DESIGN OF A PLANT TO PRODUCE 2500 LITRE/DAY OF CARBONATED GINGER DRINK

BY

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2004/18545EH

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

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING DEGREE IN CHEMICAL ENGINEERING

DECEMBER 2009.

DECLARATION

I hereby declare that this research work was conducted by me under the supervision of Engr. Manase Auta of the Department of Chemical Engineering, Federal University of Technology Minna, Niger State. I have neither copied someone's work nor has someone else done it for me. All literatures cited have been duly acknowledged in the reference.

04/02/2010

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CERTIFICATION

This is to certify that the research work carried out by Wodi Obadiah with registration number 2004/18545EH under the supervision of Engr. Manase Auta and submitted to the Chemical engineering Department Federal University of Technology, Minna. In partial fulfillment of Bachelor of Engineering (B. Eng) Degree in Chemical Engineering

………………… 02-02-2010 …………………

Engr. Manase Auta Date

Supervisor

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Engr, J.O Okafor Date

Head of Department

………………… …………………

External Examiner Date

DEDICATION

This work is dedicated to God Almighty for his love, guidance and protection throughout my academic pursuit, to my parents for their moral and financial support throughout the course, to my brothers, sisters, aunties, uncles and friends for all their wonderful contribution and support.

ACKNOWLEDGEMENT

First and foremost, I give praise and thanks to the Almighty God for his protection and provision throughout my stay in federal university of technology minna.

My sincere appreciation goes to my dear parents and my siblings for their love, support and dedication. Thanks also for your spiritual guidance.

My gratitude goes to my project supervisor Engr. Manase Auta for supporting me from conception to the completion of this project and strengthening my resolve in so many direct and indirect ways. Thanks also to all lecturers of chemical engineering department federal university of technology, minna.

I cannot find words to describe the dept I owe to all my colleagues (2008/2009 graduating students) for creating a stimulating atmosphere of academic excellence. Thanks very much and God bless you all.

ABSTRACT

This project was carried out to design a plant to produce 2500 Litres/day of carbonated ginger drink. The units of equipment required by the plant include the storage warehouse where the ginger rhizome was stored, the peeler, the washer, the crusher, the extractor which extracted tin- drink from the rhizome, the sedimentation tank, the boiler, the additive tank, the chiller and, finally, the carbonator where the final product, carbonated ginger drink was produced. The ginger drink was extracted using extractor from ginger rhizome. The diameter and height of the extractor were found to be 1.313 m and 2.626 m respectively. It was discovered that, to produce the required capacity of 2500 Litres/day, it will be necessary to pass 2354.44 kg/day of ginger rhizome into the extractor. From the economic analysis of the plant, it was calculated that the total capital investment required by the plant is N39,280,000. The plant was found to be economically viable with a pay back period of 3.018 years.

Nomenclature

M_S	Marshal and Smith index
Fm	Factor associated with material
Fp	Factor associated with Pressure
PC	Purchased equipment cost
Er	Exchange rate
Fc	Factor of cost
mw	molecular weight
Coeff	Coefficient of heat transfer
T_i	Temprature of inlet stream
T_a	Temperature of addition stream
T_l	Temperature of loss stream
T_o	Temperature of output stream
ρ	Density
R	Radius
D	Diameter
H	Height
V	Volume
μ	Viscosity
P	Power
N_s	Agitator speed
E_{roll}	Net Energy to drive a roll ball
N_{RE}	Reynolds number
Ap	Cross sectional area of pipe
Lp	Length of pipe
W	Energy
di	Internal diameter
A_c	Cross sectional area
τ	Residence time

d_b	Disperse band
T_b	Bulk temperature
C_p	Specific Heat capacity
K	Thermal conductivity
U_o	Heat transfer coefficient
N_t	Number of tubes
R	Heat capacity ratio
S	Relative influence of the overall temp difference on tube flow temp.
F	Correction factor
j_h	Heat transfer factor

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CHAPTER ONE

1.0 INTRODUCTION

1.1 GENERAL INTRODUCTION

Ginger is a common name for a plant family with about 50 genera and 1300 species. It is pantropical in distribution, although mostly Far Eastern. It is complicated, irregular flowers have one fertile stamen and a usually showy labellum, formed from two or three sterile staminodes. The family is cultivated widely in the tropics for its showy flowers and useful products, derived mostly from the rhizomes. These products include the flavouring ginger; East Indian arrowroot, a food starch; and turmeric, an important ingredient in curry powder (Encarta, 2009).

In the eastern part of the world, ginger is commonly used to enhance digestion and utilization of all other nutrients, to reduce gas, and as an overall tonic, and to improve circulation and lower cholesterol. Ginger may be used as a stimulant of the peripheral circulation in cases of bad circulation, chilblains and cramps. In feverish conditions, Ginger acts as a useful diaphoretic, promoting perspiration. As a gargle it may be effective in the relief of sore throats. Externally, it is the base on many fibrositis and muscle sprain treatments. Ginger has been used worldwide as an aromatic carminative and pungent appetite stimulant. In India, and in other countries with hot and humid climates, ginger is eaten daily and is a well-known remedy for digestion problems. Its wide-spread use is not only be due to flavour, but to the antioxidant and anti-microbial effects, necessary for preservation of food, essential in such climates (www.life-enthusiast.com/ingredient/plants/ginger.html).

Ginger Drink made from top grade ginger to give a refreshing and invigorating feeling when consumed. Modern and hygienic manufacturing techniques are used to preserve the nature taste, goodness and fragrance. It is an ideal drink for everyone (www.asiachi.com/gingerdrink.html).

There are so many benefits in the development of beverage processing industries, in terms of technological development needed to reduce the post harvest losses. From socio-economic point of view, it provides earning and increased foreign income through the export of value added processes products in addition to the bulk raw materials (Areo, 2005).

Recent development in ginger processing by adding values shows that it can be processed into ginger drink from fresh ginger rhizome. (Areo, 2005)

1.2 Problem Statement

The problem statement of this design project is: "Design of a Plant for the Production of 2500 litres per day of Carbonated Ginger Drink".

1.3 Aim and objectives of the study

This project is aimed at designing a plant for the production of carbonated ginger drink using ginger rhizome. This aim will be achieved via the realization of the following objectives:

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

1.4 Design Data

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

1.5 Need for the Study

It has been reported that ginger drink has many medicinal values. For instance, it is used as antiseptic, antibacterial, antiviral, etc. This calls for the need to set up this plant in Niger State where there exist no plant of this kind.

1.6 Scope of Work

This work is limited to the chemical engineering design of the plant for the production of carbonated ginger drink.

1.7 Approach

Based on the problem statement outlined above, this work will be will be made Computer-Aided by carrying out the drawing of the flow sheet with the aid of Microsoft Visio, material balances and flow sheeting with the aid of Microsoft Excel while the energy balances, equipment design; equipment optimization and economic analysis will be carried using MathCAD) 2000 Professional.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Ginger

Ginger is the common name for a plant family with about 50 genera and 1300 species. It is pantropical in distribution, although mostly Far Eastern. Its complicated, irregular flowers have one fertile stamen and a usually showy labellum, formed from two or three sterile staminodes. The family is cultivated widely in the tropics for its showy (lowers and useful products, derived mostly from the rhizomes. These products include the flavoring ginger Hast Indian arrowroot, a food starch; and turmeric, an important ingredient in curry powder (Encarta, 2009).

The order to which the ginger family belongs includes 8 families and some 1800 species, abundant throughout the moist tropics. Characteristically, members of the order have rhizomes (underground rootlike stems). These are often fleshy, containing large amounts of starch or other useful substances. Leaves consist of a broad blade with parallel veins running perpendicular to a thick midrib. The midrib extends into a petiole, or stalk, and a sheathing base. The bases of the leaves overlap tightly, forming a rigid pseudostem. Thus, the "trunk" of the banana tree is not a stem at all but many overlapping leaf bases. Stems, except those bearing the flowers, are rarely exposed in the ginger order, as they are underground or covered by leaf bases (Encarta, 2009).

Flowers of the order are usually showy, although sometimes bracts (specialized leaves) below the flowers or flower clusters are more showy than the flowers themselves. In about half the families of the order the three sepals and three petals arc the conspicuous parts of the flowers. These families have five or, very rarely, six fertile stamens (male parts). The other families have only one functional stamen and two to live petal-like, sterile staminodes, which are often showy; sepals and petals are less conspicuous (Encarta, 2009).

The banana family, with 2 genera and about 40 species, typically occurs in disturbed habitats in the Old World Tropics. It has unisexual, often bat-pollinated flowers. The banana originated in Southeast Asia, but it is now an important crop throughout the moist tropics, both as a local food staple and as an export crop. Bananas have sterile flowers, and the fruits develop unfertilized, so bananas contain no seeds. Production of new plants is by vegetative means, and propagation is from suckers that develop at the bases of the old plants (Encarta, 2009).

The bird-of-paradise family, with 3 genera and about 7 species, occurs in tropical America, southern Africa, and Madagascar. The traveler's tree, one of the few woody members of the order, belongs to this family. The bird-of-paradise flower and the false bird-of-paradise are cultivated for their often long-lasting flower clusters, borne in large, colorful, boat-shaped bracts.

2,1.1 Scientific Classification of Ginger

Gingers make up the family Zingiberaceae in the order Zingiberales. The flavoring ginger is classified as Zingiber officinale, East Indian arrowroot as Curcuma anguslifolia, and tumeric as Curcuma longa. The banana belongs to the family Musaceae and is classified as Musa paradisiacal. The traveler's tree, classified as Ravenala madagascariensis, and the bird-of-paradise flower, classified as Strelitzia reginae, belongs to the family Strelitziaccae (sometimes Musaceae). The false bird-of paradise belongs to the genus Heliconia of (he family Musaceae (sometimes Heliconiaceae) (Encarta, 2009).

2.1.2 History of Ginger

Ginger has an ancient history as a culinary and as a medicinal herb, and has been used in the West for at least 3,000 years. Ginger was well known to the Greeks and Romans, who used it extensively. Arabian traders took it to them by way of India and the Red Sea. By the 11th century CE, it was a common trade article from the East to Europe. Ginger is mentioned by Confucius (551-478 BCE), and in the Qur'an. Medieval Europe thought it came from the Garden of Eden.

Chinese and Ayurvedic practitioners have relied on ginger for at least 3,000 years for its anti-inflammatory properties, and have used it as a "carrier" herb, one that enables other herbs to be more effective in the body. Jamaicans and early American settlers made beer from it; and today, natural ginger ales made with fresh ginger are available as a digestive tonic. These should not be confused with most commercial brands of ginger ale as these contain so little ginger that they are nothing more than sweetened soft drinks with no medicinal value (www.innvista.com/HEALTH/herbs/ginger.htm).

2.1.3 Key Actions of Ginger

Ginger is used as (www.invista.com/HEALTH/herbs/ginger.htm):

- antiemetic/antinausea
- antispasmodic
- antiseptic
- anti-inflammatory
- antibacterial
- antiviral
- anti fungal
- anticlotting agent
- analgesic
- antitussive
- circulatory stimulant
- carminative
- expectorant
- hypotensive
- increases blood flow to an area (topically)
- promotes sweating
- relaxes peripheral blood vessels

In addition, ginger also has the following benefits (www.nona.com.my/prodiict04.htm):

- help to produce more adrenaline (an enzyme), which help & improve the blood circulation

- help to warm the heart and body, and lower the blood pressure
- reduce flu virus, good for relieving colds
- help to unwind, reduce stomach ache, and good for confinement women
- can be chewable to reduce bad breath & allergic

2.1.4 Key Components of Ginger

The key components of ginger are (www.innvista.com/HEALTH/herbs/ginger.htm):

- volatile oil (1-3% including borneol and citral - zingiberene has 20-30%)
- phenols
- alkaloid
- mucilage
- oleoresin (4-7.5% including gingerol, shogaols)

2.1.5 Medicinal Parts of Ginger

Rhizome, essential oil

Scientifically, almost all of the folk beliefs have been verified. Ginger does prevent motion sickness, thin the blood, elevate low blood pressure, lower blood cholesterol, and prevent cancer in animals.

Extracts are reported to exhibit numerous pharmacological properties, including stimulating the vasomotor and respiratory centers and lowering serum and cholesterol levels.

Chinese researchers have reported that fresh ginger is highly effective in the clinical treatment of rheumatism, acute bacterial dysentery, malaria, and inflammation of the testicles.

Ginger has proven active against such organisms as malaria, Shigella dysenteriae Staphylococcus aureus, Pscudomonas acruginosa, Candida albicans, Hscherichia col;. Klebsiella pheumoniae, Streptococcus spp., and the Salmonella spp.

Gingerol is an acrid component, responsible for most of its hot taste and stimulating properties.

The shagaols form as the plant dries and are more strongly irritant.

Ginger is not only effective for motion sickness, but it has proven to be useful in relieving postoperative nausea in trials conducted at St. Bariholomew's Hospital in London in 1990.

According to the British medical journal Lancet, ginger seems to be more effective than some standard drugs in treating motion sickness and dizziness. They said that volunteers who took ginger were able to endure artificially created seasickness in a mechanical rocking chair 57% longer than those who used Dramamine. Another study involved Danish naval cadets prone to seasickness. The ones taking ginger were less likely to develop symptoms than those on a placebo. Typically, other studies showed the opposite effect where ginger actually induced nausea and vomiting.

Zingibain is an enzyme in ginger that has anti-inflammatory properties There are also many antioxidants that counter inflammation as well. Other components reduce production of certain prostaglandins, thereby easing pain.

Gingerols, the substances that give ginger its pungency, are thought to be responsible for its usefulness in treating fever and pain. Its volatile oils may be natural killers of cold and flu viruses.

It is also used in controlling and relieving the nausea after chemotherapy treatments. Researchers in India, in 1997, tested this ability and found that ginger was able to increase the able of endurance. They have found that the acetone extracts collectively known as gingerol, were responsible for increased bile production, indicating that it plays an important role in digestion and food absorption.

Some migraine sufferers reported that ginger aborted a headache if taken during the early stages. The theory is that this ability comes from substances called shogaols and gingerols, which reduce platelet clumping, thus preventing the blood-vessel inflammation that causes migraine pain (www.innvista.com/HEALTH/herbs/ginger.htm).

2.1.6 Traditional Uses of ginger

The ginger family includes the official ginger but also cardamom, tumeric, and zedoary. Various Zingiber species arc used medicinally but do not equal ginger for benefits, including that of Turmeric, a close relative. In Asia, all members of this reedlike family are considered good for the health. The Arabs use two other members of the same family, galanga (Alpinia officinarum) and zedoary (Curcuma zedoaria) for treating stomach ailments and general weakness. The roots of these two plants are considered to be stimulants, aphrodisiacs, and, amazingly, a cure for amnesia, Pounded with olive oil, they are added to a hot bath or rubbed onto the body for any form of muscle complaints caused by overexertion. In North Africa, this usually comes from plowing; but, in the western world, it is likely to result from overexertion at the gym.

Ginger has a wide range of actions on the human body and has been found effective in the treatment of cataracts, heart disease, migraines, stroke, amenorrhea, angina. athlete's foot, bursitis, chronic fatigue, colds, flu, coughs, depression, dizziness. fever, infertility, erectile difficulties, kidney stones, Raynaud's disease, sciatica. tendinitis, and viral infections.

In China, the science of ginger is so exacting that ginger from different parts of the country are used for different purposes. Fresh ginger is used to cure coughs, nausea, S, and dysentery, as well as treating fevers and mushroom poisoning. Dried ginger used for all things that the fresh ginger is used for, as well as for hemorrhages, ervered lochia, constipation, and urinary difficulties. A natural diuretic, ginger:'"stimulates the kidneys to flush out toxins faster. The fresh root is used mainly to promote sweating and to reduce fevers while warming and soothing the body during coughs, cold, flu, and other respiratory problems. It is also an expectorant for colds and chills.

In India, ginger is used to treat chronic rheumatism in this manner. The patient drinks an infusion of ginger before going to bed, and is then covered heavily with blankets to encourage copious perspiration. This same treatment is considered beneficial in cases of colds or catarrhal attacks and during the cold stage of intermittent fevers.

The essential oil has been used in both Eastern and Western medicine for at least 400 years. In France, it is still prescribed in drops on sugar lumps for flatulence, fevers, and to stimulate the appetite.

Ginger is an excellent remedy for all manner of digestive complaints, especially nausea, gas, and colic. In Mexico, ginger is considered to be more effective than Dramamine in combating motion sickness.

In Venezuela, finger is pounded into a paste and applied to the abdomen for difficult menstruation. In Costa Rica, it is used in a decoction to relieve throat inflammatory and asthma. With the addition of honey, it is a valued remedy for coughs and bronchitis, and also serves as a sudorific in fevers.

In Panama, it is said to relieve rheumatism. In Guatemala, ginger decoctions are taken as a stomachic and tonic. In Trinidad, it is a remedy for indigestion, f- stomachache, and malaria. The fumes from an infusion in urine are inhaled to relieve head colds.

Its antiseptic qualities make it a highly beneficial remedy for intestinal infections, including some types of food poisoning.

Western herbalists regard it as a good circulatory stimulant, helping blood flow to the surface and making it a valuable remedy for chilblains and poor circulation to the extremities. By improving circulation, ginger also helps high blood pressure.

Since it stimulates peripheral circulation, it is warming to the extremities and helps prevent the kinds of chills associated with malaria, colds, and flu.

One of its more unusual uses is for burns. When used externally in a poultice or as an ointment, ginger soothes inflammation and promotes healing. The juice of fresh ginger, soaked into a cotton ball and applied to a burn, for example, acts as an immediate pain reliever (even on open blisters), reduces blistering and inflammation. and provides antibacterial protection against infection.

Some herbalists recommend mixing fresh ginger juice with a neutral oil and applying it to the scalp to control dandruff; and mixed with lemon juice, vinegar, and honey, » ginger makes a soothing gargle for a sore throat.

Wild ginger is specific for painful cramping of the bowels and stomach.

To make homemade ginger ale: Take fresh ginger and flatten the unpeeled root. Place one cup of the flattened root in a gallon of water and bring to a rolling boil. Remove from the heal, strain, and add honey to taste. It can be drunk as is or added to carbonize water (www.invista.com/HEALTH/herbs/ginger.htm).

2.2 Carbonation of Ginger Drink

This is the process of bubbling carbon dioxide into ginger drink.

Carbon dioxide is a familiar gas. Some of the oxygen that animals breathe in is combined with carbon to produce carbon dioxide that is subsequently exhaled. The bubbles in soft drinks are actually bubbles of carbon dioxide. The gas is dissolved under pressure in flavored solutions to produce many kinds of carbonated beverages (Encarta, 2009).

2.3 PROCESSING TECHNOLOGIES

2.3.1 Description of Various Processing Technologies

Ginger drink can be extracted using a variety of methods, although some are not commonly used today.

2.3.1.1 Cold pressing

Cold pressing is used to extract the ginger drink from the ginger rhizome. The rhizomes are cleaned, ground or chopped and are then pressed. It is important to note that the ginger drink extracted using this method have a relatively short shelf life, so it is always advisable to make or purchase only what one will be using within the next six months (A World of Aromatherapy, 2009).

2.3.1.2 Solvent Extraction

In this method, a polar solvent (water) solvent is added to the plant material to help dissolve the drink in the rhizome. When the solution is filtered and concentrated by boiling, the liquid known as ginger drink results.

2.3.2 Detailed Description of the Selected Technology

2.3.2.1 Flow sheet

The flow sheet for the selected processing for this project is as shown below.

