DESIGN OF A PLANT FOR THE EXTRACTION OF 100,000 LITRES PER ANNUM OF GINGER OIL BY STEAM DISTILLATION.

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF ENGINEERING (B.ENG)

NOVEMBER, 2007.

DECLARATION

I state the authencity of this work carried out by myself under supervision in the Department of Chemical Engineering, Federal University of Technology Minna.

The work of other researchers referred to was duly acknowledged. No part of this project has been previously submitted for the award of a degree.

22/12/07

Folasade G.A

Date

CERTIFICATION

The project is an original work carried out by Folasade Gabriel A. under the supervision of Prof. K.R. Onifade and meets the regulations and requirements for the award of Bachelors degree in Chemical Engineering awarded by the Federal University of Technology Minna and is approved for its literary presentation and contribution to scientific knowledge.

Prof K.R. Onifade
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Date

External Examiner

Date

DEDICATION

This work is dedicated to God Almighty who has been my sustainer and to my parents, Mr. & Mrs. S.A. Folasade.

ACKNOWLEDGEMENT

But for the efforts and unflinching support of some the success of this research project would have been but a wild dream. My parents, Mr. & Mrs. S.A. Folasde, you sacrificed your comfort on the altar of my own. No amount of appreciation is commensurate with your labour of love, I am more than grateful. My brother Daniel, your support and advice are so invaluable. I cannot but thank God for same blood that flows through our veins. Kudos! Funmi, Shegun, Kemi and others of the Shade fold, I appreciate you all.

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Above all, to my creator who knew me before I was conceived and has been by strength, I praise your Name.

ABSTRACT

Based on the design, the basic equipment were properly sized and specified after carrying out detailed material and energy balance around each of the unit and hence, the overall plant. Safety and effective waste disposal measures were considered and thus the plant can be said to be environmentally acceptable. From the economic analysis, the equipment cost of the plant is ₦416,000. The profit after tax was found to be 3 million naira per annum with pay back period of approximately one year. The plant designed so far can be said to be economically viable with rate of return on investment (ROI) of 81.24%.

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CHAPTER ONE

1.0 INTRODUCTION

Ginger is a rhizome of Zingiber officinale (family of Zingiberaceae), a nongaseous perennial plant cultivated in West Africa (Nigeria and Sierra-Leone), in South-east India and in Jamaica. Ginger has been reported to contain about 1-4% volatile oil content and from 5-8% of resinous matter, starch, Mucilage and oil of ginger to which the spice mainly owes its aroma.

Ginger oil is the essential oil obtained by steam distillation – a process in which live steam is in direct contact with the distillation system in either batch or continuous operation of the ginger spices. The essential oil possesses the aroma and flavour of the spice but lack the characteristic pungency. It finds it main application in the flavouring of beverages, but it is also used in confectionery and perfuming.

Separation processes are fundamental parts of almost every chemical process. Indeed, there are usually for more separation processes or stages in the over all process than there are chemical reactions. Separation starts with the extraction of raw materials and continued to the purification and isolation of the final product. Without an efficient separation technique, raw materials would be in short supply, more expensive and of low quality.

Efficient separation allows useful intermediate and by-product to be recovered and make it possible for non reaction starting materials to be recycled.

Distillation is a separation process, separating components in a mixture by making use of the fact that some component vaporize more rapidly than the others. When vapours are produced from a mixture, they contain the components of the original mixture but in proportion which are determined by the relative volatilities of these components. The vapour is richer in some components, those that are more volatile and so separation occurs. The vapour is condensed and then re-evaporated where further separation occurs.

1.1 Aim of the Project

To design a plant to extract 100,000 litres of ginger oil per annum by simple distillation.

1.2 Justification

The choilce emanates from the fact that steam distillation process is the cheapest and most suitable fro the large majority of essential oils as it prevents denaturing of the oil constituents.

1.3 Scope of the Design

Mathcad 14.0 was used for the material and energy balances and costing of the design work

CHAPTER TWO

2.0 LITERATURE SURVEY

2.1 HISTORY OF GINGER

When early man was exploiting as a hunter and food gathering, he discovered that certain plant stores their food resources in swollen and similar under ground structures. The advantage of this plant is that it can survive in this way through either a very cold or a very dry' season of the year, and resume growth when the weather becomes warmer or wetter, the human food gathers found that if they dry up those roots, they had a handy sources of nourishment to see them through a bad time of the year, and one that was easily stored. As family developed roots vegetables were cultivated as high yielding easily raised crops through out the world setters naturally carried them to new countries. Many are now growth thousands of moles from their first home land.

Ginger is a native of tropical Asia and is cultivated in West Indies, India, Africa, China, Japan and Indonesia. The best ginger is of Jamaican origin which is classified as number one, two and tree, and also Ratoon. All Jamaican ginger has a fine aroma. Cochin ginger India is next in quality. Chapter ones come Nigeria, Sierra-Leone Japan, Indonesian and China.

Ginger is a rhizome of zinger officinale (family of zingiberaceae). The plant is small erect perennial herb. It is considered to be the most important of all spices and condiments, and is used all over the world, largely as a condiment. The plant can be grown up to 30-90cm but needs an annual rainfall of 150cm with only a short season and a high temperature. It is propagated by splitting the rhizomes, each pieces eventually growing into a new plant. Ginger is a herb with a long narrow leave which die down each year. The flowers one purple and have complicated structure.

Ginger is a flowering tree orchids are paralled by another group of monocotyledons, the tropic gingers which have arrived at a similar conclusion by a different route with vivid and delicate flower is as show. The stems are erect and not more than 3.6cm in diameter. The flowers yellow in colour, are rarely produced; they arise on a basal stem. The root is an the from of an enlarged rhizome, 2-3cm in diameter –3 long, more often white or yellow and sometimes a dedicated pink in colour. The

BOTANY AND PROPAGATION

Ginger is a perennial herb growing up to 100cm fall-leaf sheaths which cover the stem. The leaves are spare shaped and the plant rarely flowers. The inflorescence consist of a cone of bracts with pale yellow flowers. Rhizomes are short, branching and scaly. It is grown from small portions of rhizomes, 3-5 long.

CLIMATE AND SOIL

Ginger is probably original in Asia grows in the humid tropics with at least 1500mm of rain yearly of rain and a short dry season. It is planted from sea level to 1500mm elevation, soil should loamy, rich in humus and well drained and the thrive in full sun light.

CULTIVATION AND MANAGEMENT

Soil should be well cultivated and ridged. Plant spacing should be 50cm by 25cm (900-1500kg) of rhizomes per hectare). Organic Manure and inorganic N.P.K. fertilizer should be applied. The crop should harvest at 9-10 months after planting when leaves turns yellow and a yield of up to 30tonnes of fresh ginger per hectare may be obtained.

HUSBANDARY

Ginger is exploited in compound garden and fields. They are grown in a mixture with any other plants. However, planting in pure stand will increase production. The plant is usually harvested 9-10month after planting. If the harvest is at 7-8months, the rhizomes will be smaller but more tender and easier to grind into powder. The crop can also be harvested by cutting some of the rhizome and leaving the rest of the plant in position for coming season. The rhizomes produced in this way are supposed to be large.

2:2 MEDICINAL VALUE OF GINGER

A study publicized in the journal of Ethropharmacology (Grueriwald, 1998) revealed that ginger significantly inhibit the growth of both gram-positive and gram-negative bacteria. Ginger is a stimulant that when chewed, it increases flow of saliva. When swallowed, it act as stimulating tonic, stomachic and increase the secretion of gastric juice exactly the excitability of the alimentary muscular system and dispelling gases accumulated in the stomach and bowels.

Other studies and analysis reveals that, ginger has pronounced antioxidant activity, reduced inflammation much like an analgesic, and may even help in arresting narcotic addition (Fulder, 1996).

It appears this spicy aromatic has something to offer every one. From flavor to fitness. Ginger is effective not only for indigestion, but also in preventing the symptoms of motion sickness.

Research, (J. Backin, 1996) has studied ginger effect on human health for over a decade and has become convinced through numerous trials that the aromatic spice offer a wide range potential health benefits.

He believes that, because ginger is such a potent throboxane synthesis inhibitor and prostacylin suppressor, it has theraperatic capabilities in alcohol withdrawal, in from serious burns, treating peptic ulcer as an antidepressant, in preventing ageing penile vascular changes and impotency and as an analgesic in dymenorrheal (painful menstuation).

2.3 Chemical constituents of Ginger oil

Ginger contains about 1 – 4% volatile oil, 5-8% resinous matter, starch and mucilage.

The oil is a yellowish, vicious liquid soluble in ether, sparingly soluble in alcohol and almost insoluble in water. It is obtained by steam distillation of the fleshy rhizomes. It contains majority monoteperes, and sequesterpeniod lectones, borneol, y-terpineol, nerol, neral geraniol, geramial, geranyL.acetate, B- bisabolene, zingiberanne etc.

