\times 10^{7}\,\text{Naira}$

C. Research and Development Costs, about 3% of total product cost

Assuming

$\text{Resea} := 3\% \cdot \text{TPC}$

$\text{Resea} = 1.85\times 10^{6}\,\text{Naira}$

Thus, general expenses,

$\text{Gener} := \text{Admin} + \text{Distr} + \text{Resea}$

$\text{Gener} = 1.665\times 10^{7}\,\text{Naira}$

IV. Total Production Cost = Manufacture Cost + General Expenses

$\text{TProdC} := \text{Manuf} + \text{Gener}$

$\text{TProdC} = 8.55\times 10^{7}\,\text{Naira}$

V. Gross Earnings/Income:

The selling price of ethanol is equal to

(i.e 40 Naira per litres, since $(1\text{m})^3 = 1000\text{litres}$)

$$\text{Selling\_price} := 20000\cdot\frac{\text{Naira}}{\text{m}^3}$$

$$\text{Quantity\_produced} := 18.518\cdot\frac{\text{m}^3}{\text{day}}$$

$$\text{Quantity\_produced} = 6.764\times 10^{3}\,\frac{\text{m}^3}{\text{yr}}$$

Assuming that the attainment is $\text{Attainment} := 329\cdot\text{day}$

Total income = Selling price x quantity of product manufactured

$\text{Total\_income} := \text{Selling\_price}\cdot\text{Quantity\_produced}\cdot\text{Attainment}$

$\text{Total\_income} = 1.218\times 10^{8}\,\text{Naira}$

Gross income = Total income - Total Product Cost

That is,

$\text{Gross\_income} := \text{Total\_income} - \text{TProdC}$

$\text{Gross\_income} = 3.635\times 10^{7}\,\text{Naira}$

Assuming the tax rate to be 15% (common), $\text{Tax\_rate} := 15\%$

Net profit = Gross income - Taxes

$\text{Taxes} := \text{Tax\_rate}\cdot\text{Gross\_income}$

$\text{Taxes} = 5.453\times 10^{6}\,\text{Naira}$

$\text{Net\_profit} := \text{Gross\_income} - \text{Taxes}$

$\text{Net\_profit} = 3.09\times 10^{7}\,\text{Naira}$

13.6 Rate of Return:

$$\text{Rate\_of\_return} = \frac{\text{Net\_profit}}{\text{Total\_CI}}\cdot 100\%$$

Therefore,

$$\text{ROR} := \frac{\text{Net\_profit}}{\text{Total\_CI}}\cdot 100\%$$

$\text{ROR} = 75.978\%$

13.7 Pay-Back Period:

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

Therefore,

$$PBP := \frac{1}{ROR} \cdot yr$$

$$PBP = 1.316yr$$

13.8 Cash Flow

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

$$Cash\_Flow := Total\_income - TProdC$$

$$Cash\_Flow = 3.635\times 10^{7}\,Naira$$

Net Present Worth of the Project

The net present worth (NPW) of cash flow in year n is given as

$$NPW = \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^{n}}$$

$$r := ROR$$

$$n := 1$$

Therefore,

$$NPW := \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^{n}}$$

$$NPW = 2.066\times 10^{7}\,Naira$$

Discounted Cash Flow Rate or Return

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

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

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

Chemical Engineering, 3rd Edition, pg 277,)

$$r := 53 \cdot \%$$

$$n := 61$$

$$DCFRR := r$$

$$DCF := \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^{n}}$$

$$DCF = 0\,Naira$$

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

Return on Investment

This is calculated as given thus.

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

$$ROI = \frac{Total\_profit\_less\_depreciation}{Total\_investment}$$

That is,

$$ROI := \frac{Total\_income - Depre}{Total\_income} \cdot 100\%$$

$$ROI = 96.073\%$$

Projected Income and Expenses Statement for 2008-2011

This plant was designed to produce 500m^3/month ($\text{Basis} := 317.75 \cdot \frac{\text{kmol}}{\text{day}}$) of ethanol. Making the plant attainment to be $\text{Attainment} = 329\text{day}$, the plant is thus required to produce

$\text{Basis} \cdot \text{Attainment} = 1.045 \times 10^5 \text{kmol}$

It is expected that the performance of the plant should increase every year. For instance, assuming that the plant operates at 70% capacity in the first year, 80% capacity in the second year, 90% capacity in the third year and, finally, 100% capacity in the fourth year. The project income and expenses statement for these four years are as shown below.

DESCRIPTION	**YEARS**			
	2008	**2009**	**2010**	**2011**
kmol/day	317.75	363.14	408.54	453.93
Capacity (%)	70	80	90	100
	(Naira)			
REVENUE				
Net sales(Income)	121850000	139257142.9	156664285.7	174071428.6
EXPENDITURE				
Raw material	24662000	28185142.86	31708285.71	35231428.57
Factory labour	8015000	9160000	10305000	11450000
Depreciation	4785300	5468914.286	6152528.571	6836142.857
Overhead	1819200	2079085.714	2338971.429	2598857.143
TOTAL	39281500	44893142.86	50504785.71	56116428.57
PROFIT				
Before tax	36353000	41546285.71	46739571.43	51932857.14
Tax	5452900	6231885.714	7010871.429	7789857.143
Net profit	30900100	35314400	39728700	44143000

Conclusion on the Economic Viability of the Project

The total production cost of the plant which is $\text{TProdC} = 8.55 \times 10^7 \text{Naira}$ and a net profit of $\text{Net\_profit} = 3.09 \times 10^7 \text{Naira}$ have revealed that the project is economically viable with a pay back period of $\text{PBP} = 1.316\text{yr}$.

CHAPTER FOURTEEN

14.0 RECOMMENDATIONS TO THE INDUSTRIALIST

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

i. The safety of workers, equipments and infrastructures should be highly evaluated during the design implementation stage of the design.

ii. The recycle design should be considered imperative, since it is useful in reducing the level of plant effluent, and it also reduces costs.

iii. Adequate data and technological parameters should be at the possession of the ethanol plant operators 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 plant shut down and ensure equipment salvage value. This will also take care of schedule, slippage, cost over-run and possible re-work.

v. Personnel should undergo routine training about new work ethic and equipments to improve their knowledge of the plant operation and increase overall ethanol plant productivity.

vi. Procurement of raw materials and equipments should be based on strict regulation of specification and maximum quality.

vii. The plant should not be operated above the design specification to avoid abnormal conditions and explosions.

viii. The implementation of this design work must be adequately supervised by the experts.

ix. The plant should be sited close to the source of raw materials.

x. Alternative sources of energy should be available at all times to avoid plant failure and possible sources of failure.

xi. The water and air around the plant should be monitored regularly to ensure compliance with the Environmental Protection Agency Standards.

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