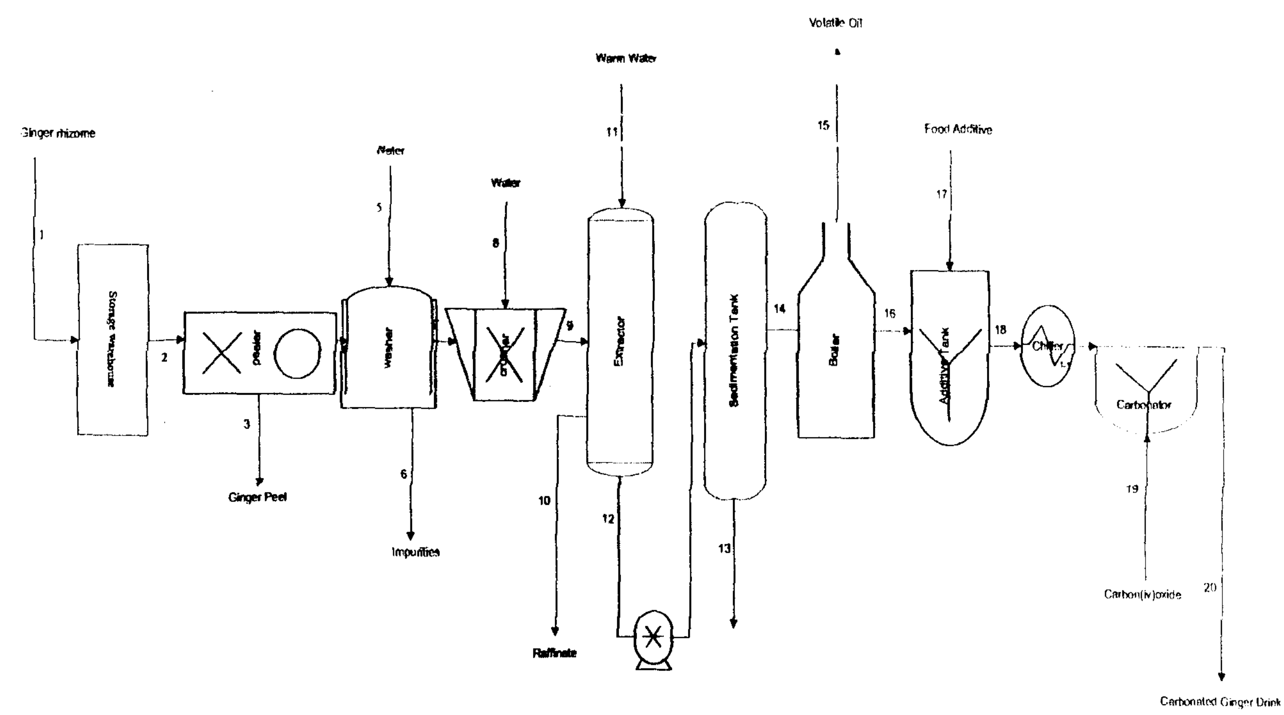


Fig 2.1: Flow sheet for the production of carbonated ginger drink

2.3.2.2 Process Description

Ginger rhizome purchased from the farm is stored in the warehouse before its processing commences. When the processing commences, ginger rhizome is transferred to the peeler where the ginger rhizome peel is removed. After this, the ginger rhizome is moved to the washer where it is washed with water that is being added to this unit. The impurities removed here include sand particles. The washed ginger is crushed in the crusher to reduce its particle size; water is added here also for effective crushing.

The next unit after the crusher is the extractor where warm water is used to extract the ginger drink from the small particle size fibres which are removed as raffinate from the system. A pump is mounted in between the extractor and sedimentation tank to transfer the extracted ginger drink to the sedimentation tank. At the sedimentation tank, the fibres with very small particle sizes that were extracted alongside with the drink is allowed to settle out and subsequently removed. The ginger is heated to a temperature of 70°C to boil away the volatile oil and kill the micro-organism present. From the boiler, the ginger drink goes to the additive lank where food additives are added. Then, it passes through a chiller where the temperature is reduced to 2-4°C. Finally, the ginger drink was carbonated in the carbonator.

2.3.3 PRESERVATIVE

A preservative is substance capable of inhibiting, retarding or arresting the process of fermentation acidification or other decomposition of food or making any of the evidences of putrefaction, the growth of food micro-organism or any deterioration of food due to micro-organism or making the evidence of such deterioration.

2.3.3.1 Chemical Preservative used

The chemical preservative used is Sodium Benzoate, also benzoate of soda, white crystalline or powder or granular sodium salt of benzoic acid of formula C_6H_5COONa. It is soluble in water and slightly soluble in alcohol. The salt is antiseptic and is commonly used as a preservative in foods. In large quantities it is toxic and fulfils antibacterial and anti fungal role . It is used medicinally in making a test of liver function.

2.3.4 Justification of the selected technology

The reason for choosing the solvent extraction method is that it has long shelf life. This means that the product can be kept for a long lime without spoiling and changing taste.

3.0 MATERIAL BALANCES

Basis: 100.00 kg/day of ginger rhizome

Components	Wt %
Drink	93.4
Fibre	2.4
Impurities	1.2
Volatile oil	1
Resinous matter	2
Total	100

Material balance around the units

UNIT 1 (STORAGE WAREHOUSE)

OPERATION: STORAGE OF GINGER RHIZOME

Assumption: No loss of materials

	IN				OUT			
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	93.40	0.00	0.00	0.00	0.00	93.40	93.40
Fibre	2.40	2.40	0.00	0.00	0.00	0.00	2.40	2.40
Impurities	1.20	1.20	0.00	0.00	0.00	0.00	1.20	1.20
Volatile oil	1.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00
Resinous matter	2.00	2.00	0.00	0.00	0.00	0.00	2.00	2.00
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	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 PEELER

Operation: Removal of the resinous material (bark)

	IN				OUT			
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	93.40	0.00	0.00	0.00	0.00	93.40	95.31
Fibre	2.40	2.40	0.00	0.00	0.00	0.00	2.40	2.45
Impurities	1.20	1.20	0.00	0.00	0.00	0.00	1.20	1.22
Volatile oil	1.00	1.00	0.00	0.00	0.00	0.00	1.00	1.02
Resinous matter	2.00	2.00	0.00	0.00	2.00	100.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	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	2.00	100.00	98.00	100.00

		UNIT 3 WASHER					
	Operation: washing of the ginger rhizome to remove the impurities						
	assumptions:						
	1. water added is 10.00% weight of ginger						
	2. 100% of the impurities is removed						
	3. water removed with the impurities is 90 % of water added						
	IN				OUT		
	input		addition		loss		output	
Components	*kg/day*	wt %	*kg/day*	wt %	*kg/day*	wt %	*kg/day*	wt %
Drink	93.40	95.31	0.00	0.00	0.00	0.00	93.40	95.52
Fibre	2.40	2.45	0.00	0.00	0.00	0.00	2.40	2.45
Impurities	1.20	1.22	0.00	0.00	1.20	11.98	0.00	0.00
Volatile oil	1.00	1.02	0.00	0.00	0.00	0.00	1.00	1.02
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	9.80	100.00	8.82	88.02	0.98	1.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	98.00	100.00	9.80	100.00	10.02	100.00	97.78	100.00

		UNIT 4 CRUSHER						
		Operation: size reduction of the ginger rhizome						
		Assumptions: water added is 10 % weight of ginger						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	95.52	0.00	0.00	0.00	0.00	93.40	86.84
Fibre	2.40	2.45	0.00	0.00	0.00	0.00	2.40	2.23
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	1.00	1.02	0.00	0.00	0.00	0.00	1.00	0.93
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.98	1.00	9.78	100.00	0.00	0.00	10.76	10.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	97.78	100.00	9.78	100.00	0.00	0.00	107.56	100.00

		UNIT 5 EXTRACTOR						
		Assumptions: 1. Water added is 15% weight of ginger						
			2. 93% of the fibre is removed as raffinate					
			3. 9% of the water present go with the raffinate					
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	86.84	0.00	0.00	0.00	0.00	93.40	78.46
Fibre	2.40	2.23	0.00	0.00	2.23	47.96	0.17	0.14
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	1.00	0.93	0.00	0.00	0.00	0.00	1.00	0.84
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	10.76	10.00	16.13	100.00	2.42	52.04	24.47	20.56
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	107.56	100.00	16.13	100.00	4.65	100.00	119.04	100.00
			UNIT 6 PUMP					
		Assumption: 100% material recovery						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	78.46	0.00	0.00	0.00	0.00	93.40	78.46
Fibre	0.17	0.14	0.00	0.00	0.00	0.00	0.17	0.14
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	1.00	0.84	0.00	0.00	0.00	0.00	1.00	0.84
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	24.47	20.56	0.00	0.00	0.00	0.00	24.47	20.56
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	119.04	100.00	0.00	0.00	0.00	0.00	119.04	100.00
			UNIT 7 SEDIMENTATION TANK					
		Operation: separation of the remaining particles from the ginger tank						
		Assumption: 100% of the remaining fibre is removed						
		IN				*OUT*		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	78.46	0.00	0.00	0.00	0.00	93.40	78.57
Fibre	0.17	0.14	0.00	0.00	0.17	100.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	1.00	0.84	0.00	0.00	0.00	0.00	1.00	0.84
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	24.47	20.56	0.00	0.00	0.00	0.00	24.47	20.59
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	119.04	100.00	0.00	0.00	0.17	100.00	118.87	100.00

UNIT 8 BOILER

Operation: Heating of the ginger drink to boiling

Assumption: 100% of the volatile oil is removed

	IN				OUT			
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	78.57	0.00	0.00	0.00	0.00	93.40	79.24
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Volatile oil	1.00	0.84	0.00	0.00	1.00	100.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	24.47	20.59	0.00	0.00	0.00	0.00	24.47	20.76
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	118.87	100.00	0.00	0.00	1.00	100.00	117.87	100.00

UNIT 9 ADDITVE TANK

Operation: Addition of food additive to the ginger drink

Assumption: Additive added is 5% of the weight of drink

	IN				*OUT*			
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	79.24	0.00	0.00	0.00	0.00	93.40	75.47
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	24.47	20.76	0.00	0.00	0.00	0.00	24.47	19.77
Additive	0.00	0.00	5.89	100.00	0.00	0.00	5.89	4.76
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	117.87	100.00	5.89	100.00	0.00	0.00	123.77	100.00

UNIT 10 CHILLER

Operation: Lowering the temperature of the ginger drink

	IN				OUT			
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	75.47	0.00	0.00	0.00	0.00	93.40	75.47
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	24.47	19.77	0.00	0.00	0.00	0.00	24.47	19.77
Additive	5.89	4.76	0.00	0.00	0.00	0.00	5.89	4.76
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	123.77	100.00	0.00	0.00	0.00	0.00	123.77	100.00

			UNIT 11 CARBONATOR					
		Operation: carbonation of the ginger drink						
		Assumption: CO_2 added is 1.5% weight of the drink						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	93.40	75.47	0.00	0.00	0.00	0.00	93.40	74.35
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Volatile oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	24.47	19.77	0.00	0.00	0.00	0.00	24.47	19.48
Additive	5.89	4.76	0.00	0.00	0.00	0.00	5.89	4.69
CO_2	0.00	0.00	1.86	100.00	0.00	0.00	1.86	1.48
Total	123.77	100.00	1.86	100.00	0.00	0.00	125.62	100.00

SCALE UP MATERIAL BALANCE

Calculation of scale up Factor.

Production rate is= 2500.00 litres/day = 2700.00kg/day

Ginger drink obtain from basis = 125.62 kg/day

Density of ginger drink is = 1100.00 kg/m3

Volumetric production is = 0.11 m3/day

conversion factor is = 1.00 m3/day =1000.00 litres/day

Volumetric production is = 114.20 litres/day

Scale up/down factor = 21.89

Material balance around the units

UNIT 1 (STORAGE WAREHOUSE)

Operation: Storage Of Ginger Rhizome

Assumption: No Loss Of Materials

	IN					OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	93.40	0.00	0.00	0.00	0.00	2044.53	93.40
Fibre	52.54	2.40	0.00	0.00	0.00	0.00	52.54	2.40
Impurities	*26.27*	*1.20*	*0.00*	*0.00*	*0.00*	*0.00*	*26.27*	*1.20*
Volatile oil	21.89	1.00	0.00	0.00	0.00	0.00	21.89	1.00
Resinous matter	43.78	2.00	0.00	0.00	0.00	0.00	43.78	2.00
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2189.00	100.00	0.00	0.00	0.00	0.00	2189.00	100.00

UNIT 2 PEELER

Operation: Removal of the resinous material (bark)

	IN					OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	93.40	0.00	0.00	0.00	0.00	2044.53	95.31
Fibre	*52.54*	*2.40*	*0.00*	*0.00*	*0.00*	*0.00*	52.54	2.45
Impurities	26.27	1.20	0.00	0.00	0.00	0.00	26.27	1.22
Volatile oil	21.89	1.00	0.00	0.00	0.00	0.00	21.89	1.02
Resinous matter	43.78	2.00	0.00	0.00	43.78	100.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2189.00	100.00	0.00	0.00	43.78	100.00	2145.22	100.00

			UNIT 3 WASHER					
		Operation: washing of the ginger rhizome to remove the impurities						
		Assumptions:						
		1. water added is 10.00% weight of ginger						
		2. 100% of the impurities is removed						
		3. water removed with the impurities is 90 % of water added						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	95.31	0.00	0.00	0.00	0.00	2044.53	95.52
Fibre	52.54	2.45	0.00	0.00	0.00	0.00	52.54	2.45
Impurities	26.27	1.22	0.00	0.00	26.27	11.98	0.00	0.00
Volatile oil	21.89	1.02	0.00	0.00	0.00	0.00	21.89	1.02
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	214.52	100.00	193.07	88.02	21.45	1.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2145.22	100.00	214.52	100.00	219.34	100.00	2140.40	100.00

			UNIT 4 CRUSHER					
		Operation: Size Reduction Of The Ginger Rhizome						
		Assumptions: Water Added Is 10 % Weight Of Ginger						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	95.52	0.00	0.00	0.00	0.00	2044.53	86.84
Fibre	52.54	2.45	0.00	0.00	0.00	0.00	52.54	2.23
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	21.89	1.02	0.00	0.00	0.00	0.00	21.89	0.93
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	21.45	1.00	214.04	100.00	0.00	0.00	235.49	10.00
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2140.40	100.00	214.04	100.00	0.00	0.00	2354.44	100.00

			UNIT 5 EXTRACTOR					
		Operation: Extraction of ginger drink with the aid of warm water						
		Assumptions: 1. Water added is 15% weight of ginger						
			2. 93 % of the fibre is removed as raffinate					
			3. 9 % of the water present go with the raffinate					
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	86.84	0.00	0.00	0.00	0.00	2044.53	78.46
Fibre	52.54	2.23	0.00	0.00	48.86	47.96	3.68	0.14
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	21.89	0.93	0.00	0.00	0.00	0.00	21.89	0.84
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	235.49	10.00	354.63	100.00	52.98	52.04	535.69	20.56
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2354.44	100.00	354.63	100.00	101.84	100.00	2605.78	100.00

			UNIT 6 PUMP					
	Operation: Transporting of the extract from the extractor to the sedimentation tank							
		Assumption: 100% material recovery						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	78.46	0.00	0.00	0.00	0.00	2044.53	78.46
Fibre	3.68	0.14	0.00	0.00	0.00	0.00	3.68	0.14
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	21.89	0.84	0.00	0.00	0.00	0.00	21.89	0.84
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	535.69	20.56	0.00	0.00	0.00	0.00	535.69	20.56
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2605.78	100.00	0.00	0.00	0.00	0.00	2605.78	100.00

			UNIT 7 SEDIMENTATION TANK					
		Operation: separation of the remaining particles from the ginger tank						
		Assumption: 100% of the remaining fibre is removed						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	78.46	0.00	0.00	0.00	0.00	2044.53	78.57
Fibre	3.68	0.14	0.00	0.00	3.68	100.00	0.00	0.00
Impurities	*0.00*	0.00	0.00	0.00	0.00	*0.00*	0.00	0.00
Volatile oil	21.89	0.84	0.00	0.00	0.00	0.00	21.89	0.84
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	535.69	20.56	0.00	0.00	0.00	0.00	535.69	20.59
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2605.78	100.00	0.00	0.00	3.68	100.00	2602.10	100.00

			UNIT 8 BOILER					
		Operation: Heating of the ginger drink to boiling						
		Assumption: 100% of the volatile oil is removed						
		IN				*OUT*		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	78.57	0.00	0.00	0.00	0.00	2044.53	79.24
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	21.89	0.84	0.00	0.00	21.89	100.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	535.69	20.59	0.00	0.00	0.00	0.00	535.69	20.76
Additive	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2602.10	100.00	0.00	0.00	21.89	100.00	2580.21	100.00

			UNIT 9 ADDITVE TANK					
		Operation: Addition of food additive to the ginger drink						
		Assumption: Additive added is 5% of the weight of drink						
		IN				OUT		
	input		addition		loss		output	
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	79.24	0.00	0.00	0.00	0.00	2044.53	75.47
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	535.69	20.76	0.00	0.00	0.00	0.00	535.69	19.77
Additive	0.00	0.00	129.01	100.00	0.00	0.00	129.01	4.76
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2580.21	100.00	129.01	100.00	0.00	0.00	2709.22	100.00

			UNIT 10 CHILLER				
		Operation: Lowering the temperature of the ginger drink					
		IN				OUT	
	input		addition		loss		output
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	75.47	0.00	0.00	0.00	0.00	2044.53	75.47
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	535.69	19.77	0.00	0.00	0.00	0.00	535.69	19.77
Additive	129.01	4.76	0.00	0.00	0.00	0.00	129.01	4.76
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2709.22	100.00	0.00	0.00	0.00	0.00	2709.22	100.00

			UNIT 11 CARBONATOR				
		Operation: carbonation of the ginger drink					
		Assumption: CO2 added is 1.5% weight of the drink					
		IN				OUT	
	input		*addition*		*loss*		*output*
Components	kg/day	wt %	kg/day	wt %	kg/day	wt %	kg/day	wt %
Drink	2044.53	75.47	0.00	0.00	0.00	0.00	2044.53	74.35
Fibre	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Volatile oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Resinous matter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	535.69	19.77	0.00	0.00	0.00	0.00	535.69	19.48
Additive	129.01	4.76	0.00	0.00	0.00	0.00	129.01	4.69
CO2	0.00	0.00	40.64	100.00	0.00	0.00	40.64	1.48
Total	2709.22	100.00	40.64	100.00	0.00	0.00	2749.86	100.00

CHAPTER FOUR

4.0 ENERGY BALANCES

Components and their molecular weights

$kmol := 1000mol$

$$\begin{pmatrix} \text{Drink} \\ \text{Fibre} \\ \text{Impurities} \\ \text{Volatile\_Oil} \\ \text{Resinous\_Matter} \\ \text{Water} \\ \text{Additives} \\ CO_2 \end{pmatrix} \qquad mw := \begin{pmatrix} 58.5 \\ 18 \\ 40 \\ 24 \\ 106 \\ 18 \\ 144 \\ 44 \end{pmatrix} \cdot \frac{kg}{kmol}$$

$kJ := 1000J$

Thermodynamics Properties:

$$coeff := \begin{pmatrix} 0.32 & 0 & 0 & 0 \\ 0.147 & 0 & 0 & 0 \\ 0.191 & 0 & 0 & 0 \\ 0.34 & 0 & 0 & 0 \\ 0.415 & 0 & 0 & 0 \\ 8.22 & 0.00015 & 0.00000134 & 0 \\ 0.287 & 0.0005 & 0 & 0 \\ 10.34 & 0.0274 & -195500 & 0 \end{pmatrix}$$

$$a := \left(\overrightarrow{\frac{coeff^{\langle 0 \rangle}}{mw}}\right) \cdot \frac{kJ}{kmol \cdot K} \qquad b := \left(\overrightarrow{\frac{coeff^{\langle 1 \rangle}}{mw}}\right) \cdot \frac{kJ}{kmol \cdot K^2}$$

$$c := \left(\overrightarrow{\frac{coeff^{\langle 2 \rangle}}{mw}}\right) \cdot \frac{kJ}{kmol \cdot K^3} \qquad d := \left(\overrightarrow{\frac{coeff^{\langle 3 \rangle}}{mw}}\right) \cdot \frac{kJ}{kmol \cdot K^4}$$