Another chief constituent of ginger is its oleoresin. It is prepared from dried ginger by solvent extractions. The oleorein contain organoleptically important oil and disinfecting agents. The yield and relative abundance of the components of the oleoresin are dependent, however, on the raw materials, solvent and extraction conditions. (oyewale, 1999). Zingerone, the pungent principle of ginger in present in the oleoreim. It is obtained from the spice's extraction with organic sol vent.

Zingerone, $C_{11}H_{14}O_3$ has the following structural formula.

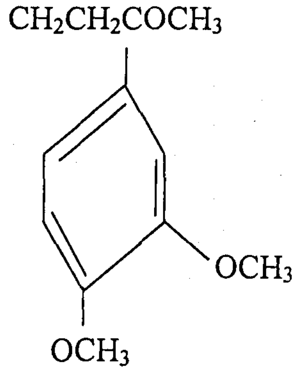

Fig. 2. 0. Structure of Zingerone

TABLE 2.0 BIOLOGICALLY ACTIVE COPMPONENT IN GINGER

SUBSTANCE	***EFFECT***
Asparegines	Promote urination
Borneol	Anagesic anti-inflammatory, protect liver
Chavicol	Kills fungi
Cincole	Lower blood pressure, antiseptic clear throat
Citral	Antilislamine antibiotic
Cumen	Narcotic
Cymen	Kill visniser, kill fungi, kill insect
Geranoil	Anticandida, kill insects
Gingerol	Analgesic stimulate, circulation, lower blood pressure
Gingerdiorie	Inhibits prostaglandin's
Limonene	Can irritate skins and deters insects
Myrecene	Kill bacteria and insects
Neral	Kill bacteria
Piriene	Remove philedum, kills insects
Shogoal	Analgetic, lower blood fever, coustric blood
Zingerone	Raise blood pressure

Source: Foulder, 1996

Starch is the chief food reserve of plant and is converted as required into sugar. It may be stored in the stem as in palm, in the tuber as in cassava or in rhizome as in ginger. On microscopic examination, starch from various plant sources is found to consist of

The size of starch granule measure along their longest axis varies from 2 x 10^{-4}cm – 15 x 10^{-2}cm (Brain and Allan, 1970).

2.4 Characterization of Ginger Essential Oil

1. Iodine Value

This is the measure of the proportion of unsaturated acid present in the oil. This is not the amount of iodine present in the oil but the test measures the amount of iodine which can be absorbed by the unsaturated acid.

$$\text{Iodine Value} = \frac{[B-S] \times N \times 126.9}{\text{Weight of sample}}$$

Where, B = Blank titration

S = Sample titration

N = normality of thiosuphate solution

126.9 = Atomic weight of iodine

2. Saponification Value.

This is a measure of the mean molecular weight of fatty acid present in the oil. The process of saponification is hydrolysis of fats and oil. The value should not exceed 20 for ginger oil.

3. Refractive Index.

This is the physical attribute of ginger oil measured by the angles through which a beam of light is bent when passing through a thin of ginger oil. This index is used in checking the range within which each fat or oil falls into and purify of such for component of a mixture. It is temperature at which most oils are leginal. The refractive index is achieved by dropping a few drops of the oil sample on the face of refractometer and after which it is closed and tightened and allowed for sometime after which refractive index is read.

4. Specific Gravity

The specific gravity is ratio of weight of a substance to the weight of a substance to the weight of equal volume of water at specific temperature. The specific gravity of oil is always less than 1.

2.5 Application / uses of Ginger

Ginger is considered to be the most important of all spices and condition and is used all over the world largely as a condiment. Ginger rhizomes, fresh or dried, crushed, grated or powdered, are used to0 season sauces and stews, and give food a characteristic rather spicy flavour. The rhizomes are also used to prepare a refreshing drink.

Medicinally ginger is said to be a stimulant and to have aphrodisiac properties. It is used on its own or with other products in remedies for stomach ache. It is believed to help the digestion of the foods with which it is consumed. It is also included in formular for sausage, mincement, army powder, party spice e.t.c.

The oil is used primarily as a food flavour in bakery foods, cakes, ginger sulps and spice sulps, as well as in soft drinks of ginger-ale type and in condiment mixture.

2.6 Methods of Extracting Ginger oil

Usually, ginger oil is being extracted by distillation. This is a separation process, separating component in a mixture by making use of the fact that some component vapourise more rapidly than others. When vapour are produced from a mixture, the contain the components of the original mixture but in proportion which are determined by the relative volatilities of these components. The vapour is richer in some components, those that are mobre volatile, and so separation occurs, in fraction distillation, the vapour is condensed and the re-evaporated where a further separation occurs.

The main use of distillation in the food industry is for concentrating essential oils, flavour and alcoholic beverage and in the deodorization of fats and oils. In some, circumstances in the food industry, distillation would appear to be good separation method but it cannot be employed directly as the distilating temperature would lead to the breakdown of the materials. In cases in which volatile materials, steam distillation may sometimes be used to effect the separation at scale temperature. Very often the molecular weight of the volatile, component that is being distilled is much greater than that of the steam, so that the vapour may contain quite large proportions of the volatile components.

Steam distillation is most commonly used since it is suitable for the large majority of essential oils and is the cheapest process in which the essential oils, in general, insoluble or only very sparing soluble in water. In some rare cases, valuable constituents may be lost during distillation, the most important oils extracted by steam distillation are oil of ginger, palmarosa, sandal wood e.t.c. Steam distillation is carried out in three different ways:

a. Water distillation.

In this process, plant material is kept in a goose necked still with water and heated by direct fire or preferably by a steam jacket or closed or perforated steam cools through out the distillation. The distilled material is in direct contact with the boiling water in the still, on cooling the distillation in the recover separates into two layers, a top layer of oil and a lower aqueous layer called aromatic water.

b. Water and steam distillation

In this method, a perforated grid or screen is inserted in the still and the plant material is placed on it. The bottom of the still is filled with water to a level cottle below the screen, which means that during the distillation the material is in contact with saturated steam and not with boiling water as in the first case.

c. Direct steam distillation

The method is about the same as the previous in as much as the plant material is not in a container with boiling water. But the steam is generated in a separate boiler and then passed into bottom of the still containing the plant material. Water is not allowed to accumulate at the bottom of the still.

2.7 Factors affecting rate of extraction

The particle size influences the rate of extraction in many ways, in most extraction processes, the smaller the particle size, the higher the extraction rate since a large area per volume will now be exposed and even reduced the resistance to mass transfer between the oil and the solvent and increase the movement of oil into case, of ginger has an optimum size at which the extraction rate is the particle size between

3.1 Assumption Made

The following assumptions were made in the design calculations, other subsequent ones were also made where necessary.

1. The column extractor is well insulated.
2. DHmix equals to zero; i.e. there are no enthalpy changes associated with mixing.
3. oil extraction start as soon as the column temperature 50-100 degree celcius.
4. Only oil in ginger rhizome from of the extractor is vaporised with steam while others are residue.
5. The condenser is counter-current and efficient.
6. The column extractor and condenser operates at 1 atmosphere.
7. In this design, 308 working days is assumed
8. Two phase horizontal seperator was chosen since there are various types of separator.

3.2 Material Balance Around Equipment

Setting the production target as a function of operating time (t) in hour/yr, and unit in kg/hr.

$P := 100000 \cdot \frac{L}{yr}$ operating time(t) $t := 7392 \frac{hr}{yr}$

$P_t := \frac{P}{t}$

$P_t = 0.014 \cdot m^3 \cdot hr^{-1}$

Converting the above to kg/hr

Density of oil ρ_{oi}

$\rho_{oil} := 876.2 kg \cdot m^{-3}$

Volumetric flow rate of oil is equivalents to p(t)=V

$P_t = 0.014 \cdot m^3 hr^{-1}$

Since density is given as $\rho = \frac{M}{V}$

This implies that mass flow rate M is

$M := \rho_{oil} \cdot P_t$

$M = 11.853 \cdot kg \cdot hr^{-1}$

The above calculation gives the targeted production in terms of kg/hr as 11.833 kg/hr

3.2.1 Material balance around the boiler

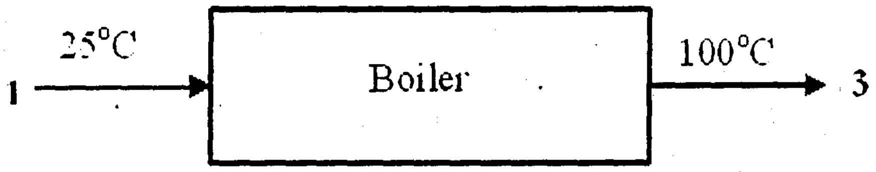

Figure 3.1 material inflow and out flow around the boiler

To enable all calculations around the boiler, the following assumptions were made

i. 50kg/hr of liquid water enters (F_3)

ii. No accumulation occurs in the boiler as such input = output

$F_3 := 50 \frac{kg}{hr}$

For input stream(liquid water), j=4

$F_4 := F_3$

$F_4 = 50 \cdot \frac{kg}{hr}$

Total input

$F_4 = 50 \cdot kg \cdot hr^{-1}$

For output stream(steam), j=3

$F_3 = 50 \cdot \frac{kg}{hr}$

Total output

$F_3 = 50 \cdot kg \cdot hr^{-1}$

3.2.2 Material balance around the the column extractor

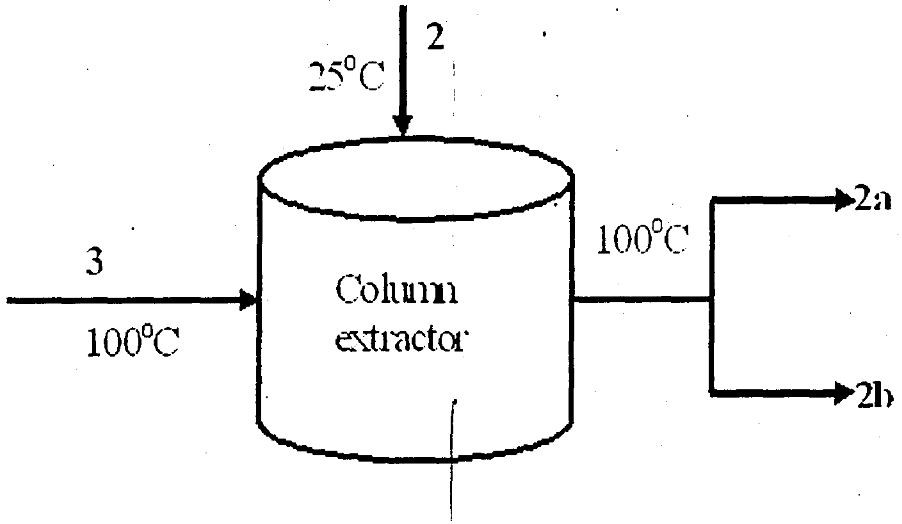

Figure 3.2 material inflow and out flow around the column extractor

Choosing one kilogram of raw material (ginger rhizome) as our basis for establishing material balance as a function of x and the corresponding input and output are calculated based on one kilogram of leaves entering the system. The resulting material balance is shown in the table below.

Let x = fraction of oil in the ginger rhizome

Fraction of oil in the ginger rhizome is chosen as 4%, therefore $x := 0.04$

TABLE 1 definations of input and out terms

COMPOUND	INPUT FRACTION	OUTPUT FRACTION
Raw material	$Rm_1 := 1$	$Rm_2 := 0$
Oil	$oil_1 := 0$	$oil_2 := x$
Residue	$Residue_1 := 0$	$Residue_2 := 1 - x$
Water	$W_3 := 50\frac{kg}{hr}$	

The flow rate(F) of each compound can be calculated by multiplying the corresponding fractions of each by a multiplication factor (E) as shown below.

$E := \frac{M}{x}$ $\qquad F_{ij} = E \cdot fractio$ of each

DEFINITIONS OF TERMS USED IN CALCULATING FLOWRATES.

F_i implies that i denotes compound and j denotes stream number.

F_j implies that j denotes stream number.

COMPOUNDS	i- VALUES
Raw materials	2
Oil	3
Water (liquid)	4
Water (steam)	5
Residue	6

For input stream $(j = 1)$	For output stream $(j = 2)$
$F_{21} := E \cdot Rm_1$	$F_{22} := E \cdot Rm_2$
$F_{21} = 296.334 \cdot \frac{kg}{hr}$	$F_{22} = 0 \cdot \frac{kg}{hr}$
$F_{31} := E \cdot oil_1$	$F_{32} := E \cdot oil_2$
$F_{31} = 0 \cdot kg \cdot hr^{-1}$	$F_{32} = 11.853 \cdot \frac{kg}{hr}$
$F_{61} := E \cdot 0$	$F_{62} := E \cdot (1 - x)$
$F_{61} = 0 \cdot kg \cdot hr^{-1}$	$F_{62} = 284.481 \cdot kg \cdot hr^{-1}$
$F_1 := F_{21} + F_{31} + F_{61}$	$F_1 = 296.334 \cdot kg \cdot hr^{-1}$

Input stream 3 (j = 3)

To calculate the mass flow rate of steam required, the assumptions made is that no water is removed from the leaves.

Let the amount of water into the column as steam be 50 kg/hr and 5% ginger rhizome as condensate with the residue while the remaining ginger rhizome as steam with oil. let y be the fraction of water that condenses with rhizome and that of steam be (1-y).

$F_{43} := 50 \frac{kg}{hr}$

$F_3 := F_{43}$

$F_3 = 50 \cdot kg \cdot hr^{-1}$

Since $\quad y := 0.05$

water as steam is given by

$$F_{52} := F_3 \cdot (1 - y)$$

This implies water that condenses with the ginger rhizome

$$F_{42} := F_3 - F_{52} \qquad F_{42} = 2.5 \cdot \frac{kg}{hr}$$

From the above

$$F_{2a} := F_{32} + F_{52}$$

$$F_{2a} = 59.353 \cdot \frac{kg}{hr}$$

$$F_{2b} := F_{42} + F_{62}$$

$$F_{2b} = 286.981 \cdot \frac{kg}{hr}$$

Total material input	**Total material output**
$F_{extractor} := F_1 + F_3$	$F_2 := F_{2a} + F_{2b} + F_{22}$
$F_{extractor} = 346.334 \cdot kg \cdot hr^{-1}$	$F_2 = 346.334 \cdot kg \cdot hr^{-1}$

3.2.3 Material balance around the condenser

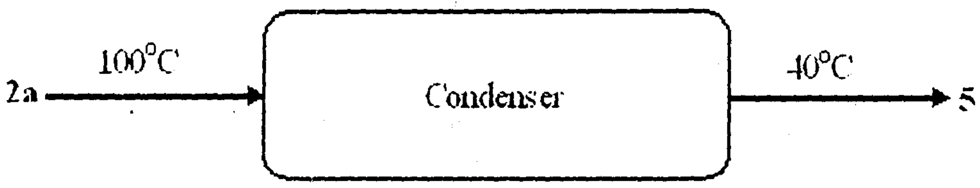

Figure 3.3 material inflow and out flow around the condenser

Assuming that:

i. Condensation was achieved up to 100%

ii. No accumulation occured as such input = ouput

For input stream	**For output stream**
$F_{2a} = 59.353 \cdot kg \cdot hr^{-1}$	$F_5 := F_{2a} \qquad F_5 = 59.353 \cdot kg \cdot hr^{-1}$
	$F_5 = 59.353 \cdot kg \cdot hr^{-1}$

Amount of oil $F_{35} := F_{32}$ $F_{35} = 11.853 \cdot kg \cdot hr^{-1}$

Amount of steam $F_{45} := F_5 - F_{35}$

$F_{45} = 47.5 \cdot kg \cdot hr^{-1}$

Total input

$F_{2a} = 59.353 \cdot kg \cdot hr^{-1}$

Total output

Total output

$F_5 = 59.353 \cdot kg \cdot hr^{-1}$

3.2.4 Material balance around the separator

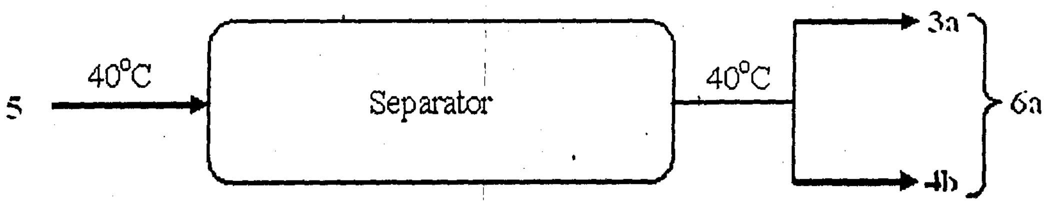

Figure 3.4 material inflow and out flow around the separator

Also making the assumptions,

i. 100% separation of oil and water was not achieved

ii. A product purity of 99.90% ginger oil and 0.10% water.

Note that this purity was set because of their differnce in densities and their immicibilities.

let the fraction of oil in the product be Y and that of water to be Q.