4.1 Energy Balances on Crusher

Material flow of components

$$n\_i := \begin{pmatrix} 2044.53 \\ 52.54 \\ 0.00 \\ 21.89 \\ 0.00 \\ 21.45 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_a := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 214.04 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

$$n\_l := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_o := \begin{pmatrix} 2044.53 \\ 52.54 \\ 0.00 \\ 21.89 \\ 0.00 \\ 235.49 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

Reference temperature: $Tr := 298K$

$$\begin{pmatrix} Ti \\ Ta \\ Tl \\ To \end{pmatrix} := \begin{pmatrix} 303 \\ 303 \\ 0 \\ 310 \end{pmatrix} \cdot K$$

Energy In

Energy of input

$$\Delta H\_i := n\_i_0 \cdot \left[\int_{Tr}^{Ti} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT\right] + n\_i_1 \cdot \int_{Tr}^{Ti} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$
$$+ n\_i_2 \cdot \int_{Tr}^{Ti} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_i_3 \cdot \int_{Tr}^{Ti} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$
$$+ n\_i_4 \cdot \int_{Tr}^{Ti} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_i_5 \cdot \int_{Tr}^{Ti} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$
$$+ n\_i_6 \cdot \int_{Tr}^{Ti} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_i_7 \cdot \int_{Tr}^{Ti} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_i = 109.582 \frac{kJ}{day}$$

Energy of addition

$$\Delta H\_a := n\_a_0 \cdot \left[\int_{Tr}^{Ta} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT\right] + n\_a_1 \cdot \int_{Tr}^{Ta} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$
$$+ n\_a_2 \cdot \int_{Tr}^{Ta} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_a_3 \cdot \int_{Tr}^{Ta} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$
$$+ n\_a_4 \cdot \int_{Tr}^{Ta} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_a_5 \cdot \int_{Tr}^{Ta} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$
$$+ n\_a_6 \cdot \int_{Tr}^{Ta} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_a_7 \cdot \int_{Tr}^{Ta} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_a = 498.599 \frac{kJ}{day}$$

$$\Delta H\_IN := \Delta H\_i + \Delta H\_a$$

$$\Delta H\_IN = 608.181 \frac{kJ}{day}$$

Energy out

Energy of output

$$\Delta H\_o := n\_o_0 \cdot \left[\int_{Tr}^{To} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT \right] + n\_o_1 \cdot \int_{Tr}^{To} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$

$$+ n\_o_2 \cdot \int_{Tr}^{To} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_o_3 \cdot \int_{Tr}^{To} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$

$$+ n\_o_4 \cdot \int_{Tr}^{To} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_o_5 \cdot \int_{Tr}^{To} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$

$$+ n\_o_6 \cdot \int_{Tr}^{To} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_o_7 \cdot \int_{Tr}^{To} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_o = 1.46 \times 10^3 \cdot \frac{kJ}{day}$$

$$\Delta H\_OUT := \Delta H\_o$$

$$\Delta H\_OUT = 1.46 \times 10^3 \cdot \frac{kJ}{day}$$

Total heat load

$$\Delta H\_1 := \Delta H\_OUT - \Delta H\_IN$$

$$\Delta H\_1 = 851.983 \frac{kJ}{day}$$

4.2 Energy balances on extractor

Material flow of components

$$n\_i := \begin{pmatrix} 2044.53 \\ 52.54 \\ 0.00 \\ 21.89 \\ 0.00 \\ 235.49 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_a := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 354.62 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

$$n\_l := \begin{pmatrix} 0.00 \\ 48.86 \\ 0.00 \\ 0.00 \\ 0.00 \\ 52.98 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_o := \begin{pmatrix} 2044.53 \\ 3.68 \\ 0.00 \\ 21.89 \\ 0.00 \\ 535.68 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

$$\begin{pmatrix} Ti \\ Ta \\ Tl \\ To \end{pmatrix} := \begin{pmatrix} 310 \\ 323 \\ 305 \\ 307 \end{pmatrix} \cdot K \qquad Tr := 298K$$

ENERGY IN

Energy of input

$$\Delta H\_i := n\_i_0 \cdot \left[\int_{Tr}^{Ti} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT \right] + n\_i_1 \cdot \int_{Tr}^{Ti} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$
$$+ n\_i_2 \cdot \int_{Tr}^{Ti} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_i_3 \cdot \int_{Tr}^{Ti} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$
$$+ n\_i_4 \cdot \int_{Tr}^{Ti} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_i_5 \cdot \int_{Tr}^{Ti} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$
$$+ n\_i_6 \cdot \int_{Tr}^{Ti} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_i_7 \cdot \int_{Tr}^{Ti} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_i = 1.46 \times 10^3 \cdot \frac{kJ}{day}$$

Energy of addition

$$\Delta H\_a := n\_a_0 \cdot \left[\int_{Tr}^{Ta} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3 \right) dT \right] + n\_a_1 \cdot \int_{Tr}^{Ta} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3 \right) dT \; ...$$
$$+ n\_a_2 \cdot \int_{Tr}^{Ta} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3 \right) dT + n\_a_3 \cdot \int_{Tr}^{Ta} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3 \right) dT \; ...$$
$$+ n\_a_4 \cdot \int_{Tr}^{Ta} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3 \right) dT + n\_a_5 \cdot \int_{Tr}^{Ta} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3 \right) dT \; ...$$
$$+ n\_a_6 \cdot \int_{Tr}^{Ta} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3 \right) dT + n\_a_7 \cdot \int_{Tr}^{Ta} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3 \right) dT$$

$$\Delta H\_a = 4.135 \times 10^3 \cdot \frac{kJ}{day}$$

$$\Delta H\_IN := \Delta H\_i + \Delta H\_a$$

$$\Delta H\_IN = 5.595 \times 10^3 \cdot \frac{kJ}{day}$$

Energy out

Energy of loss

$$\Delta H\_l := n\_l_0 \cdot \left[\int_{Tr}^{Tl} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3 \right) dT \right] + n\_l_1 \cdot \int_{Tr}^{Tl} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3 \right) dT \ldots$$

$$+ n\_l_2 \cdot \int_{Tr}^{Tl} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3 \right) dT + n\_l_3 \cdot \int_{Tr}^{Tl} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3 \right) dT \ldots$$

$$+ n\_l_4 \cdot \int_{Tr}^{Tl} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3 \right) dT + n\_l_5 \cdot \int_{Tr}^{Tl} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3 \right) dT \ldots$$

$$+ n\_l_6 \cdot \int_{Tr}^{Tl} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3 \right) dT + n\_l_7 \cdot \int_{Tr}^{Tl} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3 \right) dT$$

$$\Delta H\_l = 175.594 \frac{kJ}{day}$$

Energy of output

$$\Delta H\_o := n\_o_0 \cdot \left[\int_{Tr}^{To} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3 \right) dT \right] + n\_o_1 \cdot \int_{Tr}^{To} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3 \right) dT \ldots$$

$$+ n\_o_2 \cdot \int_{Tr}^{To} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3 \right) dT + n\_o_3 \cdot \int_{Tr}^{To} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3 \right) dT \ldots$$

$$+ n\_o_4 \cdot \int_{Tr}^{To} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3 \right) dT + n\_o_5 \cdot \int_{Tr}^{To} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3 \right) dT \ldots$$

$$+ n\_o_6 \cdot \int_{Tr}^{To} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3 \right) dT + n\_o_7 \cdot \int_{Tr}^{To} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3 \right) dT$$

$$\Delta H\_o = 2.35 \times 10^3 \cdot \frac{kJ}{day}$$

$$\Delta H\_OUT := \Delta H\_l + \Delta H\_o$$

$$\Delta H\_OUT = 2.526 \times 10^3 \cdot \frac{kJ}{day}$$

Total heat load

$$\Delta H\_5 := \Delta H\_OUT - \Delta H\_IN$$

$$\Delta H\_5 = -3.069 \times 10^3 \cdot \frac{kJ}{day}$$

4.3 Energy balances on boiler

material flow of components

$$n\_i := \begin{pmatrix} 2044.53 \\ 0.00 \\ 0.00 \\ 21.89 \\ 0.00 \\ 535.68 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_a := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

$$n\_l := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 21.89 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_o := \begin{pmatrix} 2044.53 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 535.68 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

$$\begin{pmatrix} Ti \\ Ta \\ Tl \\ To \end{pmatrix} := \begin{pmatrix} 307 \\ 0 \\ 343 \\ 343 \end{pmatrix} \cdot K$$

Energy in

Energy of input

$$\Delta H\_i := n\_i_0 \cdot \left[\int_{Tr}^{Ti} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3 \right) dT \right] + n\_i_1 \cdot \int_{Tr}^{Ti} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3 \right) dT \ldots$$
$$+ n\_i_2 \cdot \int_{Tr}^{Ti} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3 \right) dT + n\_i_3 \cdot \int_{Tr}^{Ti} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3 \right) dT \ldots$$
$$+ n\_i_4 \cdot \int_{Tr}^{Ti} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3 \right) dT + n\_i_5 \cdot \int_{Tr}^{Ti} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3 \right) dT \ldots$$
$$+ n\_i_6 \cdot \int_{Tr}^{Ti} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3 \right) dT + n\_i_7 \cdot \int_{Tr}^{Ti} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3 \right) dT$$

$$\Delta H\_i = 2.35 \times 10^3 \cdot \frac{kJ}{day}$$

$$\Delta H\_IN := \Delta H\_i$$

$$\Delta H\_IN = 2.35 \times 10^3 \cdot \frac{kJ}{day}$$

Energy out

Energy of loss

$$\Delta H\_l := n\_l_0 \cdot \left[\int_{Tr}^{Tl} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3 \right) dT \right] + n\_l_1 \cdot \int_{Tr}^{Tl} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3 \right) dT \ldots$$
$$+ n\_l_2 \cdot \int_{Tr}^{Tl} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3 \right) dT + n\_l_3 \cdot \int_{Tr}^{Tl} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3 \right) dT \ldots$$
$$+ n\_l_4 \cdot \int_{Tr}^{Tl} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3 \right) dT + n\_l_5 \cdot \int_{Tr}^{Tl} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3 \right) dT \ldots$$
$$+ n\_l_6 \cdot \int_{Tr}^{Tl} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3 \right) dT + n\_l_7 \cdot \int_{Tr}^{Tl} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3 \right) dT$$

$$\Delta H\_l = 13.955 \frac{kJ}{day}$$

Energy of output

$$\Delta H\_o := n\_o_0 \cdot \left[\int_{Tr}^{To} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT\right] + n\_o_1 \cdot \int_{Tr}^{To} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$

$$+ n\_o_2 \cdot \int_{Tr}^{To} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_o_3 \cdot \int_{Tr}^{To} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$

$$+ n\_o_4 \cdot \int_{Tr}^{To} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_o_5 \cdot \int_{Tr}^{To} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$

$$+ n\_o_6 \cdot \int_{Tr}^{To} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_o_7 \cdot \int_{Tr}^{To} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_o = 1.176 \times 10^4 \cdot \frac{kJ}{day}$$

$$\Delta H\_OUT := \Delta H\_1 + \Delta H\_o$$

$$\Delta H\_OUT = 1.177 \times 10^4 \cdot \frac{kJ}{day}$$

Total Heat Load

$$\Delta H\_8 := \Delta H\_OUT - \Delta H\_IN$$

$$\Delta H\_8 = 9.424 \times 10^3 \cdot \frac{kJ}{day}$$

4.4 Energy Balance On Chiller

Material flow of components

$$n\_i := \begin{pmatrix} 2044.53 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 535.68 \\ 129.01 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_a := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

$$n\_i := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_o := \begin{pmatrix} 2044.53 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 535.68 \\ 129.01 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day}$$

$$\begin{pmatrix} Ti \\ Ta \\ Tl \\ To \end{pmatrix} := \begin{pmatrix} 335 \\ 0 \\ 0 \\ 277 \end{pmatrix} \cdot K$$

Energy in

Energy of input

$$\Delta H\_i := n\_i_0 \cdot \left[\int_{Tr}^{Ti} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT\right] + n\_i_1 \cdot \int_{Tr}^{Ti} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$
$$+ n\_i_2 \cdot \int_{Tr}^{Ti} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_i_3 \cdot \int_{Tr}^{Ti} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$
$$+ n\_i_4 \cdot \int_{Tr}^{Ti} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_i_5 \cdot \int_{Tr}^{Ti} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$
$$+ n\_i_6 \cdot \int_{Tr}^{Ti} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_i_7 \cdot \int_{Tr}^{Ti} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_i = 9.68 \times 10^3 \cdot \frac{kJ}{day}$$

$$\Delta H\_IN := \Delta H\_i$$

$$\Delta H\_IN = 9.68 \times 10^3 \cdot \frac{kJ}{day}$$

Energy of Ouput

$$\Delta H\_o := n\_o_0 \cdot \left[\int_{Tr}^{To} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3 \right) dT \right] + n\_o_1 \cdot \int_{Tr}^{To} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3 \right) dT \ldots$$
$$+ n\_o_2 \cdot \int_{Tr}^{To} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3 \right) dT + n\_o_3 \cdot \int_{Tr}^{To} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3 \right) dT \ldots$$
$$+ n\_o_4 \cdot \int_{Tr}^{To} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3 \right) dT + n\_o_5 \cdot \int_{Tr}^{To} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3 \right) dT \ldots$$
$$+ n\_o_6 \cdot \int_{Tr}^{To} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3 \right) dT + n\_o_7 \cdot \int_{Tr}^{To} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3 \right) dT$$

$$\Delta H\_o = -5.476 \times 10^3 \cdot \frac{kJ}{day}$$

$$\Delta H\_OUT := \Delta H\_o \qquad \Delta H\_OUT = -5.476 \times 10^3 \cdot \frac{kJ}{day}$$

Total Heat Load

$$\Delta H\_10 := \Delta H\_OUT - \Delta H\_IN$$

$$\Delta H\_10 = -1.516 \times 10^4 \cdot \frac{kJ}{day}$$

4.5 Energy Balance on Carbonator

Material Flow of Components

$$n\_i := \begin{pmatrix} 2044.53 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 535.68 \\ 129.01 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_a := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 40.64 \end{pmatrix} \cdot \frac{kg}{day}$$

$$n\_I := \begin{pmatrix} 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \end{pmatrix} \cdot \frac{kg}{day} \qquad n\_o := \begin{pmatrix} 2044.53 \\ 0.00 \\ 0.00 \\ 0.00 \\ 0.00 \\ 535.68 \\ 129.01 \\ 40.64 \end{pmatrix} \cdot \frac{kg}{day}$$

$$\begin{pmatrix} Ti \\ Ta \\ Tl \\ To \end{pmatrix} := \begin{pmatrix} 277 \\ 303 \\ 0 \\ 300 \end{pmatrix} \cdot K$$

Energy In

Energy of input

$$\Delta H\_i := n\_i_0 \cdot \left[\int_{Tr}^{Ti} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT \right] + n\_i_1 \cdot \int_{Tr}^{Ti} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$
$$+ n\_i_2 \cdot \int_{Tr}^{Ti} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_i_3 \cdot \int_{Tr}^{Ti} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$
$$+ n\_i_4 \cdot \int_{Tr}^{Ti} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_i_5 \cdot \int_{Tr}^{Ti} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$
$$+ n\_i_6 \cdot \int_{Tr}^{Ti} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_i_7 \cdot \int_{Tr}^{Ti} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_i = -5.476 \times 10^3 \cdot \frac{kJ}{day}$$

Energy of Addition

$$\Delta H\_a := n\_a_0 \cdot \left[\int_{Tr}^{Ta} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT\right] + n\_a_1 \cdot \int_{Tr}^{Ta} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$
$$+ n\_a_2 \cdot \int_{Tr}^{Ta} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_a_3 \cdot \int_{Tr}^{Ta} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$
$$+ n\_a_4 \cdot \int_{Tr}^{Ta} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_a_5 \cdot \int_{Tr}^{Ta} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$
$$+ n\_a_6 \cdot \int_{Tr}^{Ta} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_a_7 \cdot \int_{Tr}^{Ta} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_a = -8.153 \times 10^{10} \cdot \frac{kJ}{day}$$

$$\Delta H\_IN := \Delta H\_i + \Delta H\_a$$

$$\Delta H\_IN = -8.153 \times 10^{10} \cdot \frac{kJ}{day}$$

Energy Out

Energy of Output

$$\Delta H\_o := n\_o_0 \cdot \left[\int_{Tr}^{To} \left(a_0 + b_0 \cdot T + c_0 \cdot T^2 + d_0 \cdot T^3\right) dT\right] + n\_o_1 \cdot \int_{Tr}^{To} \left(a_1 + b_1 \cdot T + c_1 \cdot T^2 + d_1 \cdot T^3\right) dT \ldots$$
$$+ n\_o_2 \cdot \int_{Tr}^{To} \left(a_2 + b_2 \cdot T + c_2 \cdot T^2 + d_2 \cdot T^3\right) dT + n\_o_3 \cdot \int_{Tr}^{To} \left(a_3 + b_3 \cdot T + c_3 \cdot T^2 + d_3 \cdot T^3\right) dT \ldots$$
$$+ n\_o_4 \cdot \int_{Tr}^{To} \left(a_4 + b_4 \cdot T + c_4 \cdot T^2 + d_4 \cdot T^3\right) dT + n\_o_5 \cdot \int_{Tr}^{To} \left(a_5 + b_5 \cdot T + c_5 \cdot T^2 + d_5 \cdot T^3\right) dT \ldots$$
$$+ n\_o_6 \cdot \int_{Tr}^{To} \left(a_6 + b_6 \cdot T + c_6 \cdot T^2 + d_6 \cdot T^3\right) dT + n\_o_7 \cdot \int_{Tr}^{To} \left(a_7 + b_7 \cdot T + c_7 \cdot T^2 + d_7 \cdot T^3\right) dT$$

$$\Delta H\_o = -3.229 \times 10^{10} \cdot \frac{kJ}{day}$$

$\Delta H\_OUT := \Delta H\_o$

$$\Delta H\_OUT = -3.229\times 10^{10} \cdot \frac{kJ}{day}$$

Total Heat Load

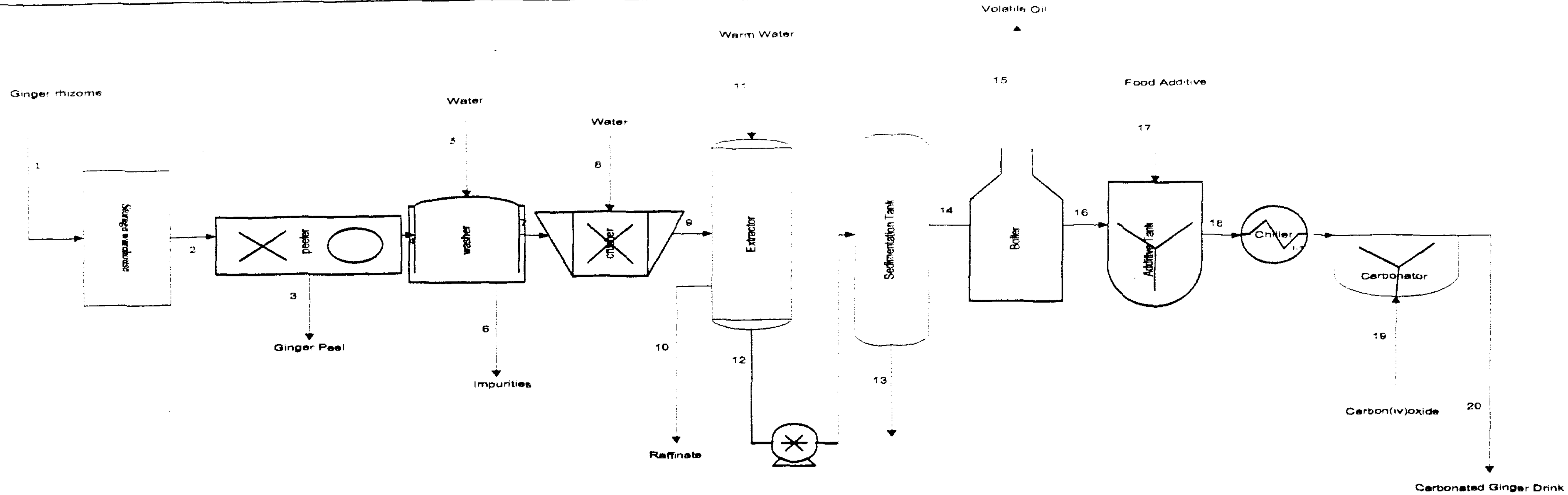
$$\Delta H\_11 := \Delta H\_OUT - \Delta H\_IN$$

$$\Delta H\_11 = 4.924\times 10^{10} \cdot \frac{kJ}{day}$$

CHAPTER FIVE

5.0 FLOW SHEET/DIAGRAM

GROUP SEVEN(7) PLANT DESIGN	Title: Production of carbonated ginger drink	Drawn by: Group 7 members	Date: 20th January, 2010
	Client: Chemical Engineering Department, FUT, Minna.	Checked by: Engr. Manase Auta	