Therefore if,

$Y := 0.999$

This implies that

$Q := 1 - Y$ $Q = 1 \times 10^{-3}$

For input stream (j=5) **For output stream (j=6)**

$F_5 = 59.353 \cdot kg \cdot hr^{-1}$

Amount of oil in the product $F_{36a} := F_{32} \cdot Y$ $F_{36a} = 11.842 \cdot \frac{kg}{hr}$

Amount of water in the product $F_{46a} := F_{32} \cdot Q$ $F_{46a} = 0.012 \cdot \frac{kg}{hr}$

Total for stream 6a $F_{6a} := F_{36a} + F_{46a}$ $F_{6a} = 11.853 \cdot \frac{kg}{hr}$

Amount of water removed $F_{46b} := F_5 - F_{6a}$ $F_{46b} = 47.5 \cdot \frac{kg}{hr}$

$F_{6b} := F_{46b}$ $F_{6b} = 47.5 \cdot kg \cdot hr^{-1}$

Total input **Total output**

$F_5 = 59.353 \cdot kg \cdot hr^{-1}$ $F_6 := F_{6a} + F_{6b}$

$F_6 = 59.353 \cdot kg \cdot hr^{-1}$

The targeted production is stream which corresonds to 11.853 kg/hr of ginger oil with 99.90% purity

CHAPTER FOUR

4.0 ENERGY BALANCE

T_d is datum temperature

ΔH is enthalpy

T_c is critical temperature

T_b is boiling temperaure

ΔH_{vapt} is heat of vapourisation at boiling point

C_p is specitic heat capacities

4.1 Energy Balance Around Equipment

$$\Delta H = \int_{T_d}^{T_f} Cp_l \, dT = MC_p \cdot \Delta Q$$

$$\Delta H_{vap} = -\Delta H_{cond} = \Delta H_{vapb} \left(\frac{T_c - Temp}{T_c - T_b} \right)^{0.38}$$

4.1.1 Energy balance around the boiler

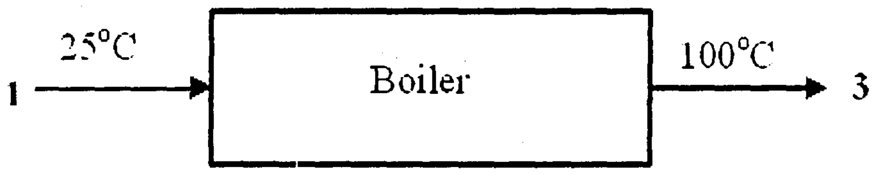

Figure 4.1 Stream in and outflow around the boiler with conditions

In this equipment heating and vapourisation occured as water changes phase from liquid to vapour i.e

1. Enthalpy of heating water from 298.15K to 373.15K

$T_{f_{53}} := 373.15K$ $\quad T_{d_{44}} := 298.15K$ $\quad C_{p\_water} := 4200J \cdot kg^{-1} \cdot K^{-1}$

$\Delta H_{vapb\_water} := 22600J \cdot kg^{-1}$ $\quad T_{b_4} := 373.15K$ $\quad T_{f_{42}} := T_{b_4}$

$T_{c\_water} := 647.2K$

$$\Delta H_{44} := \int_{T_{d_{44}}}^{T_{f_{53}}} C_{p\_water}\, dT$$

$$\Delta H_{44} = 3.15 \times 10^{5} \cdot \frac{J}{kg}$$

Heat rate is given by

$Q_4 := F_4 \cdot \Delta H_{44}$ $\quad Q_4 = 1.575 \times 10^{7} \cdot \frac{J}{hr}$

2. Enthalpy of vaporisation of water

$$\Delta H_{vap_{53}} := \Delta H_{vapb\_water} \cdot \left(\frac{T_{c\_water} - T_{f_{53}}}{T_{c\_water} - T_{b_4}} \right)^{0.38}$$

$$\Delta H_{vap_{53}} = 2.26 \times 10^{4} \cdot \frac{J}{kg}$$

Therefore heat rate is given by

$Q_{vap_{53}} := F_4 \cdot \Delta H_{vap_{53}}$. $\quad Q_{vap_{53}} = 1.13 \times 10^{6} \cdot \frac{J}{hr}$

Total heat load on the boiler

$Q_{boiler} := Q_4 + Q_{vap_{53}}$ $\quad Q_{boiler} = 1.688 \times 10^{7} \cdot \frac{J}{hr}$

4.1.2 Energy balance around the column extractor

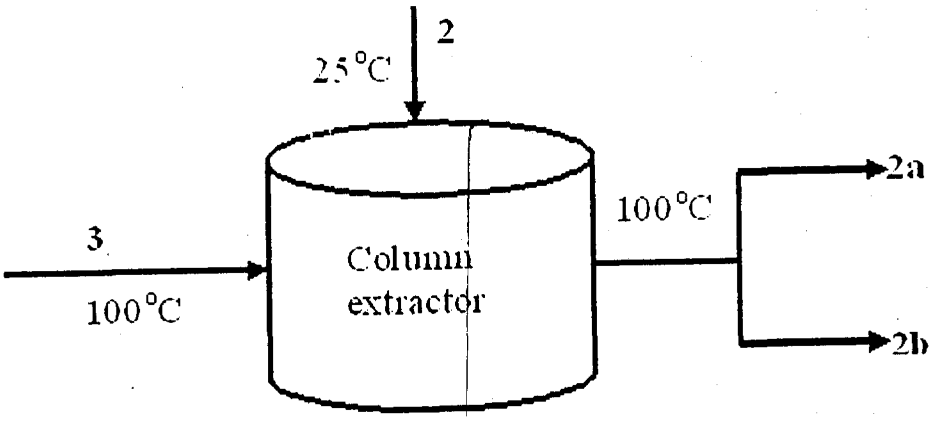

Figure 4.2 Stream in and outflow around the column extractor with conditions

In this equipment steam enters and heating and vapourisation occur since oil is being heated above its boiling point, i.e to steam temperature (373.15K)

1. Enthalpy of heating oil to 373.15K from 298.15K

$T_{b_3} := 351.15K$ $\quad C_{p\_oil} := 2.6 \cdot 10^3 \frac{J}{kg \cdot K}$ $\quad T_{d_{31}} := 298.15K$

$T_{f_{32}} := 373.15K$ $\quad T_{c\_oil} := 516.2K$ $\quad \Delta H_{vapb\_oil} := 39.13 \times 10^3 \cdot J \cdot kg^{-1}$

$$\Delta H_{32} := \int_{T_{d_{31}}}^{T_{f_{32}}} C_{p\_oil} dT \qquad \Delta H_{32} = 1.95 \times 10^5 \cdot \frac{J}{kg}$$

Heat rate is given by

$Q_{32} := F_{32} \cdot \Delta H_{32}$ $\qquad Q_{32} = 2.311 \times 10^6 \cdot \frac{J}{hr}$

2. Enthaply of vapourising oil

$$\Delta H_{vap_{32}} := \Delta H_{vapb\_oil} \cdot \left(\frac{T_{c\_oil} - T_{f_{32}}}{T_{c\_oil} - T_{b_3}} \right)^{0.38}$$

$\Delta H_{vap_{32}} = 3.706 \times 10^4 \cdot \frac{J}{kg}$

Heat rate is given by

$Q_{vap_{32}} := F_{32} \cdot \Delta H_{vap_{32}}$ $\qquad Q_{vap_{32}} = 4.393 \times 10^5 \cdot \frac{J}{hr}$

3. Enthalpy of condensing steam on the leaves at the same temperature 373.15K

$$\Delta H_{vap_{42}} := \Delta H_{vapb\_water} \cdot \left(\frac{T_{c\_water} - T_{f_{42}}}{T_{c\_water} - T_{b_4}} \right)^{0.38}$$

$\Delta H_{vap_{42}} = 2.26 \times 10^4 \cdot \frac{J}{kg}$

But

$\Delta H_{cond_{42}} := -\Delta H_{vap_{42}}$

$$\Delta H_{cond_{42}} = -2.26 \times 10^{4} \cdot \frac{J}{kg}$$

Therefore heat rate is given by

$$Q_{cond_{42}} := F_{42} \cdot \Delta H_{cond_{42}}$$

$$Q_{cond_{42}} = -5.65 \times 10^{4} \cdot \frac{J}{hr}$$

4. Enthalpy of leaves that left as residue

$T_{d_{62}} := 298.15K$ $T_{f_{62}} := 373.15K$ $C_{p\_residue} := 0.9414 \cdot 10^{3} \frac{J}{kg \cdot K}$

$$\Delta H_{62} := \int_{T_{d_{62}}}^{T_{f_{62}}} C_{p\_residue} dT$$

$$\Delta H_{62} = 7.061 \times 10^{4} \cdot \frac{J}{kg}$$

Heat rate is given by

$$Q_{62} := F_{62} \cdot \Delta H_{62}$$

$$Q_{62} = 2.009 \times 10^{7} \cdot \frac{J}{hr}$$

Total heat load on column extractor

$$Q_{extractor} := Q_{62} + Q_{cond_{42}} + Q_{vap_{32}} + Q_{32}$$

$$Q_{extractor} = 2.278 \times 10^{7} \cdot \frac{J}{hr}$$

4.1.3 Energy balance around the condenser

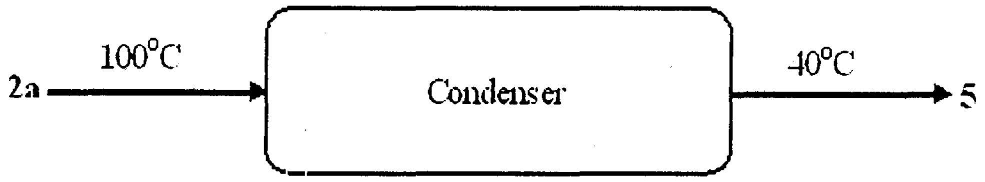

Figure 4.3 Stream in and outflow around the condenser with conditions

In this equipment cooling and condensation occur since steam is turns liquid.