Flow No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Components	Flows (Kg/day)																			
Drink	2044.53	2044.53	0.00	2044.53	0.00	0.00	2044.53	0.00	2044.53	0.00	0.00	2044.53	0.00	2044.53	0.00	2044.53	0.00	2044.53	0.00	2044.53
Fibre	52.54	52.54	0.00	52.54	0.00	0.00	52.54	0.00	52.54	48.86	0.00	3.68	3.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impurities	26.27	26.27	0.00	26.27	0.00	26.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Resinous Matter	21.89	21.89	0.00	21.89	0.00	0.00	21.89	0.00	21.89	0.00	0.00	21.89	0.00	21.89	21.89	0.00	0.00	0.00	0.00	0.00
Volatile Oil	43.78	43.78	43.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	0.00	0.00	214.52	193.07	21.45	214.04	235.49	52.98	354.63	535.69	0.00	535.69	0.00	535.69	0.00	535.69	0.00	535.69
Additive Tank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	129.01	129.01	0.00	129.01
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.64	40.64
Total	2189.00	2189.00	43.78	2145.22	214.52	219.34	2140.40	214.04	2354.44	101.84	354.63	2605.78	3.68	2602.10	21.89	2580.21	129.01	2709.22	40.64	2749.86

CHAPTER SIX

6.0 EQUIPMENT DESIGN

6.1 Design of Warehouse

Material flow of components are given as

$M\_drink := 2044.53 \cdot \frac{kg}{day}$ $M\_fibre := 52.54 \cdot \frac{kg}{day}$ $M\_impurities := 26.27 \cdot \frac{kg}{day}$

$D\_drink := 850 \cdot \frac{kg}{m^3}$ $D\_fibre := 769 \cdot \frac{kg}{m^3}$ $D\_impurities := 1071 \cdot \frac{kg}{m^3}$

$V\_drink := \frac{M\_drink}{D\_drink}$ $V\_fibre := \frac{M\_fibre}{D\_fibre}$ $V\_impurities := \frac{M\_impurities}{D\_impurities}$

$V\_drink = 2.405 \frac{m^3}{day}$ $V\_fibre = 0.068 \frac{m^3}{day}$ $V\_impurities = 0.025 \frac{m^3}{day}$

$M\_volatile\_oil := 21.89 \cdot \frac{kg}{day}$ $M\_resinous\_matter := 43.78 \cdot \frac{kg}{day}$

$D\_volatile\_oil := 804 \cdot \frac{kg}{m^3}$ $D\_resinous\_matter := 993 \cdot \frac{kg}{m^3}$

$V\_volatile\_oil := \frac{M\_volatile\_oil}{D\_volatile\_oil}$ $V\_resinous\_matter := \frac{M\_resinous\_matter}{D\_resinous\_matter}$

$V\_volatile\_oil = 0.027 \frac{m^3}{day}$ $V\_resinous\_matter = 0.044 \frac{m^3}{day}$

$V := V\_drink + V\_fibre + V\_impurities + V\_volatile\_oil + V\_resinous\_matter$

$V = 2.569 \frac{m^3}{day}$

with $clearance := 15\% \cdot V$ at the top of the house

$V\_warehouse := clearance + V$

$V\_warehouse = 2.955 \frac{m^3}{day}$

Assuming the warehouse to be cuboid in shape

$$V\_house = L\_house \cdot B\_house \cdot H\_house$$

where L, B, and H are length, breadth and height respectively

Assuming

$$Length = 2 \cdot B\_house$$

and

$$Height = B\_house$$

$$V\_house = 2 \cdot B\_house^{3}$$

$$B\_house := \left[\frac{(V\_warehouse \cdot day)}{2}\right]^{\frac{1}{3}}$$

$$B\_house = 1.139\,m$$

$$H\_house := B\_house$$

$$H\_house = 1.139\,m$$

$$L\_house := 2 \cdot B\_house$$

$$L\_house = 2.278\,m$$

The area occupied by the warehouse is given by

$$A\_warehouse := 2 \cdot [(L\_house \cdot H\_house) + (L\_house \cdot B\_house) + (B\_house \cdot H\_house)]$$

$$A\_warehouse = 12.972\,m^{2}$$

6.2 Design of Peeler

$M\_drink := 2044.53 \cdot \frac{kg}{day}$ $M\_fibre := 52.54 \cdot \frac{kg}{day}$ $M\_impurities := 26.27 \cdot \frac{kg}{day}$

$D\_drink := 850 \cdot \frac{kg}{m^3}$ $D\_fibre := 769 \cdot \frac{kg}{m^3}$ $D\_impurities := 1071 \cdot \frac{kg}{m^3}$

$V\_drink := \frac{M\_drink}{D\_drink}$ $V\_fibre := \frac{M\_fibre}{D\_fibre}$ $V\_impurities := \frac{M\_impurities}{D\_impurities}$

$V\_drink = 2.405 \frac{m^3}{day}$ $V\_fibre = 0.068 \frac{m^3}{day}$ $V\_impurities = 0.025 \frac{m^3}{day}$

$M\_volatile\_oil := 21.89 \cdot \frac{kg}{day}$ $M\_resinous\_matter := 43.78 \cdot \frac{kg}{day}$

$D\_volatile\_oil := 804 \cdot \frac{kg}{m^3}$ $D\_resinous\_matter := 993 \cdot \frac{kg}{m^3}$

$V\_volatile\_oil := \frac{M\_volatile\_oil}{D\_volatile\_oil}$ $V\_resinous\_matter := \frac{M\_resinous\_matter}{D\_resinous\_matter}$

$V\_volatile\_oil = 0.027 \frac{m^3}{day}$ $V\_resinous\_matter = 0.044 \frac{m^3}{day}$

$V := V\_drink + V\_fibre + V\_impurities + V\_volatile\_oil + V\_resinous\_matter$

$V = 2.569 \frac{m^3}{day}$

with $clearance := 15\% \cdot V$ at the top of the peeler

$$V\_peeler := clearance + V$$

$$V\_peeler = 2.955\frac{m^3}{day}$$

mathematically the volume of the peeler is given as

$$V\_peeler = \pi \cdot R\_peeler^2 \cdot H\_peeler$$

$$R\_Peeler = \frac{D\_peeler}{2}$$

$$V\_peeler = \pi \cdot \left(\frac{D\_peeler}{2}\right)^2 \cdot H\_peeler$$

$$V\_peeler = \pi \cdot \left(\frac{D\_peeler^2}{4}\right) \cdot H\_peeler$$

assuming that

$$\left(\frac{H\_peeler}{D\_peeler}\right) = k$$ then

$$H\_peeler = k \cdot D\_peeler$$

substituting for H

$$V\_peeler = \pi \cdot \left(\frac{D\_peeler^2}{4}\right) \cdot (k \cdot D\_peeler)$$

$$4 \cdot V\_peeler = k \cdot \pi \cdot D\_peeler^3$$

$$D\_peeler^3 = \left(4 \cdot \frac{V\_peeler}{k \cdot \pi}\right)$$

$$D\_peeler = \left(4 \cdot \frac{V\_Peeler}{k \cdot \pi}\right)^{\frac{1}{3}}$$

taking $k := 2$

$$D\_peeler := \left[\frac{(4 \cdot V\_peeler \cdot day)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

$$D\_peeler = 1.234m$$

$$H\_peeler := k \cdot D\_peeler$$

$$H\_peeler = 2.469m$$

the area is calculated to be

$$A\_peeler := 2\pi \cdot \left(\frac{D\_peeler}{2}\right) \cdot H\_peeler + 2\pi \cdot \left(\frac{D\_peeler}{2}\right)^2$$

$$A\_peeler = 11.969m^2$$

6.3 Design of Washer

the specification of the washer is given thus:

Type: Vessel

Material of construction: Steel

A rough estimate of the washer volume required can be made by taking a hold-up time of 5 to 10 min

which is usually sufficient where emulsions are not likely to form.

The washer vessel is a tubular vessel to contain the ginger to be washed so that the dirty particles in

the body of the ginger can be removed.

the washer is a cylinderical vessel where the peeled ginger is washed.

$M\_drink := 2044.53 \cdot \frac{kg}{day}$ $M\_fibre := 52.54 \cdot \frac{kg}{day}$ $M\_impurities := 26.27 \cdot \frac{kg}{day}$

$V\_drink := \frac{M\_drink}{D\_drink}$ $V\_fibre := \frac{M\_fibre}{D\_fibre}$ $V\_impurities := \frac{M\_impurities}{D\_impurities}$

$V\_drink = 2.405 \frac{m^3}{day}$ $V\_fibre = 0.068 \frac{m^3}{day}$ $V\_impurities = 0.025 \frac{m^3}{day}$

$M\_volatile\_oil := 21.89 \cdot \frac{kg}{day}$ $M\_water := 214.52 \cdot \frac{kg}{day}$

$V\_volatile\_oil := \frac{M\_volatile\_oil}{D\_volatile\_oil}$ $D\_water := 1000 \cdot \frac{kg}{m^3}$

$V\_volatile\_oil = 0.027 \frac{m^3}{day}$ $V\_water := \frac{M\_water}{D\_water}$

$V\_water = 0.215 \frac{m^3}{day}$

$V := V\_drink + V\_fibre + V\_impurities + V\_volatile\_oil + V\_water$

$$V = 2.74 \frac{m^3}{day}$$

with $clearance := 15\% \cdot V$ at the top of the washer

$$V\_washer := V + clearance$$

$$V\_washer = 3.151 \frac{m^3}{day}$$

mathematically the volume of the washer is given as

$$V\_washer = \pi \cdot R\_washer^2 \cdot H\_washer$$

and

$$R\_washer = \frac{D\_washer}{2}$$

$$V\_washer = \pi \cdot \left(\frac{D\_washer}{2}\right)^2 \cdot H\_washer$$

$$V\_washer = \pi \cdot \left(\frac{D\_washer^2}{4}\right) \cdot H\_washer$$

assuming that

$$\left(\frac{H\_washer}{D\_washer}\right) = k$$

then $H\_washer = k \cdot D\_washer$

substituting for H

$$V\_washer = \pi \cdot \left(\frac{D\_washer^2}{4}\right) \cdot k \cdot D\_washer$$

$$4 \cdot V\_washer = k \cdot \pi \cdot D\_washer^{3}$$

$$D\_washer^{3} = \left[\frac{(4 \cdot V\_washer)}{k \cdot \pi}\right]$$

$$D\_washer = \left[\frac{(4 \cdot V\_washer)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

taking $k := 2$

$$D\_washer := \left[\frac{(4 \cdot V\_washer \cdot day)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

$$D\_washer = 1.261\,m$$

$$H\_washer := k \cdot D\_washer$$

$$H\_washer = 2.522\,m$$

the area is calculated to be

$$A\_washer := 2\pi \cdot \left(\frac{D\_washer}{2}\right) \cdot H\_washer + 2\pi \cdot \left(\frac{D\_washer}{2}\right)^{2}$$

$$A\_washer = 12.492\,m^{2}$$

It should be noted that that the washer will have something like an agitator inside which will ensure

proper mixing of the ginger and the water for good washing operation

Assuming viscous flow, the power is given as

$$P = \left(\frac{K_{2}}{g_{c}}\right) \cdot \mu \cdot \left(N_{s}\right)^{2} \cdot (D)^{3} \qquad \text{(Ernest, 1995)}$$

where

K_2 is a constant

N_s is the speed of the agitator

D is the diameter of the agitator

μ is the viscosity of the liquid

knowing that

$$gc := 1 \cdot \frac{(kg \cdot m)}{N \cdot s^2}$$

$$K2 := 155.0($$

$$\mu := 0.62 \cdot 10^{-3} \cdot \frac{(N \cdot s)}{m^2}$$

$$D := 0.30 \cdot m$$

$$Ns := 40 \cdot \frac{rad}{s}$$

$$P\_washer := \left(\frac{K2}{gc}\right) \cdot \mu \cdot (Ns)^2 \cdot (D)^3$$

$$P\_washer = 4.152W$$

for the voltage of 150V, the amount of current required is

$$Voltage\_washer := 150 \cdot volt$$

$$P\_washer = I\_washer \cdot Voltage\_washer$$

$$I\_washer := \frac{P\_washer}{Voltage\_washer}$$

$$I\_washer = 0.028A$$

6.4 Design of crusher

Type; continous stirred media mill

Material of construction; steel

the crusher is a vessel that is used to rupture the ginger with the aid of the crushing ability it

posseses. the crushing ability of the crusher will be associated with the rolls inside the crusher. As

such, the design of the crusher will take the space of the rolls into account so as not to

underestimate the capacity of the crusher.

$M\_drink := 2044.53 \cdot \frac{kg}{day}$ $M\_fibre := 52.54 \cdot \frac{kg}{day}$ $M\_volatile\_oil := 21.89 \cdot \frac{kg}{day}$

$V\_drink := \frac{M\_drink}{D\_drink}$ $V\_fibre := \frac{M\_fibre}{D\_fibre}$ $V\_volatile\_oil := \frac{M\_volatile\_oil}{D\_volatile\_oil}$

$V\_drink = 2.405\frac{m^3}{day}$ $V\_fibre = 0.068\frac{m^3}{day}$ $V\_volatile\_oil = 0.027\frac{m^3}{day}$

$M\_water := 235.49 \cdot \frac{kg}{day}$

$V\_water := \frac{M\_water}{D\_water}$

$V\_water = 0.235\frac{m^3}{day}$

$V := V\_drink + V\_fibre + V\_volatile\_oil + V\_water$

$V = 2.736\frac{m^3}{day}$

with $clearance := 15\% \cdot V$ at the top of the crusher

$V\_crusher := V + clearance$

$V\_crusher = 3.147\frac{m^3}{day}$

mathematically the volume of the crusher is given as

$$V\_crusher = \pi \cdot R\_crusher^2 \cdot H\_crusher$$

and

$$R\_crusher = \frac{D\_crusher}{2}$$

$$V\_crusher = \pi \cdot \left(\frac{D\_crusher}{2}\right)^2 \cdot H\_crusher$$

$$V\_crusher = \pi \cdot \left(\frac{D\_crusher^2}{4}\right) \cdot H\_crusher$$

assuming that

$$\left(\frac{H\_crusher}{D\_crusher}\right) = k$$

then

$$H\_crusher = k \cdot D\_crusher$$

substituting for H

$$V\_crusher = \pi \cdot \left(\frac{D\_crusher^2}{4}\right) \cdot k \cdot D\_crusher$$

$$4 \cdot V\_crusher = k \cdot \pi \cdot D\_crusher^3$$

$$D\_crusher^3 = \left(4 \cdot \frac{V\_crusher}{k \cdot \pi}\right)$$

$$D\_crusher = \left[\frac{(4 \cdot V\_crusher)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

taking $k := 2$

$$D\_crusher := \left[\frac{(4 \cdot V\_crusher \cdot day)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

$$D\_crusher = 1.261 m$$

$$H\_crusher := k \cdot D\_crusher$$

$$H\_crusher = 2.521 m$$

the area is calculated to be

$$A\_crusher := 2\pi \cdot \left(\frac{D\_crusher}{2}\right) \cdot H\_crusher + 2\pi \cdot \left(\frac{D\_crusher}{2}\right)^2$$

$$A\_crusher = 12.481 m^2$$

the net power to drive a roll ball was found to be

$$E = [(1.64 \cdot L - 1) \cdot K + 1] \cdot (1.64 \cdot D)^{2.5} \cdot E_2 \qquad \text{(Perry)}$$

where

E is the net power to drive a roll

L is the inside length of the crusher

D is the mean inside diameter of the crusher

E_2 is the net power used by a 0.6-0.6m laboratory roll under similar operating conditions

K

is a constant which is 0.9 for rolls less than 1.5m long and 0.85 for mills over 1.5m long

now choosing

$$L := H\_crusher$$

$$K := 0.9$$

$D := D\_crusher$

$E_2 := 9.5 \cdot W$

$$E\_roll := [(1.64 \cdot L - 1 \cdot m) \cdot K + 1 \cdot m] \cdot (1.64 \cdot D)^{2.5} \cdot E_2 \cdot m^{-3.5}$$

$E\_roll = 223.106W$

6.5 Design of extractor

Type; vertical plate extractor (Bonotto extractor)

mode of feeding: countercurrent

material: steel

$M\_drink := 2044.53 \cdot \frac{kg}{day}$

$V\_drink := \frac{M\_drink}{D\_drink}$

$V\_drink = 2.405 \frac{m^3}{day}$

$M\_fibre := 52.54 \cdot \frac{kg}{day}$

$V\_fibre := \frac{M\_fibre}{D\_fibre}$

$V\_fibre = 0.068 \frac{m^3}{day}$

$M\_volatile\_oil := 21.89 \cdot \frac{kg}{day}$

$V\_volatile\_oil := \frac{M\_volatile\_oil}{D\_volatile\_oil}$

$V\_volatile\_oil = 0.027 \frac{m^3}{day}$

$M\_water := 590.11 \cdot \frac{kg}{day}$

$V\_water := \frac{M\_water}{D\_water}$

$V\_water = 0.59 \frac{m^3}{day}$

$$V := V\_drink + V\_fibre + V\_volatile\_oil + V\_water$$

$V = 3.091 \frac{m^3}{day}$

with $clearance := 15\% \cdot V$ at the top of the extractor

$$V\_extractor := V + clearance$$

$$V\_extractor = 3.555 \frac{m^3}{day}$$

mathematically the volume of the extractor is given by

$$V\_extractor = \pi \cdot R\_extractor^2 \cdot H\_extractor$$

and

$$R\_extractor = \frac{D\_extractor}{2}$$

$$V\_extractor = \pi \cdot \left(\frac{D\_extractor}{2}\right)^2 \cdot H\_extractor$$

$$V\_extractor = \pi \cdot \left(\frac{D\_extractor^2}{4}\right) \cdot H\_extractor$$

assuming that

$$\left(\frac{H\_extractor}{D\_extractor}\right) = k$$

then $H\_extractor = k \cdot D\_extractor$

substituting for H

$$V\_extractor = \pi \cdot \left(\frac{D\_extractor^2}{4}\right) \cdot k \cdot D\_extractor$$

$$4 \cdot V\_extractor = k \cdot \pi \cdot D\_extractor^3$$

$$D\_extractor^3 = \left[\frac{(4 \cdot V\_extractor)}{k \cdot \pi}\right]$$

$$D\_extractor = \left[\frac{(4 \cdot V\_extractor)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

taking $k := 2$

$$D\_extractor := \left[\frac{(4 \cdot V\_extractor \cdot day)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

$D\_extractor = 1.313m$

$H\_extractor := k \cdot D\_extractor$

$H\_extractor = 2.626m$

the area is calculated to be

$$A\_extractor := 2\pi \cdot \left(\frac{D\_extractor}{2}\right) H\_extractor + 2\pi \cdot \left(\frac{D\_extractor}{2}\right)^2$$

$A\_extractor = 13.538m^2$

6.6 Design of pump

Data

flow rate, $M := 2605.77 \cdot \frac{kg}{day}$

pressures $P1 := 1.05 \cdot 10^5 \frac{N}{m^2}$

$P2 := 1.1 \cdot 10^5 \cdot \frac{N}{m^2}$

$z_1 := 0 \cdot m$

$z_2 := 30 \cdot m$

pump efficiency $\eta := 70\%$

pipe dimensions:

$d\_i := 225 \cdot mm$

$L\_p := 900 \cdot m$

fluid properies

viscosity $\mu := 0.62 \cdot 10^{-3} \cdot \frac{(N \cdot s)}{m^2}$

density $\rho := 874 \cdot \frac{kg}{m^3}$

cross sectional area of pipe:

$$A\_p := \left(\frac{\pi}{4}\right) \cdot d\_i^2$$

$$A\_p = 0.04m^2$$

minimum fluid velocity:

$$u\_f := \frac{M}{A\_p \cdot \rho}$$

$$u\_f = 8.679 \times 10^{-4} m \cdot s^{-1}$$

Reynolds number:

$$NRe := \frac{(\rho \cdot u\_f \cdot d\_i)}{\mu}$$

$$NRe = 275.27$$

Absolute roughness $roughness\_abs := 0.046 \cdot mm$

Relative roughness

$$roughness\_rel := \frac{roughness\_abs}{d\_i}$$

$$roughness\_rel = 2.044\times 10^{-4}$$

from friction chart, friction factor $f := 0.0019$

Total length of pipeline, including miscellaneous losses,

$$L\_p\_total := L\_p + 600 \cdot d\_i$$

$$L\_p\_total = 1.035\times 10^{3} m$$

friction loss in pipeline (Sinnot, 1999)

$$\Delta P\_f := 8 \cdot f \cdot \left(\frac{L\_p\_total}{d\_i}\right) \cdot \left[\frac{\rho \cdot \left(u\_f^2\right)}{2}\right]$$

$$\Delta P\_f = 0.023 \frac{N}{m^2}$$

minimum difference in elevation

$$\Delta z := z_1 - z_2$$

$$\Delta z = -30m$$

pressure difference

$$\Delta P := P1 - P2$$

$$\Delta P = -5\times 10^{3} \frac{N}{m^2}$$

Energy balance:

$$W := g \cdot \Delta z + \left(\frac{\Delta P}{\rho}\right) - \left(\frac{\Delta P\_f}{\rho}\right)$$

$$W = -299.92 \frac{J}{kg}$$

power

$$Pump\_power := \left|\frac{(W \cdot M)}{\eta}\right|$$

$$Pump\_power = 0.013kW$$

Static head:

difference in elevation, $\Delta z = -30m$

difference in pressure, $\Delta P = -5 \times 10^3 \frac{N}{m^2}$

pressure as head of liquid, $Head\_static := \frac{\Delta P}{\rho \cdot g}$

$$Head\_static = -0.583m$$

Dynamic Head:

As an initial value, the fluid velocity is taken to be $u := 1 \cdot \frac{m}{s}$

$$u := \begin{pmatrix} 1 \\ 1.5 \\ 2 \\ 2.5 \\ 3 \end{pmatrix} \cdot \frac{m}{s}$$

Volumetric flow rate

$$V\_r := u \cdot A\_p$$

$$V\_r = \begin{pmatrix} 0.04 \\ 0.06 \\ 0.08 \\ 0.099 \\ 0.119 \end{pmatrix} m^3 \cdot s^{-1}$$

Reynolds number

$$NRe := \frac{(\rho \cdot u \cdot d\_i)}{\mu}$$

$$NRe = \begin{pmatrix} 3.172\times 10^5 \\ 4.758\times 10^5 \\ 6.344\times 10^5 \\ 7.929\times 10^5 \\ 9.515\times 10^5 \end{pmatrix}$$

Pressure drop:

$$\Delta P\_f := 8 \cdot f \cdot \left(\frac{L\_p\_total}{d\_i}\right) \cdot \frac{\left(\rho \cdot u^2\right)}{2}$$

$$\Delta P\_f = \begin{pmatrix} 3.056\times 10^4 \\ 6.875\times 10^4 \\ 1.222\times 10^5 \\ 1.91\times 10^5 \\ 2.75\times 10^5 \end{pmatrix} \frac{N}{m^2}$$

Pressure as head of liqud

$$Head\_dynamic := \frac{\Delta P\_f}{\rho \cdot g}$$

$$Head\_dynamic = \begin{pmatrix} 3.565 \\ 8.021 \\ 14.26 \\ 22.281 \\ 32.084 \end{pmatrix} m$$

Total head, $Head := Head\_static + Head\_dynamic$

$$Head = \begin{pmatrix} 2.982 \\ 7.438 \\ 13.676 \\ 21.697 \\ 31.501 \end{pmatrix} m$$

$$Table := augment\left(\frac{u}{\frac{m}{s}}, \frac{V\_r}{\frac{m^3}{s}}, \frac{Head\_dynamic}{m}, \frac{Head}{m}\right)$$

$$Table = \begin{pmatrix} 1 & 0.04 & 3.565 & 2.982 \\ 1.5 & 0.06 & 8.021 & 7.438 \\ 2 & 0.08 & 14.26 & 13.676 \\ 2.5 & 0.099 & 22.281 & 21.697 \\ 3 & 0.119 & 32.084 & 31.501 \end{pmatrix}$$

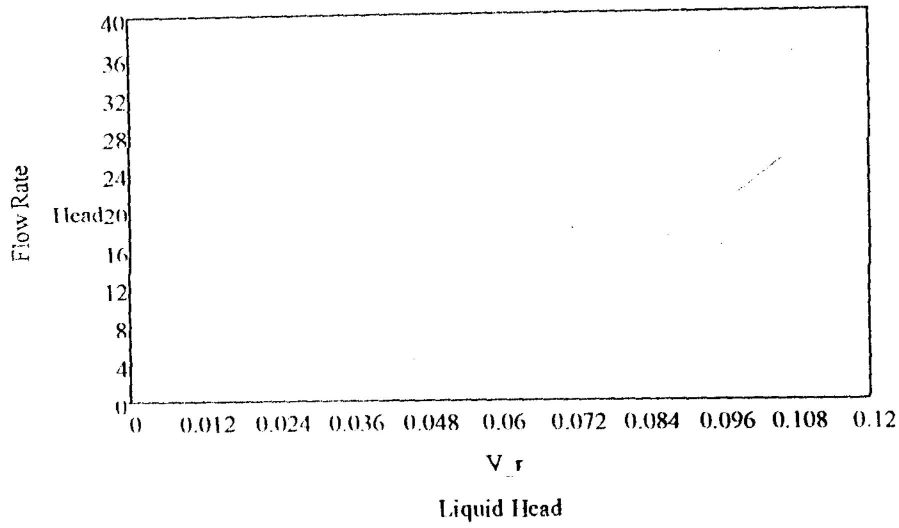


Fig 1 : Pump performance curve

6.7 Design of sedimentation tank

The quantities of the materials going into the tank have been obtained from the material

balances around the tank to be

calculation of settling velocity:

this is given as

$$u\_d = \frac{[d\_d \cdot g \cdot (\rho\_d - \rho\_c)]}{18 \cdot \mu\_c}$$ *for falling case (Sinnot, 1999)*

where

d_d	is particle diameter
u_d	settling (terminal) velocity of the dispersal phase droplets with diameter d;
ρ_c	density of the continous phase;
ρ_d	density of the dispersal phase
μ_c	viscosity of the continous phase
g	gravitational accelaration

so taking

$$d\_d := 0.2 \cdot mm$$

$$g := 9.807 \cdot \frac{m}{s^2}$$

$$\rho\_d := 850 \cdot \frac{kg}{m^3}$$

$$\rho\_c := 1000 \cdot \frac{kg}{m^3}$$

$$\mu\_c := 0.62 \cdot 10^{-3} \cdot \frac{(N \cdot s)}{m^2}$$

$$u\_d := \frac{\left[d\_d^2 \cdot g \cdot (\rho\_c - \rho\_d)\right]}{18 \cdot \mu\_c}$$

$$u\_d = 5.273 \times 10^{-3} \, m \cdot s^{-1}$$

As flow rate is small, a vertical cylinderical vessel is used.

The continous phase volumetric flow rate is given thus:

The mass flow rate of the continous phase is

$$M\_c := 535.68 \cdot \frac{kg}{day}$$

$$L\_c := \frac{M\_c}{\rho\_c}$$

$$L\_c = 0.536 \frac{m^3}{day}$$

hence area of the interface:

$$A_i := \frac{L_c}{u_d}$$

$$A_i = 1.176 \times 10^{-3}\ m^2$$

Diameter of the interface:

$$D_{sed\_tank} := \sqrt{\frac{(4 \cdot A_i)}{\pi}}$$

$$D_{sed\_tank} = 0.039 m$$

Taking the height as twice the diameter (a reasonable value for the cylinder), then

$$H_{sed\_tank} := 2 \cdot D_{sed\_tank}$$

$$H_{sed\_tank} = 0.077 m$$

taking the dispersal band as $d_b := 10\% \cdot H_{sed\_tank}$

$$d_b = 7.739 \times 10^{-3}\ m$$

the residence time is given as;

$$\tau := \frac{d_b}{u_d}$$

$$\tau = 1.468 s$$

6.8 Design of boiler

Basis: 1 hour of operation

mass of drink to be boiled,

$$m\_a := 2602.10 \cdot \frac{kg}{day}$$

Given:

The fluids are:

Water:

Inlet temperature, $Tin\_1 := (75 + 273) \cdot K$

Outlet temperature $Tout\_1 := (40 + 273) \cdot K$

Drink:

Inlet temperature, $Tin\_2 := (45 + 273) \cdot K$

Outlet temperature, $Tout\_2 := (90 + 273) \cdot K$

The drink coming out of the sedimentation tank are boiled from a lower temperature to a

higher one in a shell and tube type heat exchanger. hot water which enters the heat exchanger

as it cools to Tout_1=313K is used as the heating liquid.

Bulk temperature of water: $T\_bw := \frac{(Tin\_1 + Tout\_1)}{2}$

$$T\_bw = 330.5K$$

Bulk temperature of drink: $T\_bd := \frac{(Tin\_2 + Tout\_2)}{2}$

$$T\_bd = 340.5K$$

Properies of components at bulk temperature:

$$\begin{pmatrix} T\_b \\ \rho \\ C\_p \\ K \\ \mu \end{pmatrix} = \begin{pmatrix} \text{"Bulk temperature"} \\ \text{Density} \\ \text{"Specific heat capacity"} \\ \text{"Thermal conductivity"} \\ \text{Viscosity} \end{pmatrix}$$

$$kJ := 1000 \cdot J \qquad cP := 10^{-2} \cdot poise$$

Water

$$\begin{pmatrix} T\_bw \\ \rho\_w \\ C\_pw \\ K\_w \\ \mu\_w \end{pmatrix} := \begin{bmatrix} \frac{(Tin\_1 + Tout\_1)}{2} \\ 994.86 \cdot \frac{kg}{m^3} \\ 4.184 \cdot \frac{kJ}{kg \cdot K} \\ 0.623 \cdot \frac{W}{m \cdot K} \\ 0.8 \cdot cP \end{bmatrix}$$

Drink

$$\begin{pmatrix} T\_bd \\ \rho\_d \\ C\_pd \\ K\_d \\ \mu\_d \end{pmatrix} := \begin{bmatrix} \frac{(Tin\_2 + Tout\_2)}{2} \\ 1850 \cdot \frac{kg}{m^3} \\ 1.4435 \cdot \frac{kJ}{kg \cdot K} \\ 0.655 \cdot \frac{W}{m \cdot K} \\ 0.62 \cdot 10^{-3} \cdot \frac{(N \cdot s)}{m^2} \end{bmatrix}$$

1. Heat load:

The heat load on the heat exchanger is calculated from the energy balance to be

$$Q\_boiler := 9.424 \cdot 10^{3} \cdot \frac{kJ}{day}$$

Mass of water required is calculated as

$$m\_w := \left| \frac{Q\_boiler}{C\_pw \cdot (Tout\_1 - Tin\_1)} \right|$$

$$m\_w = 64.354 \frac{kg}{day}$$

2. Log Mean Temperature Difference, LMTD:

Temperatures	Inlet	Outlet
Water	Tin_1 = 348K	Tout_1 = 313K
Drink	Tin_2 = 318K	Tout_2 = 363K

Temperature Difference

$$LMTD := \frac{[(Tin\_2 - Tout\_1) - (Tout\_2 - Tin\_1)]}{\ln\left[\frac{(Tin\_2 - Tout\_1)}{(Tout\_2 - Tin\_1)}\right]}$$

$$LMTD = 9.102K$$

$$R := \frac{Tin\_2 - Tout\_2}{Tout\_1 - Tin\_1}$$

$R = 1.286$

$$S := \frac{(Tout\_1 - Tin\_1)}{(Tin\_2 - Tin\_1)}$$

$S = 1.167$

taking the LMTD correction factor to be $F\_T := 0.834$

$LMTD\_c := 0.834 \cdot LMTD$

$LMTD\_c = 7.591K$

3. Routing:

Shell side = drink

Tube side = Cooling water

4. Determination of area:

assuming $Uo := 6 \cdot \frac{1}{m^2 \cdot K}$

$$A\_exchanger := \frac{Q\_boiler \cdot s^3}{Uo \cdot LMTD\_c \cdot kg \cdot m^2}$$

$A\_exchanger = 2.395m^2$

5. Choice of tubes:

From the tubing characteristics as given in Perry, the following dimensions of the tube are choosen.

1 inch outer diameter tubes with 1.25 inch triangular pitch, 16 BWG

Outer diameter, $Do := 1.0 \cdot in$ $Do = 0.025m$

Inner diameter, $Di := 0.87 \cdot in$ $Di = 0.022m$

Pitch, $P := 31.75 \cdot mm$ $P = 0.032m$

assuming the tube to be of length, $Lt := 3 \cdot m$

number of tubes,
$$Nt := \frac{A\_exchanger}{\pi \cdot Do \cdot Lt}$$

$$Nt = 10.003$$

6. Correction of heat transfer area:

From the tube count table, we have for TEMA P or S (1-4 exchanger)

1 shell Pass and 4 tube passes

diameter of shell, $Ds := 635 \cdot mm$

corrected heat transfer area

$$A\_corrected := \pi \cdot Do \cdot Lt \cdot Nt$$

$$A\_corrected = 2.395m^2$$

corrected heat transfer coefficient

$$Uoc := \frac{Q\_boiler}{A\_corrected \cdot LMTD\_c \cdot m\_w}$$

$$Uoc = -26.859\frac{W}{m^2 \cdot K}$$

7. Calculation of inside heat transfer coefficient

Area of the tubes, $$At := \frac{\left(\pi \cdot Di^2 \cdot Nt\right)}{4 \cdot Np}$$

$$At = 9.591 \times 10^{-4} m^2$$

mass velocity, $$Gs := \frac{m\_w}{At}$$

$$Gs = 0.777 m^{-2} \cdot kg \cdot s^{-1}$$

velocity inside the tubes, $$Vt := \frac{m\_w}{\rho\_w \cdot At}$$

$$Vt = 7.806 \times 10^{-4} m \cdot s^{-1}$$

the above velocity is within acceptable limits.

Reynolds number $$NRe := \frac{(Gs \cdot Di)}{\mu\_w}$$

$$NRe = 21.451$$

Prandt number $$NPr = \frac{(\mu\_w \cdot C\_pw)}{K\_w}$$

$$NPr := 5.37$$

given that $$\left[\frac{(hi \cdot Di)}{K\_w}\right] = j\_H \cdot NRe \cdot NPr^{\frac{1}{3}}$$

$$hi = \frac{\left(j\_H \cdot NRe \cdot NPr^{\frac{1}{3}} \cdot K\_w\right)}{Di}$$

taking $j\_H := 0.003$

$$hi := \frac{\left(j\_H \cdot NRe \cdot NPr^{\frac{1}{3}} \cdot K\_w \right)}{Di}$$

$$hi = 3.813 \frac{W}{m^2 \cdot K}$$

8. calculation of outside heat transfer coefficient:

length of tube, $Lt := 3m$

baffle spacing, $Ls := 0.266 \cdot Ds$

$Ls = 0.169m$

number of baffles $Nb := \left(\frac{Lt}{Ls} \right) - 1$

$Nb = 16.761$

$$Sm := \frac{[Ls \cdot (P - Do) \cdot Ds]}{P}$$

$Sm = 0.021m^2$

$$Vs := \frac{m\_a}{Sm \cdot \rho\_d}$$

$Vs = 7.589 \times 10^{-4} m \cdot s^{-1}$

Equivalent diameter $De := 1.1 \cdot \frac{\left(P^2 - 0.917 \cdot Do^2\right)}{Do}$

$De = 0.018m$

Reynolds number $NRe := \frac{(De \cdot Gs)}{\mu\_d}$

$NRe = 22.59$

Prandt number $NPr = \frac{(\mu\_d \cdot C\_pd)}{K\_d}$

$NPr := 1.36($

from graph, $j\_H := 0.01($

$$ho := j\_H \cdot NRe \cdot NPr^{\frac{1}{3}} \cdot \left(\frac{\mu\_d}{\mu\_w}\right)^{0.14} \cdot \frac{K\_d}{De}$$

$$ho = 16.689\frac{W}{m^2 \cdot K}$$

$$\left(\frac{1}{Uo}\right) = \left(\frac{1}{ho}\right) + \left(\frac{Do}{Di}\right)\cdot\left(\frac{1}{hi}\right) + \left[\frac{\left(Do \cdot \ln\left(\frac{Do}{Di}\right)\right)}{2 \cdot K\_w}\right] + \left(\frac{1}{hod}\right) + \left(\frac{Do}{Di}\right)\cdot\left(\frac{1}{hid}\right)$$