1. Enthalpy of cooling steam to 313.15K

$T_{d_{52}} := 373.15K \qquad T_{f_{45}} := 313.15K$

$$\Delta H_{45} := \int_{T_{d_{52}}}^{T_{f_{45}}} C_{p\_water}\, dT$$

$$\Delta H_{45} = -9.072 \times 10^{8} kg^{-1} \cdot s \cdot \frac{J}{hr}$$

Heat rate is given by

$$Q_{45} := F_{45} \cdot \Delta H_{45}$$

$$Q_{45} = -1.197 \times 10^{7} \cdot \frac{J}{hr}$$

2. Enthalpy of condensation of steam to 313.15K from 373.15K

$$\Delta H_{vap_{45}} := \Delta H_{vapb\_water} \cdot \left(\frac{T_{c\_water} - T_{f_{45}}}{T_{c\_water} - T_{b_4}} \right)^{0.38}$$

$$\Delta H_{vap_{45}} = 2.437 \times 10^{4} \cdot \frac{J}{kg}$$

But, $\Delta H_{cond_{45}} := -\Delta H_{vap_{45}}$

$$\Delta H_{cond_{45}} = -2.437 \times 10^{4} \cdot \frac{J}{kg}$$

Therefore heat rate is given by

$$Q_{cond_{45}} := F_{45} \cdot \Delta H_{cond_{42}}$$

$$Q_{cond_{45}} = -1.073 \times 10^{6} \cdot \frac{J}{hr}$$

3. Enthalpy of cooling oil to 313.15K

$$\Delta H_{35} := \int_{T_{d_{52}}}^{T_{f_{45}}} C_{p\_oil}\, dT$$

$\Delta H_{35} = -1.56 \times 10^{5} \cdot \frac{J}{kg}$

Heat rate is given by

$Q_{35} := F_{35} \cdot \Delta H_{35}$

$Q_{35} = -1.849 \times 10^{6} \cdot \frac{J}{hr}$

4. Enthalpy of condensation of oil to 313.15K from 373.15K

$$\Delta H_{vap_{35}} := \Delta H_{vapb\_oil} \cdot \left(\frac{T_{c\_oil} - T_{f_{45}}}{T_{c\_oil} - T_{b_4}} \right)^{0.38}$$

$\Delta H_{vap_{35}} = 4.47 \times 10^{4} \cdot \frac{J}{kg}$

But

$\Delta H_{cond_{35}} := -\Delta H_{vap_{35}}$

$\Delta H_{cond_{35}} = -4.47 \times 10^{4} \cdot \frac{J}{kg}$

Therefore heat rate is given by

$Q_{cond_{35}} := F_{35} \cdot \Delta H_{cond_{35}}$

$Q_{cond_{35}} = -5.299 \times 10^{5} \cdot \frac{J}{hr}$

Total heat load on condenser

$Q_{condenser} := Q_{35} + Q_{45} + Q_{cond_{45}} + Q_{cond_{35}}$

$Q_{condenser} = -1.542 \times 10^{7} \cdot \frac{J}{hr}$

Total energy requirement for the Process

$Q := Q_{boiler} + Q_{condenser} + Q_{extractoı}$

$Q = 2.424 \times 10^{7} \cdot \frac{J}{hr}$

CHAPTER FIVE

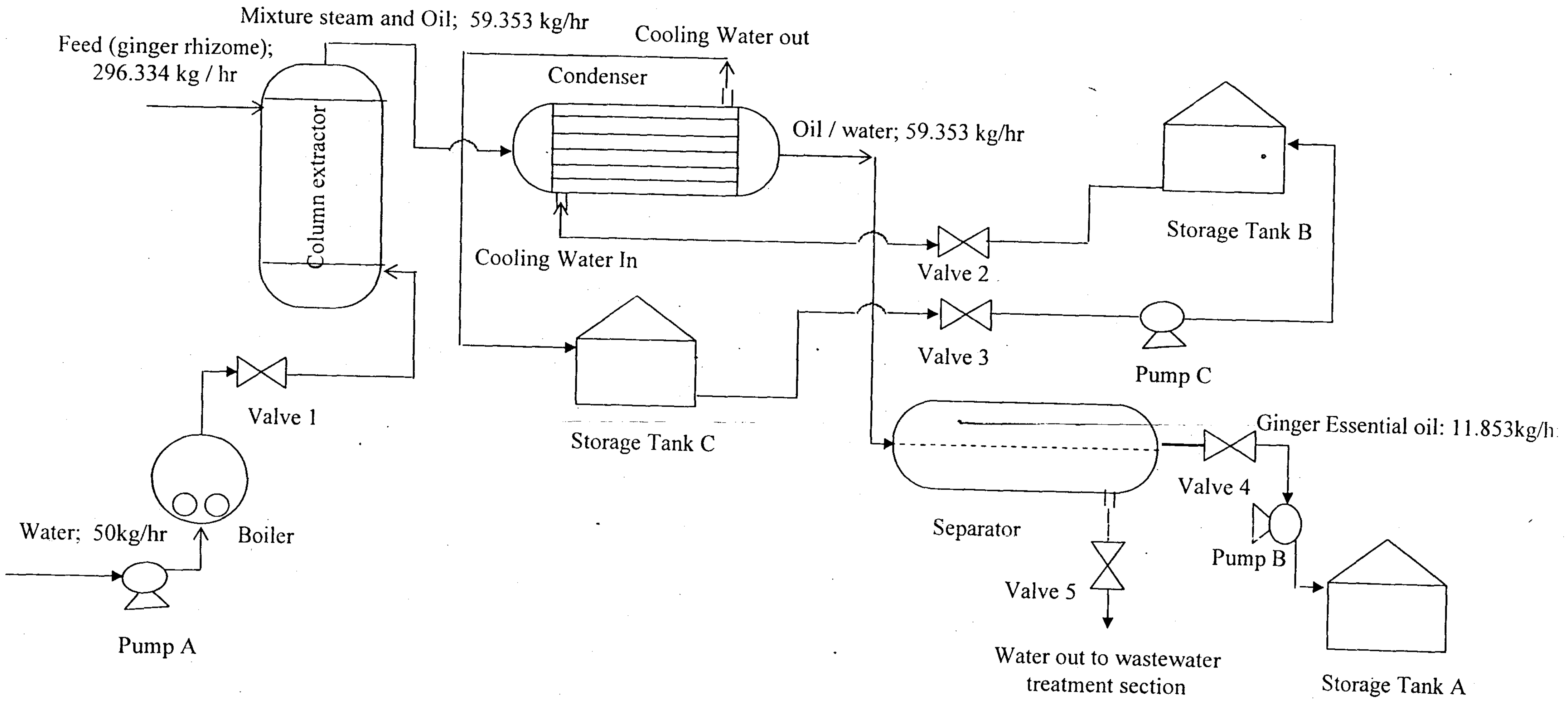

FIGURE 5.1 FLOWSHEET FOR EXTRACTION OF GINGER ESSENTIAL OIL FROM GINGER RHIZOME

CHAPTER SIX

6.0 SIZING AND DESIGN OF EQUIPMENT

6.1 Sizing oF Equipment

6.1.1 Sizing of column Extractor

Steam and raw material enters in to the system and the volume of the reactor is proportional to the amount of input to it. therefore

Volume or reactor = Volume of raw material+Volume of steam

Recall that Density= $\frac{\text{mass(kg)}}{\text{volume}\left(\text{m}^3\right)}$ i.e, $\rho = \frac{m}{V}$

This implies that $V = \frac{m}{\rho}$

Density of rhizome $\rho_{rhizome} := 1800\text{kg}\cdot\text{m}^{-3}$

Density of water $\rho_{water} := 1000\text{kg}\cdot\text{m}^{-3}$

Volume of water $V_{water} := \frac{F_3}{\rho_{water}}$

$V_{water} = 0.05\,\text{m}^3$

Volume of leaves $V_{rhizome} := \frac{F_{21}}{\rho_{rhizome}}$

$V_{rhizome} = 0.163\,\text{m}^3$

Total volume of column extractor

$V_{extr} := V_{rhizome} + V_{water}$ $V_{extr} = 0.213\,\text{m}^3$

Calculation of height and diameter of column

The reactor is assumed to be cylindrical and height/diameter ratio of 2.5 is chosen.