(Sinnot, 1999)

wherre

inside film fluid coefficient, $hi := 8000 \cdot \frac{W}{m^2 \cdot K}$

inside dirt coefficient, $hid := 5000 \cdot \frac{W}{m^2 \cdot K}$

outside dirt coefficient, $hod := 3000 \cdot \frac{W}{m^2 \cdot K}$

$$Uo := \left[\left(\frac{1}{ho}\right) + \left(\frac{Do}{Di}\right)\cdot\left(\frac{1}{hi}\right) + \left[\frac{\left(Do \cdot \ln\left(\frac{Do}{Di}\right)\right)}{2 \cdot K\_w}\right] + \left(\frac{1}{hod}\right) + \left(\frac{Do}{Di}\right)\cdot\left(\frac{1}{hid}\right)\right]^{-1}$$

$$Uo = 15.757\frac{W}{m^2 \cdot K}$$

9. pressure drop calculation:

for tube side,

friction factor, $f := 0.079 \cdot NRe^{-0.25}$

$f = 0.036$

$$\Delta PL := \frac{\left(4 \cdot f \cdot Lt \cdot Vt^2 \cdot \rho\_w\right)}{2 \cdot Di}$$

$$\Delta PL = 5.964 \times 10^{-3} \frac{N}{m^2}$$

$$\Delta Pt := 2.5 \cdot \rho\_w \cdot \frac{Vt^2}{2}$$

$$\Delta Pt = 7.577 \times 10^{-4} \frac{N}{m^2}$$

$$\Delta P\_tube := Np \cdot (\Delta PL + \Delta Pt)$$

$$\Delta P\_tube = 0.027 \frac{N}{m^2}$$

for shell side

$NRe = 22.5$

$b := 2 \cdot 10^{-3}$

baffle cut $Lc := 25\% \cdot Ds$

$Lc = 0.159 m$

$$Pp := \left[\frac{(\sqrt{3})}{2}\right] \cdot P$$

$$Pp = 0.027\,m$$

$$f\_k := 0.25$$

$$Nc := Ds \cdot \left[\frac{\left[1 - 2 \cdot \left(\frac{Lc}{Ds}\right)\right]}{Pp}\right]$$

$$Nc = 11.547$$

$$\Delta Pc := \left[\frac{\left(b \cdot f\_k \cdot m\_a^2 \cdot Nc\right)}{\rho\_w \cdot Sm^2}\right] \cdot \left(\frac{\mu\_w}{\mu\_d}\right)^{0.14}$$

$$\Delta Pc = 1.185 \times 10^{-5} \frac{N}{m^2}$$

Pressure drop in end zones:

number of cross rows in each window, $Ncw := 0.8 \cdot \frac{Lc}{Pp}$

$$Ncw = 4.619$$

$$\Delta Pe := \Delta Pc \cdot \left(1 + \frac{Ncw}{Nc}\right)$$

$$\Delta Pe = 1.66 \times 10^{-5} \frac{N}{m^2}$$

pressure drop in window zones;

$$b := 5 \cdot 10^{-4}$$

Area for flow through window zone, $Sw = Swg - Swt$

Gross window area, $Swg := 100 \cdot in^2$ $Swg = 0.065 m^2$

Area occupied by tubes, $Swt = \left(\frac{Nt}{8}\right) \cdot (1 - Fc) \cdot \pi \cdot Do^2$

from the graph in Perry, Fig. 10-16, Pg. 10-28,

$Fc := 0.65$

$Swt := \left(\frac{Nt}{8}\right) \cdot (1 - Fc) \cdot \pi \cdot Do^2$

$Swt = 8.87 \times 10^{-4} m^2$

$Sw := Swg - Swt$

$Sw = 0.064 m^2$

$$\Delta Pw := \frac{\left[b \cdot m\_a^2 \cdot (2 \cdot 0.6 \cdot Ncw)\right]}{Sm \cdot Sw \cdot \rho\_d}$$

$\Delta Pw = 9.954 \times 10^{-7} \frac{N}{m^2}$

Therefore the total pressure drop on the shell side is calculated by the relation below:

$\Delta P\_shell := 2 \cdot \Delta Pe + (Nb - 1) \cdot \Delta Pc + Nb \cdot \Delta Pw$

$\Delta P\_shell = 2.367 \times 10^{-4} \frac{N}{m^2}$

Summary of process design for heat exchanger

Mass flow rate of drink $m\_a = 0.03 kg \cdot s^{-1}$

Mass flow rate of water $m\_w = 7.448 \times 10^{-4} kg \cdot s^{-1}$

Shell outer diameter, $Ds = 0.635 m$

number of tubes $Nt = 10.003$

tube outer diameter, $Do = 0.025m$

pitch $P = 0.032m$

tube length $Lt = 3m$

shell side pressure drop, $\Delta P\_shell = 2.367 \times 10^{-4} \frac{N}{m^2}$

tube side pressure drop, $\Delta P\_tube = 0.027 \frac{N}{m^2}$

Heat exchanger type = TEMA P OR S type 1-4 Heat Exchanger

6.9 Design of Chiller

Basis: 1 hour of operation

Mass of drink to the chiller, $m\_a := 2709.21 \cdot \frac{kg}{day}$

The fluids are:

Water

Inlet temperature, $Tin\_1 := (30 + 273) \cdot K$

Outlet temperature, $Tout\_1 := (65 + 273) \cdot K$

Drink

Inlet temperature $Tin\_2 := (45 + 273) \cdot K$

Outlet temperature, $Tout\_2 := (4 + 273) \cdot K$

The drink coming out from the sedimentation tank are boiled from a lower temperature to a higher

one in a shell and tube type heat exchanger. hot water which enters the heat exchanger as it cool to

$Tout\_1 = 338K$ is used as the heating liquid.

Bulk temperature of water: $$T\_bw := \frac{(Tin\_1 + Tout\_1)}{2}$$

$$T\_bw = 320.5K$$

Bulk temperature of drink: $$T\_bd := \frac{(Tin\_2 + Tout\_2)}{2}$$

$$T\_bd = 297.5K$$

Properties of components at bulk temperature:

$$\begin{pmatrix} T\_b \\ \rho \\ C\_p \\ K \\ \mu \end{pmatrix} = \begin{pmatrix} \text{"Bulk temperature"} \\ \text{Density} \\ \text{"Specific heat capacity"} \\ \text{"Thermal conductivity"} \\ \text{Viscosity} \end{pmatrix}$$

Water

$$\begin{pmatrix} T\_bw \\ \rho\_w \\ C\_pw \\ K\_w \\ \mu\_w \end{pmatrix} := \begin{bmatrix} \frac{(Tin\_1 + Tout\_1)}{2} \\ 994.86 \cdot \frac{kg}{m^3} \\ 4.184 \cdot \frac{kJ}{kg \cdot K} \\ 0.623 \cdot \frac{W}{m \cdot K} \\ 0.8 \cdot cP \end{bmatrix}$$

drink

$$\begin{pmatrix} T\_bd \\ \rho\_d \\ C\_pd \\ K\_d \\ \mu\_d \end{pmatrix} := \begin{bmatrix} \frac{(Tin\_2 + Tout\_2)}{2} \\ 1850 \cdot \frac{kg}{m^3} \\ 1.4435 \cdot \frac{kJ}{kg \cdot K} \\ 0.655 \cdot \frac{W}{m \cdot K} \\ 0.62 \cdot 10^{-3} \cdot \frac{(N \cdot s)}{m^2} \end{bmatrix}$$

1. Heat load

The heat load on the heat exchanger is calculated from the energy balance to be,

$$Q\_chiller := -1.516 \cdot 10^4 \cdot \frac{kJ}{day}$$

mass of water required is calculated as

$$m\_w := \left| \frac{Q\_chiller}{C\_pw \cdot (Tout\_1 - Tin\_1)} \right|$$

$$m\_w = 103.524 \frac{kg}{day}$$

2. Log Mean Temperature Difference, LMTD:

Temperatures	Inlet	Outlet
water	Tin_1 = 303K	Tout_1 = 338K
drink	Tin_2 = 318K	Tout_2 = 277K

Temperature difference

$$LMTD := \frac{[(Tin\_2 - Tout\_1) - (Tout\_2 - Tin\_1)]}{\ln\left[\frac{(Tin\_2 - Tout\_1)}{(Tout\_2 - Tin\_1)}\right]}$$

$LMTD = -22.869K$

$$R := \frac{(Tin\_2 - Tout\_2)}{(Tout\_1 - Tin\_1)}$$

$R = 1.171$

$$S := \frac{(Tout\_1 - Tin\_1)}{(Tin\_2 - Tin\_1)}$$

$S = 2.333$

taking the LMTD correction factor to be, $F\_T := 0.834$

$LMTD\_c := 0.834 \cdot LMTD$

$LMTD\_c = -19.073K$

3. Routing

Shell side = drink

Tube side = cooling water

4. Determination of Area:

assuming $Uo := 0.5 \cdot \frac{W}{m^2 \cdot K}$

Then area can be calculated as $A\_exchanger = \frac{Q\_chiller}{Uo \cdot LMTD\_c}$

$A\_exchanger := 18.396 \cdot m^2$

5. Choice of Tubes

From the tubing characteristics as given in Perry, the following dimensions of the tube are choosen

1 inch outer diameter tubes with 1.25 inch triangular pitch, 16 BWG

Outer diameter, $Do := 1.0 \cdot in$ $Do = 0.025m$

Inner diameter, $Di := 0.87 \cdot in$ $Di = 0.022m$

Pitch $P := 31.75 \cdot mm$ $P = 0.032m$

Assuming the tube to be of length, $Lt := 3 \cdot m$

Number of tubes, $Nt := \frac{A\_exchanger}{\pi \cdot Do \cdot Lt}$

$$Nt = 76.846$$

6. Correction of Heat Transfer Area:

From the tube count table, we have for TEMA Por S (1-4 exchanger)

1 Shell Pass and 4 Tube Passes $Np := 4$

Diameter of shell, $Ds := 635 \cdot mm$

Corrected heat transfer area, $A\_corrected := \pi \cdot Do \cdot Lt \cdot Nt$

$$A\_corrected = 18.396m^2$$

Corrected heat transfer coefficient, Uoc

$$Uoc = \frac{Q\_chiller}{A\_corrected \cdot LMTD\_c}$$

$$Uoc := 0.5 \cdot \frac{W}{m^2 \cdot K}$$

7. Calculation of inside Heat transfer coefficient:

Area of the tubes, $At := \frac{(\pi \cdot Di^2 \cdot Nt)}{4 \cdot Np}$

$At = 7.368\times 10^{-3} m^2$

Mass velocity, $Gs := \frac{m\_w}{At}$ $Gs = 0.163 m^{-2} \cdot kg \cdot s^{-1}$

Velocity inside the tubes, $Vt := \frac{m\_w}{\rho\_w \cdot At}$

$Vt = 1.635\times 10^{-4} m \cdot s^{-1}$

Reynolds number, $NRe := \frac{(Gs \cdot Di)}{\mu\_w}$

$NRe = 4.492$

Prandt number, $NPr = \frac{(\mu\_w \cdot C\_pw)}{K\_w}$

$NPr := 5.37$

taking $j\_H := 0.003$

$$hi := \frac{\left(j\_H \cdot NRe \cdot NPr^{\frac{1}{3}} \cdot K\_w\right)}{Di}$$

$hi = 0.799 \frac{W}{m^2 \cdot K}$

8. Calculation of Outside Heat Transfer Coefficient

Length of tube, $Lt = 3m$

Baffle spacing, $Ls := 0.266 \cdot Ds$

$Ls = 0.169m$

number of baffles $Nb := \left(\frac{Lt}{Ls}\right) - 1$

$Nb = 16.761$

$$Sm := \frac{[Ls \cdot (P - Do) \cdot Ds]}{P}$$

$Sm = 0.021m^2$

$$Vs := \frac{m\_a}{Sm \cdot \rho\_d}$$

$Vs = 7.901 \times 10^{-4} m \cdot s^{-1}$

Equivalent diameter,

$$De := 1.1 \cdot \frac{\left(P^2 - 0.917 \cdot Do^2\right)}{Do}$$

$De = 0.018m$

Reynolds number, $NRe := \frac{(De \cdot Gs)}{\mu\_d}$

$NRe = 4.73$

Prandt number $NPr = \frac{(\mu\_d \cdot C\_pd)}{K\_d}$

$NPr := 1.36($

from graph $j\_H := 0.01($

$$ho := j\_H \cdot NRe \cdot NPr^{\frac{1}{3}} \cdot \left(\frac{\mu\_d}{\mu\_w}\right)^{0.14} \cdot \left(\frac{K\_d}{De}\right)$$

$$ho = 3.495 \frac{W}{m^2 \cdot K}$$

$$\left(\frac{1}{Uo}\right) = \left(\frac{1}{ho}\right) + \left(\frac{Do}{Di}\right) \cdot \left(\frac{1}{hi}\right) + \left[\frac{\left(Do \cdot \ln\left(\frac{Do}{Di}\right)\right)}{2 \cdot K\_w}\right] + \left(\frac{1}{hod}\right) + \left(\frac{Do}{Di}\right) \cdot \left(\frac{1}{hid}\right)$$

where

inside film coefficient, $hi := 8000 \cdot \frac{W}{m^2 \cdot K}$

inside dirt coefficient, $hid := 5000 \cdot \frac{W}{m^2 \cdot K}$

outside dirt coefficient, $hod := 3000 \cdot \frac{W}{m^2 \cdot K}$

$$Uo := \left[\left(\frac{1}{ho}\right) + \left(\frac{Do}{Di}\right) \cdot \left(\frac{1}{hi}\right) + \left[\frac{\left(Do \cdot \ln\left(\frac{Do}{Di}\right)\right)}{2 \cdot K\_w}\right] + \left(\frac{1}{hod}\right) + \left(\frac{Do}{Di}\right) \cdot \left(\frac{1}{hid}\right)\right]^{-1}$$

$$Uo = 3.452 \frac{W}{m^2 \cdot K}$$

9. Pressure drop Calculation:

for the tube side

friction factor $f := 0.079 \cdot NRe^{-0.25}$

$f = 0.054$

$$\Delta PL := \frac{\left(4 \cdot f \cdot Lt \cdot Vt^2 \cdot \rho\_w\right)}{2 \cdot Di}$$

$$\Delta PL = 3.866\times 10^{-4}\ \frac{N}{m^2}$$

$$\Delta Pt := 2.5 \cdot \rho\_w \cdot \left(\frac{Vt^2}{2}\right)$$

$$\Delta Pt = 3.323\times 10^{-5}\ \frac{N}{m^2}$$

$$\Delta P\_tube := Np \cdot (\Delta PL + \Delta Pt)$$

$$\Delta P\_tube = 1.679\times 10^{-3}\ \frac{N}{m^2}$$

For shell side

pressure drop in the cross flow section:

$$NRe = 4.73$$

$$b := 2 \cdot 10^{-3}$$

Baffle cut, $Lc := 25\% \cdot Ds$

$$Pp := \left[\frac{(\sqrt{3})}{2}\right] \cdot P$$

$$Pp = 0.027m$$

$$f\_k := 0.2\text{:}$$

$$Nc := Ds \cdot \frac{\left[1 - 2 \cdot \left(\frac{Lc}{Ds}\right)\right]}{Pp}$$

$$Nc = 11.547$$

$$\Delta Pc := \left[\frac{\left(b \cdot f\_k \cdot m\_a^2 \cdot Nc\right)}{\rho\_w \cdot Sm^2}\right] \cdot \left(\frac{\mu\_w}{\mu\_d}\right)^{0.14}$$

$$\Delta Pc = 1.285 \times 10^{-5} \frac{N}{m^2}$$

Pressure drop in end zones

number of cross flow rows in each window, $Ncw := 0.8 \cdot \frac{Lc}{Pp}$

$$Ncw = 4.619$$

$$\Delta Pc := \Delta Pc \cdot \left(1 + \frac{Ncw}{Nc}\right)$$

$$\Delta Pc = 1.799 \times 10^{-5} \frac{N}{m^2}$$

Pressure drop in window zones:

$$b := 5 \cdot 10^{-4}$$

Area for flow through window zone, $Sw = Swg - Swt$

Gross window area, $Swg := 100 \cdot in^2$ $Swg = 0.065 m^2$

Area occupied by tubes,

from the graph in Perry, fig. 10-16 Pg. 10-28

$$Fc := 0.65$$

$$Swt := \left(\frac{Nt}{8}\right) \cdot (1 - Fc) \cdot \pi \cdot Do^2$$

$$Swt = 6.814 \times 10^{-3} m^2$$

$$Sw := Swg - Swt$$

$Sw = 0.058m^2$

$$\Delta Pw := \frac{\left[b \cdot m\_a^2 \cdot (2 \cdot 0.6 \cdot Ncw)\right]}{Sm \cdot Sw \cdot \rho\_d}$$

$$\Delta Pw = 1.19 \times 10^{-6} \frac{N}{m^2}$$

Therefore, the total pressure drop on the shell side is calculated by the following relation

$$\Delta P\_shell := 2 \cdot \Delta Pc + (Nb - 1) \cdot \Delta Pc + Nb \cdot \Delta Pw$$

$$\Delta P\_shell = 2.585 \times 10^{-4} \frac{N}{m^2}$$

Summary of process design for heat exchanger:

mass flow rate of drink: $m\_a = 0.031 kg \cdot s^{-1}$

mass flow rate of water: $m\_w = 1.198 \times 10^{-3} kg \cdot s^{-1}$

shell outer diameter: $Ds = 0.635m$

number of tubes: $Nt = 76.846$

tube outer diameter: $Do = 0.025m$

pitch $P = 0.032m$

tube length: $Lt = 3m$

shell side pressure drop: $\Delta P\_shell = 2.585 \times 10^{-4} \frac{N}{m^2}$

tube side pressure drop: $\Delta P\_tube = 1.679 \times 10^{-3} \frac{N}{m^2}$

6.10 Design of Additive Tank

Type: cone and screw mixer

Material: Steel

Material of construction: Galvanised mild steel

Calculation of flow

The quantity of flow is defined as the amount of fluid that moves axially or radially away from the

impeller at the surface or periphery of rotation. This flow quantity is never actually measured, but its

relative relation to head characterizes the particular system. The flow rate, Q, is usually available $Q = K_1 \cdot N \cdot D^3$

from the manufacturer for a given impeller. In this case, it is given as:

N = speed of rotation, $\frac{rad}{sec}$

D = impeller diameter, m

$K1$ = proportionality constant, a function of the impeller shape

so for this calculation

$K_1 := 0.40$

$Ns := 45 \cdot \frac{rad}{s}$

$D := 0.254 \cdot m$ (Ernest, 1977)

since

$$Q := K_1 \cdot Ns \cdot D^3$$

$$Q = 0.295 m^3 \cdot s^{-1}$$

Calculation of flow number

The flow number is probably the most important dimensionless group used to represent

the actual flow during mixing in a vessel. Flow number, N_Q (or pumping number) is given as:

$$N\_Q = \frac{Q}{Nm \cdot D^3}$$

where Nm = impeller speed of rotation, rad per sec

Q = Flow rate, $\frac{m^3}{sec}$

D = Impeller diameter, m

It shouldbe noted that,

$$Nm := Ns$$

$$Q = 0.295 m^3 \cdot s^{-1}$$

$$N\_Q := \frac{Q}{Nm \cdot D^3}$$

$$N\_Q = 0.4$$

N_Q is strongly dependent on the flow regime, Reynolds Number, NRe, and installation geometry

of the impeller.

Calculation of Reynolds Number for mixing

The Reynolds number(NRe) for mixing is given as

$$NRe = \frac{\left(10.754 \cdot N \cdot D^2 \cdot Sg\right)}{\mu}$$

where

D = impeller diameter, m

Nm = impeller speed, rad/sec

μ = fluid viscosity kg/m.s

r = fluid density, kg/m^3

Sg = fluid specific gravity

Np = power number

Therefore to calculate the Reynolds number,

$$Sg := 0.09 \qquad \mu := 1 \cdot 10^{-2} \cdot \frac{kg}{m \cdot s}$$

$$NRe := \frac{\left[10.754 \cdot \left(\frac{kg}{m^3}\right) \cdot Ns \cdot D^2 \cdot Sg\right]}{\mu}$$

$$NRe = 280.991$$

So since the Reynolds number is less than 300, it shows that the flow is viscous.

Therefore, the power can now be calculated with the formula of viscous flow which is given as outlined

below.