$V_{extr} = \frac{\pi\,D^2 H}{4}$ But $H = 2.5D$

Therefore,

$$D_{extr} := \left(V_{extr} \cdot \frac{4}{2.5\pi}\right)^{\frac{1}{3}}$$

$$D_{extr} = 0.477\,m$$

$$H_{extr} := 2.5D_{exti}$$

$$H_{extr} = 1.192\,m$$

6.1.2 Sizing of Condenser

Heat transfer area of the condenser.

$$-Q = U \cdot A_{condenser} \cdot \Delta Tm$$

U = overall convection coefficient

DTm = log mean temperature difference

A = The heat transfer area

$$U := 540 \frac{W}{m^2 \cdot K}$$

$$T_{h\_in} := 373.15K \qquad T_{h\_out} := 313.15K$$

$$T_{c\_in} := 298.15K \qquad T_{c\_out} := 323.15K$$

$$\Delta Tm := \frac{\left(T_{h\_in} - T_{h\_out}\right) - \left(T_{c\_out} - T_{c\_in}\right)}{\ln\left(\frac{T_{h\_in} - T_{h\_out}}{T_{c\_out} - T_{c\_in}}\right)}$$

$$\Delta Tm = 39.979\,K$$

$$A_{condenser} := \frac{-Q_{condensei}}{\Delta Tm \cdot U}$$

$$A_{condenser} = 0.198 \cdot m^2$$

6.1.3 Sizing of separator

Water and gingeroil enters in to the system and the volume of the reactor is proportional to the amount of input to it. therefore

Volume of separator = Volume of oil + Volume of water

From Density= $\frac{\text{mass(kg)}}{\text{volume}(m^3)}$ i.e. $V = \frac{m}{\rho}$

Volume of water $V_{water} := \frac{F_{45}}{\rho_{water}}$

$V_{water} = 0.048\,m^3$

Volume oil $V_{oil} := \frac{F_{35}}{\rho_{oil}}$

$V_{oil} = 0.014\,m^3$

Total volume of seperator column

$V_{sep} := V_{water} + V_{oi}$

$V_{sep} = 0.061\,m^3$

For safety purposes allow 12% additional volume. therefore

$V_{seps} := V_{sep} \cdot \left(1 + \frac{12}{100}\right)$

$V_{seps} = 0.068\,m^3$

Calculation of height and diameter of separator

The separator is assumed to be cylindrical and height/diameter ratio of six is chosen.

$V_{sep} = \frac{\pi\, D^2 H}{4}$ But $H = 6D$

Therefore,

$D_{sep} := \left(V_{seps} \cdot \frac{4}{6\pi}\right)^{\frac{1}{3}}$

$D_{sep} = 0.244\,m$

$H_{sep} := 6D_{sep}$

$H_{scp} = 1.463\,m$

6.1.4 Sizing of the boiler

Heat transfer area of the boiler.

$-Q = U \cdot A_{boiler} \cdot \Delta Tm$ $\qquad U := 540 \dfrac{W}{m^2 \cdot K}$

$T_{h\_in_1} := 298.15K \qquad T_{h\_out_1} := 373.15K$

$$\Delta Tm := \frac{T_{h\_in_1} - T_{h\_out_1}}{\ln\left(\dfrac{T_{h\_in_1}}{T_{h\_out_1}}\right)}$$

$\Delta Tm = 334.249\,K$

$$A_{boiler} := \frac{Q_{boiler}}{\Delta Tm \cdot U}$$

$A_{boiler} = 0.026 \cdot m^2$

6.1.5 Sizing of pumps

Pumps sizing is done under atmospheric pressure.

gravitational acceleration $\quad g := 10 \dfrac{m}{s^2}$

Pressure (atmospheric) $\quad P_{atm} := 1atm$

Pump A: pumping water to boiler

Height of Pump $\quad Hp_a := \dfrac{P_{atm}}{g \cdot \rho_{water}}$

$Hp_a = 10.133\,m$

Pump B: pumping of essential oil to storage tank

Height of pump $Hp_b := \frac{P_{atm}}{g \cdot \rho_{oil}}$

$Hp_b = 11.564\,m$

Pump C: pumping of recycled water from tank C back to tank B

Height of Pump $Hp_c := \frac{P_{atm}}{g \cdot \rho_{water}}$

$Hp_c = 10.133\,m$

6.1.6 Sizing of storage tanks

Storage tank A: Oil storage tank

Flow rate of essential oil $F_6 := 11.853 \frac{kg}{hr}$

Oil flow rate per annum $F_{oil} := F_6\left(7392 \frac{hr}{yr}\right)$

$F_{oil} = 8.762 \times 10^4 \cdot \frac{kg}{yr}$

Allowing for 30% safety allowance $F_{oil_1} := 1.40 F_{oi}$

$F_{oil_1} = 1.227 \times 10^5 \cdot \frac{kg}{yr}$

Volumetric flow rate of tank A $V_3 := \frac{F_{oil_1}}{\rho_{oil}}$

$V_3 = 139.996 \cdot m^3 \cdot yr^{-1}$

Minimum required velocity for the oil storage tank A:

Volumetric flowrate: $v_{min} := 4.2 \cdot 10^{-4} \frac{m}{s}$

Cross-sectional area of the sorage tank A:

$A_{cs} := \frac{V_3}{v_{mir}}$

$A_{cs} = 0.011\,m^2$

Diameter of the storage tank A:

$$D_s := 2 \cdot \sqrt{\frac{A_{cs}}{\pi}}$$

$D_s = 0.116\,m$

Storage tank B: water storage tank

Flow rate of water $F_w := 120\frac{kg}{hr}$

Water flow rate per annum $F_{oil} := F_w\left(7392\frac{hr}{yr}\right)$

$F_{oil} = 8.87 \times 10^5 \cdot \frac{kg}{yr}$

Allowing for 30% safety allowance $F_{oil_1} := 1.40F_{oi}$

$F_{oil_1} = 1.242 \times 10^6 \cdot \frac{kg}{yr}$

Volumetric flow rate of tank B $V_3 := \frac{F_{oil_1}}{\rho_{oil}}$

$V_3 = 1.417 \times 10^3 \cdot m^3 \cdot yr^{-1}$

Minimum required velocity for the oil storage tank B:

Volumetric flowrate: $v_{min} := 0.5 \cdot 10^{-3}\frac{m}{s}$

Cross-sectional area of the sorage tank B:

$$A_{cs} := \frac{V_3}{v_{mir}}$$

$A_{cs} = 0.09\,m^2$

Diameter of the storage tank B:

$$D_s := 2 \cdot \sqrt{\frac{A_{cs}}{\pi}}$$

$D_s = 0.338\,m$

Cooling water tanks B and C for the condenser operates on the same conditions, hence they have the same cross-sectional area and diameter.

6.2 Chemical and Mechanical Design of Major Equipment

The detailed chemical and mechanical design of the major equipment are as shown below;

6.2.1 Detail chemical design of the column extractor

Material for construction:

Material selected for construction is stainless steel or carborn steel and an insulator made up of fiber with binder and baked.

Choice of material seleted:

It is a good conductor of heat and has a good heat transfer coefficient.

Sizing of column extractor

Steam and raw material enters in to the system and the volume of the reactor is proportional to the amount of input to it. therefore,

Volume or reactor = Volume of raw material+Volume of steam

Recall that Density= $\frac{\text{mass(kg)}}{\text{volume}\left(m^3\right)}$ i.e. $\rho = \frac{m}{V}$

This implies that $V = \frac{m}{\rho}$

Density of leaves $\rho_{rhizome} := 1800\text{kg}\cdot m^{-3}$

Density of water $\rho_{water} := 1000\text{kg}\cdot m^{-3}$

Volume of water $V_{water} := \frac{F_3}{\rho_{water}}$

$$V_{water} = 0.05\,m^3$$

Volume of ginger rhizome $V_{rhizome} := \frac{F_{21}}{\rho_{rhizom}}$

$V_{rhizome} = 0.163\,m^3$

Total volume of column extractor

$V_{extr} := V_{rhizome} + V_{water}$

$V_{extr} = 0.213\,m^3$

Calculation of height and diameter of column

The reactor is assumed to be cylindrical and height/diameter ratio of 2.5 is chosen.

$V_{extr} = \frac{\pi\, D^2 H}{4}$ But $H = 2.5D$

Therefore,

$$D_{extr} := \left(V_{extr} \cdot \frac{4}{2.5\pi}\right)^{\frac{1}{3}}$$

$D_{extr} = 0.477\,m$

$H_{extr} := 2.5 D_{extr}$

$H_{extr} = 1.192\,m$

Calculation for heat transfer area of the column

Heat transfer area of the of the column (Q) is

$-Q = U_c \cdot A \cdot \Delta Tm$

Where temperature difference

$\Delta Tm_{\ extr} := T_{h\_out_1} - T_{h\_in_1}$

$\Delta Tm_{\ extr} = 75\,K$

Let Insulator thickness $\delta := 0.02m$

Heat transfer coefficient of insulator $\gamma := 5500 \frac{W}{m^2 \cdot K}$

Heat transfer coefficient of Alminium $\alpha := 275.9 \cdot \frac{W}{m^2 \cdot K}$

Overal heat transfer coefficient $U_c = \left(\frac{\delta}{\gamma} + \frac{1}{\alpha}\right)^{-1}$

$$U_c := \left(\frac{0.02}{5500} + \frac{1}{275.9}\right)^{-1} \cdot \frac{W}{m^2 \cdot K}$$

$$U_c = 275.623 \cdot \frac{W}{m^2 \cdot K}$$

Heat transfer area $A_{heat} := \frac{Q_{extractor}}{U_c \cdot \Delta Tm_{extr}}$

$$A_{heat} = 0.306 m^2$$

Inner holding case for the extractor

The duty of this is to ease transfer of heat and also to remove spent materials from the system. material used for its construction is aluminium alloy and an allowance of 0.006m is two casing is chosen.

Allowance between the two casing $\xi := 0.006m$

Therefore

Diameter of casing $D_{case} := D_{extr} - \xi$

$$D_{case} = 0.471 m$$

Take flat sheet bar width $W_{fs} := 0.002m$

Bar spacing $B_s := 45^o$

Therefore

Numbers of vertical bars $N_v := \frac{360}{B_s}$

$$N_v = 8 \cdot bars$$

Total bar length $T_{bl} := N_v \cdot H_{extr}$

$$T_{bl} = 9.538\,m$$

Circumference

$$C_{extr} := \pi\, D_{exti}$$

$$C_{extr} = 1.498\,m$$

Bracing support material length

$$B_{sml} := 5 \cdot C_{exti}$$

$$B_{sml} = 7.491\,m$$

Base material lenght using Grid method

$$B_{ml} := 3.52m$$

Total material length

$$T_{ml} := B_{ml} + B_{sml} + T_{bl}$$

$$T_{ml} = 20.549\,m$$

Total area of inner case holding

$$T_{aich} := T_{ml} \cdot W_{fs}$$

$$T_{aich} = 0.041\,m^2$$

Length of casing

$$L_{case} := \frac{A_{heat} - T_{aich}}{\pi \cdot D_{extr}}$$

$$L_{case} = 0.177\,m$$

Difference between calculated Length of case and calculated height of the packed is given by

$$D_{iff} := L_{case} - H_{exti}$$

$$D_{iff} = -1.015\,m$$

Pressure drop along the packed bed

The pressure on the packed bed is dependent on the density of the rhizome.

An optimum steam liquid ratio is required for the process. the formular correlating the pressure of a packed bed for a single incompressible fluid through an incompressible bed is below. The bed was considered fairly incompressible based on experimental observation. corrective coefficient is introduced to possible compression of leaves in the bed. The formula is below

$$\Delta P = \frac{2 \cdot f_{mG}^{2} \cdot L(1-\varepsilon)^{3-n}}{D_p \cdot g_c \cdot \rho\phi_s^{3-n} \cdot \varepsilon^3}$$

Where

Length of the bed $L_{pb} := H_{ext}$

$L_{pb} = 1.192\,m$

Dimension constant g_c

Average diameter of particle defined as equivalent to the diameter of sphere of the same volume as the particle

Volume of a sphere $V_{shp} = \frac{4}{3} \cdot \pi\, r^3$

But

Average Volume of rhizome branch $V_p := 1.5 \cdot 10^{-3} m^3$

Radius of particle $R_p := \sqrt[3]{3 \frac{V_p}{4\pi}}$

$R_p = 0.071\,m$

Diameter of particle $D_p := 2 \cdot R_p$

$D_p = 0.142\,m$

Voidage (Fractional free volume) $\varepsilon := \frac{V_{rhizom}}{V_{extr}}$

$\varepsilon = 0.765$

Exponent (n), a function of modified Reynolds Number Nre is calculated below

Vicsousity of steam $\mu_w := 8.0 \cdot 10^{-4} N \cdot s \cdot m^{-2}$

Flow rate of steam $G := F_4$

$G = 0.014\,kg \cdot s^{-1}$

Reynolds Number $N_{RE} = \frac{D_p \cdot G}{\mu_w}$

$$N_{RE} := \frac{0.142025 \cdot 0.013889}{8.0 \cdot 10^{-4}}$$

$$N_{RE} = 2.466$$

From chart $n := 1$

Shape factor (fs) defines as the quotient of area of sphere equivalent to volume of the particle divided by the actual the actual surface of particle.

$$\phi_s = \frac{V_p}{0.785 D_p^2}$$

$$\phi_s := \frac{15 \cdot 10^{-3}}{0.785 \times 0.142025^2}$$

$$\phi_s = 0.947$$

Density of fluid(steam)

$\rho_f := \rho_{water}$

$\rho_f = 1 \times 10^3 m^{-3} \cdot kg$

Frictional factor which is a function of Nre

$$f_m := \frac{100}{N_{RE}}$$

$$f_m = 40.556$$

Therefore, pressure drop

$$\Delta P := \frac{2 \cdot f_m \cdot G^2 \cdot L_{pb} \cdot (1 - \varepsilon)^{3-n}}{D_p \cdot g_c \cdot \rho_f \cdot \phi_s^{3-n} \cdot \varepsilon^3}$$

$$\Delta P = 1.8 \times 10^{-5} m^3 \cdot kg^{-1}$$

The observed insignificant pressure drop is expected considerng that it takes place under atmospheric pressure. Approximate velocity drop can be calculated using velocity head concept.

$$\Delta P = \Delta h = 50\left(\frac{v^2}{2.g_c}\right)$$

$$\frac{0.000138}{g_c} = 50\left(\frac{v^2}{2.g_c}\right)$$

This implies that, velocity (v)

$$v := \sqrt{\frac{\Delta P \cdot 2}{50} \cdot \frac{kg}{s}}$$

$$v = 8.486 \times 10^{-4} kg \cdot s^{-1}$$

This implies that the actual mass velocity of steam from the boiler to the column should be maximum

$$V_{act} := v + F_4$$

$$V_{act} = 0.015 kg \cdot s^{-1}$$

6.2.2 Detail chemical design of the condenser

Fluids allocation

Essential oil is corrosive and there for allocated to the tube side while water is allocated to the shell side since it is not corrosive.

Type of consenser selected

A simple square pitch and a 1 pass tube

Cooling water flowrate

$T_{h\_in} := 373.15K$ $\quad$ $T_{h\_out} := 313.15K$

$T_{c\_in} := 298.15K$ $\quad$ $T_{c\_out} := 323.15K$

cooling water flow rate

$$C_{wf} := \frac{-Q_{condenser}}{\int_{T_{c\_in}}^{T_{c\_out}} C_{p\_water}\,dT}$$

$$C_{wf} = 146.881 \cdot \frac{kg}{hr}$$

Calculation of heat transfer area of the condenser

Heat transfer area of the condenser.

$$-Q = U \cdot A_{condenser} \cdot \Delta Tm$$

U = overall convection coefficient and it is given as $U := 540 \frac{W}{m^2 \cdot K}$

DTm = log mean temperature difference

A = the heat transfer area

$$\Delta Tm_i := \frac{\left(T_{h\_in} - T_{h\_out}\right) - \left(T_{c\_out} - T_{c\_in}\right)}{\ln\left(\frac{T_{h\_in} - T_{h\_out}}{T_{c\_out} - T_{c\_in}}\right)}$$

$$\Delta Tm_i = 39.979 K$$

Calculation for dimensionless temperature for one pass and two tubes passes

$$R := \frac{T_{h\_in} - T_{h\_out}}{T_{c\_out} - T_{c\_in}} \qquad R = 2.4$$

$$S := \frac{T_{c\_out} - T_{c\_in}}{T_{h\_in} - T_{c\_in}} \qquad S = 0.333$$

Temperature correlation factor from graph $F_t := 0.85$

Therefore Actual ΔTm

$$\Delta Tm := F_t \cdot \Delta Tm_i$$

$$\Delta Tm = 33.982 K$$

$$A_{trial} := \frac{-Q_{condenser}}{\Delta Tm \cdot U}$$

$$A_{trial} = 0.233 \cdot m^2$$

The above area calculated is the trial area At

From standard then following parameters were chosen

Internal diameter	$D_i := 16mm$	$D_i = 0.016\,m$
Outer diameter	$D_o := 20mm$	$D_o = 0.02\,m$
Tube length	$L_{tb} := 550mm$	$L_{tb} = 0.55\,m$
Allowance for welding	$A_{fw} := 10mm$	$A_{fw} = 0.01\,m$
Actual tube length	$L_{atb} := L_{tb} - A_{fw}$	$L_{atb} = 0.54\,m$
Area of one tube	$A_s := D_o \cdot \pi \cdot L_{atb}$	$A_s = 0.034\,m^2$
Number of tubes	$N_t := \frac{A_{trial}}{A_s}$	$N_t = 6.881$
Using square pitch and a 1 pass tube.	$P_t := 1.25 \cdot D_o$	$P_t = 0.025\,m$
	$K_1 := 0.215$	$n_1 := 2.207$
Tube bundle diameter	$D_b := D_o \cdot \left(\frac{N_t}{K_1}\right)^{\frac{1}{n_1}}$	$D_b = 0.096\,m$

Allow bundle clearance of of 10mm. therefore

Bundle clearance	$B_c := 10mm$	$B_c = 0.01\,m$
Number of tube in the center row (Nr)	$N_r := \frac{D_b}{P_t}$	$N_r = 3.847$
Shell side diameter	$D_s := B_c + D_b$	$D_s = 0.106\,m$