Calculation of power

s

power is the external measure of the mixer performance. the power put into the system

must be absorbed through friction in viscous and turbulent shear stress and dissipated as

heat. The poewr requirment of a system is a function of the impeller shape, size, speed of

rotation, fluid density and viscosity, vessel dimensions and internal attachments, and

position of the impeller in this enclosed system. The power requirments cannat always be $P = Q\rho H$

calculated for any system with a great degree of reliablility. However, for those systems

and/or configurations with known data, good correlation is the result. The relations are for viscous flow, that is, for NRe between 10 to 300, the power is expressed as

$$P = \left(\frac{K_2}{gc}\right) \cdot \mu \cdot N^2 \cdot D^3$$

where K2 is a constant that is obtained from Ernest, 1977

$$gc := \frac{(1 \cdot kg \cdot m)}{newton \cdot s^2}$$

$$K_2 := 41.0($$

$$P := \left(\frac{K_2}{gc}\right) \cdot \mu \cdot Ns^2 \cdot D^3$$

$$P = 13.605 m^2 \cdot kg \cdot s^{-3}$$

Calculation of Froude Number

$$NFr := \frac{\left(D \cdot Ns^2\right)}{g}$$

$$NFr = 52.447$$

Calculation of turbine impeller diameter

assuming that three impellers are used

$$n := 3$$

$$\rho := 1000 \cdot \frac{kg}{m^3}$$

$$D\_T := 137 \cdot \left[\frac{P}{\left(3 \cdot \rho \cdot Ns^3\right)}\right]^{\frac{1}{5}}$$

$$D\_T = 4.744 m$$

Calculations of the geometric dimensions of the additive mixer

$M\_drink := 2044.53 \cdot \frac{kg}{day}$ $M\_water := 535.68 \cdot \frac{kg}{day}$ $M\_additive := 129.01 \cdot \frac{kg}{day}$

$V\_drink := \frac{M\_drink}{D\_drink}$ $V\_water := \frac{M\_water}{D\_water}$ $D\_additive := 1316 \cdot \frac{kg}{m^3}$

$V\_drink = 2.405 \frac{m^3}{day}$ $V\_water = 0.536 \frac{m^3}{day}$ $V\_additive := \frac{M\_additive}{D\_additive}$

$V\_additive = 0.098 \frac{m^3}{day}$

$V := V\_drink + V\_water + V\_additive$

$V = 3.039 \frac{m^3}{day}$

with $clearance := 15\% \cdot V$ at the top of the tank

$V\_additive\_tank := V + clearance$

$V\_additive\_tank = 3.495 \frac{m^3}{day}$

mathematically the volume of the additive tank is given by

$$V\_additive\_tank = \pi \cdot R\_additive\_tank^2 \cdot H\_additive\_tank$$

and

$$R\_additive\_tank = \frac{D\_additive\_tank}{2}$$

$$V\_additive\_tank = \pi \cdot \left(\frac{D\_additive\_tank}{2}\right)^2 \cdot H\_additive\_tank$$

$$V\_additive\_tank = \pi \cdot \left(\frac{D\_additive\_tank^2}{4}\right) \cdot H\_additive\_tank$$

assuming

$$\left(\frac{H\_additive\_tank}{D\_additive\_tank}\right) = k$$

then

$$H\_additive\_tank = k \cdot D\_additive\_tank$$

substituting for H,

$$V\_additive\_tank = \pi \cdot \left(\frac{D\_additive\_tank^2}{4}\right) \cdot k \cdot D\_additive\_tank$$

$$4 \cdot V\_additive\_tank = k \cdot \pi \cdot D\_additive\_tank^3$$

$$D\_additive\_tank^3 = \frac{(4 \cdot V\_additive\_tank)}{k \cdot \pi}$$

$$D\_additive\_tank = \left[\frac{(4 \cdot V\_additive\_tank)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

taking $k := 2$

$$D\_additive\_tank := \left[\frac{(4 \cdot V\_additive\_tank \cdot day)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

$$D\_additive\_tank = 1.305m$$

$$H\_additive\_tank := k \cdot D\_additive\_tank$$

$$H\_additive\_tank = 2.611\,m$$

The area is calculated to be

$$A\_additive\_tank := 2\pi \cdot \left(\frac{D\_additive\_tank}{2}\right) \cdot H\_additive\_tank + \left(\frac{D\_additive\_tank}{2}\right)^2$$

$$A\_additive\_tank = 11.134m^2$$

6.11 Design of Carbonator

The quantities of the materials going into the thank have been obtained from the material balances

around the tank to be

$M\_drink := 2044.53 \cdot \frac{kg}{day}$ $M\_water := 535.68 \cdot \frac{kg}{day}$ $M\_additive := 129.01 \cdot \frac{kg}{day}$

$V\_drink := \frac{M\_drink}{D\_drink}$ $V\_water := \frac{M\_water}{D\_water}$ $V\_additive := \frac{M\_additive}{D\_additive}$

$V\_drink = 2.405 \frac{m^3}{day}$ $V\_water = 0.536 \frac{m^3}{day}$ $V\_additive = 0.098 \frac{m^3}{day}$

$V := V\_drink + V\_water + V\_additive$

$V = 3.039 \frac{m^3}{day}$

with $clearance := 15\% \cdot V$ at the top of the carbonator

$V\_carbonator := V + clearance$

$V\_carbonator = 3.495 \frac{m^3}{day}$

Mathematically the volume of the carbonator is

$V\_carbonator = \pi \cdot R\_carbonator^2 \cdot H\_carbonator$

and

$$R\_carbonator = \frac{D\_carbonator}{2}$$

$$V\_carbonator = \pi \cdot \left(\frac{D\_carbonator}{2}\right)^2 \cdot H\_carbonator$$

$$V\_carbonator = \pi \cdot \left(\frac{D\_carbonator^2}{4}\right) \cdot H\_carbonator$$

assuming that

$$\frac{H\_carbonator}{D\_carbonator} = k$$

then ,

$$H\_carbonator = k \cdot D\_carbonator$$

substituting for H,

$$V\_carbonator = \pi \cdot \left(\frac{D\_carbonator^2}{4}\right) \cdot k \cdot D\_carbonator$$

$$4 \cdot V\_carbonator = k \cdot \pi \cdot D\_carbonator^3$$

$$D\_carbonator^3 = \left(4 \cdot \frac{V\_carbonator}{k \cdot \pi}\right)$$

$$D\_carbonator = \left(4 \cdot \frac{V\_carbonator}{k \cdot \pi}\right)^{\frac{1}{3}}$$

taking $k := 2$

$$D\_carbonator := \left[\frac{(4 \cdot V\_carbonator \cdot day)}{k \cdot \pi}\right]^{\frac{1}{3}}$$

$$D\_carbonator = 1.305m$$

$$H\_carbonator := k \cdot D\_carbonator$$

$$H\_carbonator = 2.611m$$

The Area is thus calculated to be

$$A\_carbonator := 2\pi \cdot \left(\frac{D\_carbonator}{2}\right) \cdot H\_carbonator + 2\pi \cdot \left(\frac{D\_carbonator}{2}\right)^2$$

$$A\_carbonator = 13.385\,m^2$$

CHAPTER SEVEN

7.0 EQUIPMENT OPTIMIZATION

7.1 Optimization of extractor

In optimizing the first step is clearly to define the objective; that is, the criterion to be used to

judge the performance of the system. In engineering design, the objective of optimizing any equipment must be an economical one. This is because for any chemical plant set up, the primary

objective is to maximize the profit. This can be approached based on the fact that, in order to

minimize cost of construction. For the ectractor, the total surface area is given as

$$A\_extractor = 2 \cdot \pi \cdot R\_extractor^2 + 2 \cdot \pi \cdot R\_extractor \cdot H\_extractor$$

and

$$R\_extractor = \frac{D\_extractor}{2}$$

where $R\_extractor$ = "radius of the extractor tube"

$D\_extractor$ = "diameter of the extractor"

$H\_extractor$ = "height of the extractor"

π = "pie, a constant"

so the formular becomes

$$A\_extractor = 2 \cdot \pi \cdot \left(\frac{D\_extractor}{2}\right)^2 + 2\pi \cdot \left(\frac{D\_extractor}{2}\right) \cdot H\_extractor$$

$$A\_extractor = 2\pi \cdot \left(\frac{D\_extractor^2}{4}\right) + 2\pi \cdot \left(\frac{D\_extractor}{2}\right) \cdot H\_extractor$$

$$A\_extractor = \pi \cdot \left(\frac{D\_extractor^2}{2}\right) + \pi \cdot D\_extractor \cdot H\_extractor$$

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

$$A\_extractor = f(D\_extractor, H\_extractor)$$

where the objective function is

$$A\_extractor = \pi \cdot \left(\frac{D\_extractor^2}{2}\right) \cdot \pi \cdot D\_extractor \cdot H\_extractor$$

and the constraints are

$D = D\_minimun$ and $H = H\_minimun$

so that the equation becomes

$$f(D\_extractor, H\_extractor) = \pi \cdot \left(\frac{D\_extractor^2}{2}\right) \cdot \pi \cdot D\_extractor \cdot H\_extractor$$

noting that the volume of the equipment is given as

$$V\_extractor = \pi \cdot R\_extractor^2 \cdot H\_extractor$$

with

$$R\_extractor = \frac{D\_extractor}{2}$$

$$V\_extractor = \pi \cdot \left(\frac{D\_extractor}{2}\right)^2 \cdot H\_extractor$$

$$V\_extractor = \pi \cdot \left(\frac{D\_extractor^2}{4}\right) \cdot H\_extractor$$

making the height subject of the formular becomes

$$H\_extractor = \frac{(4 \cdot V\_extractor)}{\pi \cdot D\_extractor^2}$$

$$f(D\_extractor, H\_extractor) = \pi \cdot \left(\frac{D\_extractor^2}{2}\right) \cdot \pi \cdot D\_extractor \cdot \frac{(4 \cdot V\_extractor)}{\pi \cdot D\_extractor^2}$$

simplifying

$$f(D\_extractor, H\_extractor) = \pi \cdot \left(\frac{D\_extractor^2}{2}\right) \cdot \pi \cdot \frac{(4 \cdot V\_extractor)}{\pi \cdot D\_extractor}$$

It can now be seen that from the above equation that the area is a function of the diameter if the

volume is kept constant.

The above expression is now the optimized diameter of the equipment

from,

$$f(D\_extractor) = \pi \cdot \left(\frac{D\_extractor^2}{2}\right) \cdot \pi \cdot \frac{(4 \cdot V\_extractor)}{\pi \cdot D\_extractor}$$

differentiating the above equation yields

$$\left(\frac{d}{d(D\_extractor}\right) f(D\_extractor) = \pi \cdot D\_extractor - \left(\frac{4}{D\_extractor^2}\right) \cdot V\_extractor$$

At optimum point, the derivative is equated to zero, that is

$$\left(\frac{d}{d(D\_extractor}\right) f(D\_extractor) = \pi \cdot D\_extractor - \left(\frac{4}{D\_extractor^2}\right) \cdot V\_extractor = 0$$

taking the last two expressions,

$$\pi \cdot D\_extractor - \left(\frac{4}{D\_extractor^2}\right) \cdot V\_extractor = 0$$

$$\pi \cdot D\_extractor = \left(\frac{4}{D\_extractor^2}\right) \cdot V\_extractor$$

$$D\_extractor^2 \cdot D\_extractor = \frac{(4 \cdot V\_extractor)}{\pi}$$

$$D\_extractor^3 = \frac{(4 \cdot V\_extractor)}{\pi}$$

$$D\_extractor = \sqrt[3]{\left[\frac{(4 \cdot V\_extractor)}{\pi}\right]}$$

$$H\_extractor = \frac{(4 \cdot V\_extractor)}{\pi \cdot D\_extractor^2}$$

substituting for $D\_extractor$ *in this* expression yeilds

$$H\_extractor = \frac{(4 \cdot V\_extractor)}{\pi \cdot \left[\sqrt[3]{\left[\frac{(4 \cdot V\_extractor)}{\pi}\right]}\right]^2}$$

simplifying

$$H\_extractor = \left(\frac{V\_extractor^{\frac{1}{3}}}{\pi^{\frac{1}{3}}}\right) \cdot \sqrt[3]{2^2}$$

Numerically with

$$V\_extractor := 3.555 \cdot \frac{m^3}{day}$$

$$D\_extractor := \sqrt[3]{\frac{(4 \cdot V\_extractor \cdot day)}{\pi}}$$

$$D\_extractor = 1.654m$$

$$H\_extractor := \left[\frac{(V\_extractor \cdot day)^{\frac{1}{3}}}{\pi^{\frac{1}{3}}}\right] \cdot \sqrt[3]{2^2}$$

$$H\_extractor = 1.654\,m$$

It therefore means that the optimum diameter and height of the equipment are

$$D\_extractor = 1.654\,m$$

$$H\_extractor = 1.654\,m$$

CHAPTER EIGHT

8.0 SAFETY AND QUALITY CONTROL

8.1 Safety

Safety is an area of engineering and public health that deals with the protection of workers health, through control of the work environment to reduce or eliminate hazards. Industrial accidents and unsafe working conditions can result in temporary or permanent injury, illness, or even death. They also take a toll in reduced efficiency and loss of productivity. (Encarta, 2009)

8.I.I General Safety Rules Follow relevant instructions

a) Before attempting to operate the plant, all relevant manufacturer's instructions and local regulations should be understood and implemented.

b) It is irresponsible and dangerous to misuse equipment or ignore instruction, regulations or warnings.

c) The specified maximum operating conditions must not be exceeded. (Odigure. 1998)

Operation

a. It must be ensured that all staff must be fully aware of the potential hazards when the plant is being operated.

b. Serious injury can result from touching apparently stationary equipment or rotating belt.

c. No metallic object should be allowed into the plant. Otherwise, the gear motor of the affected conveyor must be set in the reverse direction and discharge the entrained materials.

Maintenance

a) A badly maintained plant is a potential hazard. It must be ensured that competent members of staff is responsible for organizing maintenance and repairs on a planned basis.

b) Faulty equipment must be permitted to be operated. Repairs must be carried out competently and the operation must be checked. (Odigure, 1998)

Using electricity

a) At least once a month, the electrical cables should be checked to ensure that they are operating normally.

b) Electricity is the commonest cause of accidents in the factory, it must be respected.

c) It must be ensured that electricity supply has been disconnected from the equipment before attempting repairs or adjustment.

d) It must be known that water and electricity are not compatible and can cause serious injury if they come into contact.

e) The plant must always be disconnected from electricity when not in use. (Odigure, 1998)

Avoiding fire or explosion

i. It must be ensured that the factory is provided with adequate fire extinguishers appropriate to the potential dangers.

ii. It must be known that empty vessels having inflammable liquids can contain vapours and explode if ignited.

Handling poisons or toxic materials

a) Food must not be allowed to be brought into or consumed in the factory.

b) Smoking should not be allowed in the factory premises. Notices should be so displayed and enforced. (Odigure, 1998)

Avoiding cuts and burns

a) Care must be taken when handling sharp edged components. Undue force must not be exerted on glass or fragile items.

b) Hot surfaces cannot, in most cases, be totally shielded and can produce severe burns even when not "visibly hot". Common sense must be used always!

Eye protection

a) Facilities for eye irritation should always be available

Ear protection

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

Guard and safety devices

a) Guards and safety devices must be installed on the plant to protect the operators. The equipment must not be operated with such devices removed.

b) Safety gauges, cut-out and other safety devices must be set to protect the equipment. Interference with these devices may create a potential hazard.

c) It is impossible to guard the operator against all contingencies. Common sense 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 Organization (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 reject able as well as acceptable products can be produced at high rates.

8.2.1 Quality assurance

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

8.2.1.1 Principles of quality assurance

The principles of quality assurance include the following:

i. Management involvements and objective (management) involvement is very essential to ensure quality.

ii. Programming and planning.

iii. Application of quality control principles.

iv. Design and specification control.

v. Purchasing control and vendor appraisal.

vi. Production control.

vii. Marketing and service quality functions.

viii. Proper documentation.

ix. Non-conformance control.

x. Remedial action.

xi. Defect and failure analysis.

8.2.1.2 Quality management

Quality management involves all activities of the overall management functions that determine the quality policy, objective and responsibilities and implement 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.

CHAPTER NINE

9.0 PROCESS CONTROL AND INSTRUMENTATION

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

9.1 Types of control instruments

The control instruments are of four major categories

a) Temperature controllers (TC)

b) Pressure controller (PC)

c) Flow controller (FC)

d) Level controller (LC)

9.2 Control Mechanism

The pneumatic control hardware is recommended for this process it will be powered by instrument air supplies.The control mechanism for this process consist of a sensor to detect the process variables; a transmitter to convert the sensor into an equivalent "signal" a controller that compares this process signal with a desired set point value and produces an appropriate controller output signal and a final control element (pneumatic activator) that changes the manipulated variable with the use of a mechanical action.

9.3 Control Sensors

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

1) Flow sensor: The orifice meter can be employed in the process since it is simple and of low cost.

2) Temperature sensor: The recommended temperature sensors are resistance thermometer detectors (RTDS) and Thermocouples. The l00v pt (-2000C to 850C) and type N (0-13000) are both sufficient for RTDS and thermocouples respectively.

3) Pressure sensors: Bourdon - Tube pressure gauge can be used.

4) Level sensor: float activated devices are sufficient.

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

9.4 Transmitters, Controllers and Control Valves

The transmitter is the inter-phase between the process and 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 most 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.

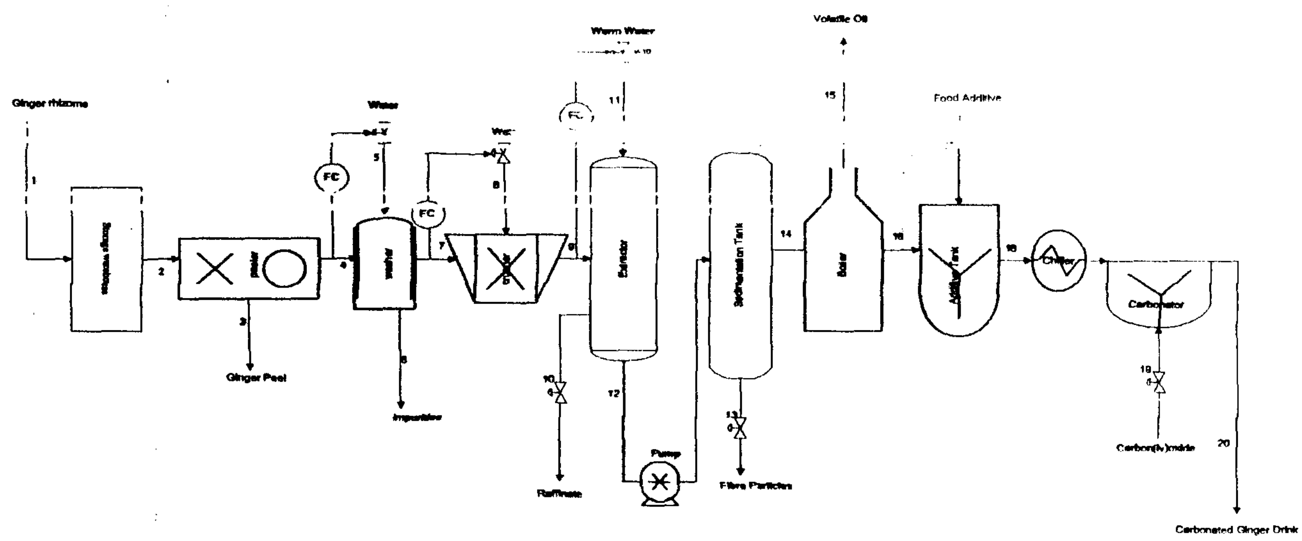


Fig. 9.1 Control of plant for the production of carbonated ginger drink

CHAPTER TEN

10.0 ENVIRONMENTAL ACCEPTABILITY

Any new project or technology involving hazardous materials requires a rational approach of assessing the suitability and acceptability to the environment and man. (Giwa, 2004).

Various legislations govern the emission of pollutants into the environment. The environmental friendliness of the process choice adopted from the design process is of utmost importance to the relevant government agencies responsible for environmental protection. Awareness of the relevant federal regulations is an essential component of a legally acceptable plant design. (Giwa, 2004).

10.1 Identification of Possible Pollutants

The possible pollutant in this plant is carbon dioxide (CO_2). This can emanate from the leakages from the carbonator during the process carbonating the drink.

10.2 Suggestions on the Treatment of the Pollutants

It is suggested that the carbonator should be well fitted so that leakages can be avoided and hence, carbon dioxide pollution can be avoided. In case of the pollution, the carbon dioxide can be absorbed using water.

CHAPTER ELEVEN

11.0 START UP AND SHUT DOWN PROCEDURE

Start up time may he 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 plant should be such that it can be easily and safely operated. The operating limits of the plant should not be exceeded and dangerous mixtures must not be formed as a result of abnormal states of concentration, composition, temperature, phase, pressure, reactants and products.

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

i. All scaffolds and temporary piping and supports should be removed.

ii. Lines and equipment should be flushed out.

iii. Pumps, motors/turbines and compressors should be run.

iv. Hydrostatic or pneumatic lines and equipment should be tested.

v. Laboratory and sampling schedule should be prepared.

vi. All instruments should be inspected and tested.

11.1 Start Up Procedures

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

i. The heat exchanger should be started up using auxiliary fuel to begin production.

ii. The extractor should be heated up and maintained at their operating temperatures and pressures.

iii. The inlet and outlet valves of the reactors should be opened up.

iv. The compressor valve to supply air at a regulated pressure should be opened.

v. All the inlet and outlet valves to the reactor should be shut as soon as the feed enters the reactor in order to achieve maximum extraction.

vi. The outlet value of the reactor should be opened for the evacuation of the reactor contents.

vii. The outlet valve of the reactor should be locked before opening the inlet valve before further entering of the feed into the reactor.

11.2 Shut Down Procedures

The shut down procedures for the plant are as outlined below

i. The supply of ginger into the crusher should be stopped

ii. The supply of the carbon dioxide to the carbonator should be cut off.

iii. The water supply to the washer for the washing should also be terminated,

iv. The supply of warm water into the extractor should be stopped.

v. The supply of heat to the boiler for boiling the juice should also be cut off.

CHAPTER TWELVE

12.0 SITE FOR PLANT LOCATION

The location of the plant can have a crucial effect on the profitability of the project and the scope for future expansion. Many factors must be considered when selecting a suitable site, and they are as outlined below:

i. Location, with respect to the marketing area.

ii. Raw materials supply.

iii. Transport facilities.

iv. Availability of labour.

v. Availability of utilities.

vi. Availability of suitable land.

vii. Environmental impact and effluent disposal.

viii. Local community considerations.

ix. Climate.

x. Political and strategic considerations.

12.1 Factors Considered for Site and Plant Location

The factors considered for site and plant location are as described thus.

12.1.1 Location, with respect to the marketing area

For a material produced in bulk quantities where the cost of the product per tone is relatively low and the cost of transport is a significant fraction of the sales price, the plant should be located close to the primary market. This consideration will be less important for low volume production, high-priced products; such as pharmaceuticals.

12.1.2 Raw materials

The availability and price of suitable raw materials will often determine the site location. A plant producing bulk materials like the ginger drink is best located close to the source of the major raw materials where this is also close to the marketing area.

12.1.3 Transport

The transport of materials and products to and from the plant will be an overriding consideration for site selection. If practicable, a site should be selected that is close to at least tow major forms of transport: road, rail, waterway (canal or river), or a sea port. Road transport is being increasingly used, and is suitable for local distribution from a central warehouse. Rail transport will be cheaper for the long-distance transport of bulk chemicals. Air transport is convenient and efficient for the movement of personnel and essential equipment and supplies, and the proximity of the site to a major airport should be considered.

12.1.4 Availability of labour

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

12.1.5 Utilities (Services)

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

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

12.1.6 Environmental impact and effluent disposal

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

12.1.7 Local community considerations

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

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

12.1.8 Availability of suitable land

Sufficient suitable land must be available for the proposed plant and for future expansion. The land should be ideally flat, well drained and have suitable load bearing capacity. A full site evaluation should be made to determine the need for pining or other special foundations. It should also be available at low cost.

12.1.9 Climate

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

12.1.10 Political and strategic consideration

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

12.2 Selection of Site

Careful consideration of the factors for the site selection outlined above reveals that the best site for this project is the suburb of Niger State.

12.3 Justification of the Selected Site

Actually, the site selected based on the fact that it satisfied more than 75% of the factors considered. For instance, it is close to the source and market apart from having good road network.

CHAPTER THIRTEEN

13.0 ECONOMIC ANALYSIS

13.1 Purchase Equipment cost

13.1.1 Purchase cost of warehouse

$er := 147$ $\quad Naira := 1$

$M\_S := 110($ $\quad Fm := 1$ $\quad Fp := 1$ $\quad Fc := Fm \cdot Fp$

$B\_house := 1.139 \cdot m$ $\quad H\_house := 1.139 \cdot m$

$$PC\_house := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{B\_house}{ft}\right)^{1.066} \cdot \left(\frac{H\_house}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_house = 6.905 \times 10^{5} \cdot Naira$

13.1.2 Purchase cost of Peeler

$M\_S := 110($ $\quad Fm := 1$ $\quad Fp := 1$ $\quad Fc := Fm \cdot Fp$

$D\_peeler := 1.234 \cdot m$ $\quad H\_peeler := 2.439 \cdot m$

$$PC\_peeler := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D\_peeler}{ft}\right)^{1.066} \cdot \left(\frac{H\_peeler}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_peeler = 1.385 \times 10^{6} \cdot Naira$

13.1.3 Purchase cost of washer

$M\_S := 110($ $\quad Fm := 1$ $\quad Fp := 1$ $\quad Fc := Fm \cdot Fp$

$D\_washer := 1.261 \cdot m$ $\quad H\_washer := 2.522 \cdot m$

$$PC\_washer := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D\_washer}{ft}\right)^{1.066} \cdot \left(\frac{H\_washer}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_washer = 1.456\times 10^{6} \cdot Naira$

13.1.4 Purchase cost of crusher

$M\_S := 110($ $\quad Fm := 1 \quad Fp := 1 \quad Fc := Fm \cdot Fp$

$D\_crusher := 1.261 \cdot m \qquad H\_crusher := 2.521 \cdot m$

$$PC\_crusher := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D\_crusher}{ft}\right)^{1.066} \cdot \left(\frac{H\_crusher}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_crusher = 1.455\times 10^{6} \cdot Naira$

13.1.5 Purchase cost of extractor

$M\_S := 110($ $\quad Fm := 1 \quad Fp := 1 \quad Fc := Fm \cdot Fp$

$D\_extractor := 1.313 \cdot m \qquad H\_extractor := 2.626 \cdot m$

$$PC\_extractor := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D\_extractor}{ft}\right)^{1.066} \cdot \left(\frac{H\_extractor}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_extractor = 1.57\times 10^{6} \cdot Naira$

13.1.6 Purchase cost of pump

$C\_pump := 96($ $\qquad pump\_power := 0.013 \cdot kW$

$S\_pump := \dfrac{pump\_power}{kW} \qquad n\_pump := 0.8$

$PC\_pump := C\_pump \cdot S\_pump^{n\_pump} \cdot er \cdot Naira$

$PC\_pump = 4.373\times 10^{3} \cdot Naira$

13.1.7 Purchase cost of sedimentation tank

$M\_S := 110($ $\quad Fm := 1$ $\quad Fp := 1$ $\quad Fc := Fm \cdot Fp$

$D\_sed\_tank := 0.039 \cdot m$ $\quad H\_sed\_tank := 0.077 \cdot m$

$$PC\_sed\_tank := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D\_sed\_tank}{ft}\right)^{1.066} \cdot \left(\frac{H\_sed\_tank}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_sed\_tank = 2.181 \times 10^{3} \cdot Naira$

13.1.8 Purchase cost of boiler

$kJ := 1000 \cdot J$

$M\_S := 110($ $\quad Fm := 1$ $\quad Fp := 1$ $\quad Fc := Fm \cdot Fp$

$Q\_boiler := 9.424 \cdot 10^{3} \cdot \frac{kJ}{day}$

$$PC\_boiler := \left(\frac{M\_S}{280}\right) \cdot \left[5520 \cdot \left(\frac{|Q\_boiler|}{10^{6} \cdot \frac{BTU}{hr}}\right)^{0.83} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_boiler = 4.542 \times 10^{3} \cdot Naira$

13.1.9 Purchase cost of additive tank

$M\_S := 110($ $\quad Fm := 1$ $\quad Fp := 1$ $\quad Fc := Fm \cdot Fp$

$D\_additive\_tank := 1.305 \cdot m$ $\quad H\_additive\_tank := 2.611 \cdot m$

$$PC\_additive\_tank := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D\_additive\_tank}{ft}\right)^{1.066} \cdot \left(\frac{H\_additive\_tank}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$PC\_additive\_tank = 1.553 \times 10^{6} \cdot Naira$

13.1.10 Purchase cost of chiller

$M\_S := 110($ $\quad Fm := 1 \quad Fp := 1 \quad Fc := Fm \cdot Fp$

$$Q\_chiller := -1.515 \cdot 10^{4} \frac{kJ}{day}$$

$$PC\_chiller := \left(\frac{M\_S}{280}\right) \cdot \left[5520 \cdot \left(\frac{|Q\_chiller|}{10^{6} \cdot \frac{BTU}{hr}}\right)^{0.83} \cdot Fc\right] \cdot er \cdot Naira$$

$$PC\_chiller = 6.735 \times 10^{3} \cdot Naira$$

13.1.11 Purchase cost carbonator

$M\_S := 110($ $\quad Fm := 1 \quad Fp := 1 \quad Fc := Fm \cdot Fp$

$D\_carbonator := 1.305 \cdot m \qquad H\_carbonator := 2.611 \cdot m$

$$PC\_carbonator := \left(\frac{M\_S}{280}\right) \cdot \left[101.9 \cdot \left(\frac{D\_carbonator}{ft}\right)^{1.066} \cdot \left(\frac{H\_carbonator}{ft}\right)^{0.802} \cdot Fc\right] \cdot er \cdot Naira$$

$$PC\_carbonator = 1.553 \times 10^{6} \cdot Naira$$

total purchase cost of equipments

$$PC\_total := PC\_house + PC\_peeler + PC\_washer + PC\_crusher + PC\_extractor + PC\_pump \ldots + PC\_sed\_tank + PC\_boiler + PC\_additive\_tank + PC\_carbonator$$

$$PC\_total = 9.674 \times 10^{6} \cdot Naira$$

ESTIMATION OF TOTAL CAPITAL INVESTMENT

1. Direct costs

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

1. purchased equipment cost (PEC), as calculated

$PEC := PC\_total$

$PEC = 9.674 \times 10^{6} \cdot Naira$

2. installation, including insulation and painting, 25-55 % of PEC, assuming

$insta := 40\% \cdot PEC$

$insta = 3.87 \times 10^{6} \cdot Naira$

3. instrumentation and controls, installed, 6-30 % of PEC, assuming

$instr := 11\% \cdot PEC$

$instr = 1.064 \times 10^{6} \cdot Naira$

4. piping installed, 10-80 % of PEC, assuming

$pip := 30\% \cdot PEC$

$pip = 2.902 \times 10^{6} \cdot Naira$

5. electrical, installed, 10-40 % of PEC, assuming

$elect := 15\% \cdot PEC$

$elect = 1.451 \times 10^{6} \cdot Naira$

$CA := PEC + insta + instr + pip + elect$

$CA = 1.896 \times 10^{7} \cdot Naira$

B. buildings, process and auxiliaryb 10-70 % of PEC, assuming

$$build := 20\% \cdot PEC$$

$$build = 1.935\times 10^{6} \cdot Naira$$

C. service facilities and yard improvements, 40-100 % of PEC, assuming

$$serv := 50\% \cdot PEC$$

$$serv = 4.837\times 10^{6} \cdot Naira$$

D. land, 4-8 % of PEC, assuming

$$land := 5\% \cdot PEC$$

$$land = 4.837\times 10^{5} \cdot Naira$$

Thus

$$Direct\_cost := CA + build + serv + land$$

$$Direct\_cost = 2.622\times 10^{7} \cdot Naira$$

II. indirect cost

A. engineering and supervision, 5-30 % direct cost, assuming

$$engin := 13\% \cdot Direct\_cost$$

$$engin = 3.408\times 10^{6} \cdot Naira$$

B. construction expense and contractor fee, 6-30 % of direct cost, assuming

$$const := 15\% \cdot Direct\_cost$$

$$const = 3.932\times 10^{6} \cdot Naira$$

C. contingency, 5-15 % of direct cost, assuming

$$conti := 7\% \cdot Direct\_cost$$

$$conti = 1.835\times 10^{6} \cdot Naira$$

thus

$$Indirect\_cost := engin + const + conti$$

$$Indirect\_cost = 9.176\times 10^{6}\cdot Naira$$

III. fixed capital investment

$$Fixed\_CI := Direct\_cost + Indirect\_cost$$

$$Fixed\_CI = 3.539\times 10^{7}\cdot Naira$$

IV. working capital, 11-20 % of fixed capital investment, assuming

$$Working\_C := 11\% \cdot Fixed\_CI$$

$$Working\_C = 3.893\times 10^{6}\cdot Naira$$

V. Total Capital Investment (TCI)

$$TCI := Fixed\_CI + Working\_C$$

$$TCI = 3.928\times 10^{7}\cdot Naira$$

ESTIMATION OF TOTAL PRODUCT COST

1. Manufacturing cost

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

i. Depreciation, assuming

$$depre := 10\% \cdot Fixed\_CI + 3\% \cdot build$$

$$depre = 3.597\times 10^{6}\cdot Naira$$

ii. Local taxes, 1-4 % of FCI, assuming

$$tax := 3.5\% \cdot Fixed\_CI$$

$$tax = 1.239\times 10^{6}\cdot Naira$$

iii. Insurance, 0.4-1 % of FCI, assuming

$$insur := 0.6\% \cdot Fixed\_CI$$

$$insur = 2.123 \times 10^{5} \cdot Naira$$

iv. Rent, 8-12 % of FCI, assuming

$$rent := 10\% \cdot Fixed\_CI$$

$$rent = 3.539 \times 10^{6} \cdot Naira$$

thus

$$Fixed\_charges := depre + tax + insur + rent$$

$$Fixed\_charges = 8.587 \times 10^{6} \cdot Naira$$

B. Direct production cost (operating cost)

fixed charges is 10-20 % of total product cost

assuming $$Fixed\_charges = 15\% \cdot TPC$$

$$TPC := \frac{Fixed\_charges}{15\%}$$

$$TPC = 5.725 \times 10^{7} \cdot Naira$$

i. Raw materials, 10-50 % of TPC, assuming

$$Raw\_mat := 15\% \cdot TPC$$

$$Raw\_mat = 8.587 \times 10^{6} \cdot Naira$$

ii. Operating labour (OL), 10-20 % of TPC, assuming

$$OL := 10\% \cdot TPC$$

$$OL = 5.725 \times 10^{6} \cdot Naira$$

iii. Direct supervisory and clerical labour (DS & CL), 10-25 % of OL, assuming

$$DS := 15\% \cdot OL$$

$$DS = 8.587\times 10^5 \cdot Naira$$

iv. Utilities, 10-20% of TPC, assuming

$$util := 12.5\% \cdot TPC$$

$$util = 7.156\times 10^6 \cdot Naira$$

v. Maintenance and repairs (M&R), 2-10 % of FCI, assuming

$$maint := 3.7\% \cdot Fixed\_CI$$

$$maint = 1.309\times 10^6 \cdot Naira$$

vi. Operating supplies, 10-20 % of M&R , assuming

$$OS := 17\% \cdot maint$$

$$OS = 2.226\times 10^5 \cdot Naira$$

vii. Laboratory charges, 10-20 % of OS, assuming

$$lab := 15\% \cdot OS$$

$$lab = 3.339\times 10^4 \cdot Naira$$

viii. Patent and royalties, 0-6 % of TPC, assuming

$$paten := 4.5\% \cdot TPC$$

$$paten = 2.576\times 10^6 \cdot Naira$$

Thus

$$DPC := Raw\_mat + OL + DS + util + maint + OS + lab + paten$$

$$DPC = 2.647\times 10^7 \cdot Naira$$

C. Plant overhead costs

$$Plant\_Overhead := 55\% \cdot (OL + DS + maint)$$

$$Plant\_Overhead = 4.341\times 10^{6} \cdot Naira$$

Manufacturing cost is therefore:

$$Manuf := DPC + Fixed\_charges + Plant\_Overhead$$

$$Manuf = 3.94\times 10^{7} \cdot Naira$$

II. General expenses

A. Administrative costs, 2-6 % of TPC, assuming

$$admin := 3\% \cdot TPC$$

$$admin = 1.717\times 10^{6} \cdot Naira$$

B. Distribution and selling costs, 2-20 % of TPC, assuming

$$distr := 11\% \cdot TPC$$

$$distr = 6.297\times 10^{6} \cdot Naira$$

C. Research and development costs, about 5 % TPC, assuming

$$resea := 5\% \cdot TPC$$

$$resea = 2.862\times 10^{6} \cdot Naira$$

D. Financing (interest), 0-10 % of TCI, assuming

$$interest := 5\% \cdot TCI$$

$$interest = 1.964\times 10^{6} \cdot Naira$$

Thus General expenses

$$Gen := admin + distr + resea + interest$$

III. Total Product Cost

$TProdC := Manuf + Gen$

$TProdC = 5.224\times 10^{7} \cdot Naira$

V. Gross Earnings/income (revenue expectations):

the selling price of the product is

$Selling\_price := 67.0 \cdot \frac{Naira}{kg}$

$Quantity\_produced := 2750.00 \cdot \frac{kg}{day}$

$Attainment := 312 \cdot day$

$Total\_income := Selling\_price \cdot Quantity\_produced \cdot Attainment$

$Total\_income = 5.749\times 10^{7} \cdot Naira$

$Gross\_income := Total\_income - TPC$

$Gross\_income = 2.367\times 10^{5} \cdot Naira$

Tax rate is 45% of gross income

$taxes := 45\% \cdot Gross\_income$

$taxes = 1.065\times 10^{5} \cdot Naira$

$Net\_profit := Gross\_income - taxes$

$Net\_profit = 1.302\times 10^{5} \cdot Naira$

Rate Of Return

$ROR := \left(\frac{Net\_profit}{TCI}\right) \cdot 10($

$$ROR = 33.14 \cdot \%$$

$$Cash\_flow := Total\_income - TProdC$$

$$Cash\_flow = 5.247 \times 10^{6} \cdot Naira$$

Pay Back Period

$$PBP := \left(\frac{1}{ROR}\right) \cdot yr$$

$$PBP = 3.018 \cdot yr$$

Return On Investment

$$ROI = \frac{Total\_profit\_less\_depreciation}{Total\_investment}$$

Thus

$$ROI := \left[\frac{(Total\_income - depre)}{Total\_income}\right] \cdot 100\%$$

$$ROI = 93.742 \cdot \%$$

13.8 CONCLUSION ON THE ECONOMIC VIABILITY OF THE PROJECT

The total production cost of the plant which is TProdC=52,240,000 Naira and a net profit of 130,200 Naira have revealed that the project is Economically viable with a payback period of 3.018years.

CHAPTER FOURTEEN

14.0 RECOMMENDATIONS TO THE INDUSTRIALIST

14.1 General Recommendations

Having carried out the design of the plant for the production of carbonated ginger drink, the following recommendations are made to the industrialists to be noted during the construction, start-up and operational phases of the plant:

i. The safety of workers, equipments and infrastructures should be highly evaluated during the design implementation stage of the design.

ii. Adequate data and technological parameters should be at the possession of the plant operations at all time to forestall any unwanted accident.

iii. Routine turn around plant maintenance should be of paramount importance in the design. An articulate and organized maintenance team should safeguard quick plant shut down and ensure equipment salvage value.

iv. Personnel should undergo routine training about new work ethic and equipments to improve their knowledge of the plant operation and increase overall plant productivity.

v. Procurement of raw materials and equipments should be based on strict regulation of specification and maximum quality.

vi. Plant should not be operated above the design specification to avoid abnormal conditions and explosions.

vii. The implementation of this design work must be adequately supervised by the experts.

viii. The plant should be sited close to the source of raw materials.

ix. Alternative sources of energy should be available at all times to avoid plant failure and possible sources of failure.

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