Tube side calculations;

water mean temperature	$T_t := \frac{T_{c\_in} + T_{c\_out}}{2}$	$T_t = 310.65\,K$

Tube cross sectional area	$T_{csa} := \frac{\pi}{4} \cdot D_i^2$	$T_{csa} = 2.011 \times 10^{-4} m^2$
Tube per pass	$T_{pp} := \frac{N_t}{2}$	$T_{pp} = 3.44$
Total flow area	$A_{tf} := T_{pp} \cdot T_{csa}$	$A_{tf} = 6.917 \times 10^{-4} m^2$
Water flow rate	$C_{wf} = 0.041 kg \cdot s^{-1}$	
Water mass velocity	$W_{mv} := \frac{C_{wf}}{A_{tf}}$	$W_{mv} = 58.983 m^{-2} \cdot kg \cdot s^{-1}$
Density of water	$\rho_{water} = 1 \times 10^3 m^{-3} \cdot kg$	
Water viscousity	$\mu_w = 8 \times 10^{-4} m^{-2} \cdot s \cdot N$	
Water linear velocity	$V_L := \frac{W_{mv}}{\rho_{water}}$	$V_L = 0.059 m \cdot s^{-1}$
Heat transfer coefficient	$H_i = C_{p\_water} \cdot \left(\frac{1.35 + D_o T_t}{D_i^2} \right) \cdot V_L^{0.8}$	
	$T_t = 310.65K - 273.15 = 37.5°C$	
	$H_i := 4200 \cdot \left(\frac{1.35 + 0.02 \cdot 310.65}{0.016^2} \right) \cdot 0.058983^{0.8} \cdot \frac{W}{m^2 K}$	
	$H_i = 1.289 \times 10^7 \cdot \frac{W}{m^2 K}$	
Reynolds	$R_{ey} := \frac{W_{mv} \cdot D_i}{\mu_w}$	$R_{ey} = 1.18 \times 10^3$

Shell side calculations

Mean temperature of shell side	$T_s := \frac{T_{h\_in} + T_{h\_out}}{2}$	$T_s = 343.15K$
Choice of baffle spacing	$B_{sc} := \frac{D_s}{5}$	$B_{sc} = 0.021 m$
Using square pitch and a 1 pass tube.	$P_t := 1.25 \cdot D_o$	$P_t = 0.025 m$

Cross flow area $A_{cf} := \left[\frac{(P_t - D_o)\cdot B_{sc}\cdot D_s}{P_t}\right]$ $A_{cf} = 4.509\times 10^{-4}\,m^2$

Mass flow rate of oil $F_{2a} = 0.016\,kg\cdot s^{-1}$

Oil mass velocity $O_{mv} := \frac{F_{2a}}{A_{cf}}$ $O_{mv} = 36.566\,m^{-2}\cdot kg\cdot s^{-1}$

Equivalent Diameter $D_{eq} := \frac{1.27}{D_o}\cdot\left(P_t^{\,2} - D_o^{\,2}\right)$ $D_{eq} = 0.014\,m$

Oil viscousity $\mu_{oil} := 6.92\cdot 10^{-4}\,N\cdot m^{-2}s$

Density of steam+oil $\rho_{ow} := 876.43\,kg\cdot m^{-3}$

Oil linear velocity $V_{L\_oil} := \frac{O_{mv}}{\rho_{ow}}$ $V_{L\_oil} = 0.042\,m\cdot s^{-1}$

Heat capacity $C_{ap} := 7200\,J\cdot kg^{-1}\cdot K^{-1}$

Thermal conductivity $K_f := 1.242\,W\cdot m^{-1}K^{-1}$

Reynolds $Re := \frac{O_{mv}\cdot D_{eq}}{\mu_{oil}}$ $Re = 754.963$

Prandtle Number $Pr := \frac{C_{ap}\cdot\mu_{oil}}{K_f}$ $Pr = 4.012$

From chart at15% baffle cut $j_h := 2.5\cdot 10^{-2}$

Take into account viscousity correction the heat transfer coefficient h_s can be calculated from Nusselt equation

$$Nu = h_s\cdot\frac{D_{eq}}{K_f} = j_h\cdot Re\cdot Pr^{0.33}\left(\frac{\mu_{oil}}{\mu_w}\right)^{0.14}$$

This implies that

$$h_s := j_h\cdot Re\cdot Pr^{0.33}\cdot\left(\frac{\mu_{oil}}{\mu_w}\right)^{0.14}\cdot\frac{K_f}{D_{eq}}$$

$$h_s = 2.543 \times 10^3 \cdot \frac{W}{m^2 K}$$

Estimate tube wall temperature

Mean temperature difference

$$T_{md} := T_s - T_t$$

$$T_{md} = 32.5 K$$

Heat transfer coefficient $U := 540 \frac{W}{m^2 \cdot K}$

Mean temperature difference across the oil film

$$T_{mc} := \left(\frac{U}{h_s}\right) \cdot T_{mc}$$

$$T_{mc} = 6.902 K$$

Mean wall temperature

$$T_{mw} := T_s - T_{mc}$$

$$T_{mw} = 336.248 K$$

Thermal conductivity K_w of tube wall material (aluminium alloy) $K_w := \alpha$

Inside fluid coefficient $h_{id} := 10800 W \cdot m^{-2} K^{-1}$

outside fluid coefficient $h_{od} := 10800 W \cdot m^{-2} K^{-1}$

Overal heat transfer coefficient U_{ov} is given by the relationship below

$$U_{ov} = \frac{1}{\frac{1}{h_s} + \frac{1}{h_{od}} + \frac{D_o \cdot \ln\left(\frac{D_o}{D_i}\right)}{2K_w} + \frac{\frac{D_o}{D_i}}{h_{id}} + \frac{\frac{D_o}{D_i}}{H_i}}$$

$$U_{ov} := \frac{1}{\frac{1}{1751.002} + \frac{1}{10800} + \frac{0.02 \cdot \ln\left(\frac{D_o}{D_i}\right)}{2 \times 275.9} + \frac{\frac{D_o}{D_i}}{10800} + \frac{\frac{D_o}{D_i}}{12890949.640}} \cdot \frac{W}{m^2 K}$$

$$U_{ov} = 1.27 \times 10^3 \cdot \frac{W}{m^2 K}$$

New heat transfer area for the condenser is given by

New Area $A_{new} := \frac{-Q_{condenser}}{U_{ov} \cdot \Delta Tm}$

$$A_{new} = 0.099 m^2$$

This show a great reduction in the heat transfer area required for the condenser

6.2.3 Detail mechanical design of the column extractor

(1) Shell:

Diameter = 2.3 m

Operating pressure = 1 atm = $0.00010329 \frac{kg}{m^2}$

Design pressure = 1.1 * operating pressure = 1.1 * 0.00010329 = $0.00011362 \frac{kg}{m^2}$

Operating temperature = 97 oC

Design temperature = 1.1 * 97 = 106.7 oC

Shell material Carbon
steel
Shell Double welded bolt joints stress
relieved

Allowable stress for shell material $0.095 \frac{kg}{m^2}$

Insulation material Asbestos

Density of insulation $0.0575 \frac{kg}{m^2}$

(2) Head: Torosperical dished head

Material
Carbon steel

Allowable tensile stress $0.095 \frac{kg}{m^2}$

(1) Calculations of shell thckness:

Considering the vessel as an internal pressure vessel.

Thickness of shell (m) t_s

Design pressure $P := 0.00011362 \frac{kg}{m^2}$

Diameter of the shell $D_i := 2.3m$

Allowable / permissible tensile stress $f := 0.095 \frac{kg}{m^2}$

Corrosion allowance $C := 0.002m$

Joint efficiency ; Considering double welded butt joint with backing strip J = 85%

$J := 0.85$

$$t_s := \frac{P \cdot D_i}{(2 \cdot f \cdot J) - P} + C$$

$t_s = 3.619 \times 10^{-3} m$

Taking the thickness of the shell as $t_s = 0.006$ m

(2) Head shallow dished or torospherica head:

Crown radius = outer diameter of the shell (R_c)

But $t_s := 0.006m$

$R_c := D_i + 2 \cdot t_s$

$R_c = 2.312m$

Knukle radius (R_k)

$R_k := 0.06 \cdot R_c$

$R_k = 0.139m$

W = stress intensification factor

$$W := \frac{1}{4}\left(3 + \sqrt{\frac{R_c}{R_k}}\right)$$

$W = 1.771$

$$t_h := \frac{P \cdot R_c \cdot W}{2 \cdot f \cdot J}$$

$t_h = 2.88 \times 10^{-3} m$

Therefore, thickness of head is $t_h = 0.006$ m

Weight of head

Inside cover radius $i_{cr} := 0.019m$

Straight flange length $S_f := 0.038m$

$\rho_s := 7700 \frac{kg}{m^3}$ $h := 5.994 \cdot 10^{-3} m$

$$D := R_c + \frac{R_c}{24} + 2 \cdot S_f + \frac{2}{3} \cdot i_{cr}$$

$D = 2.497 m$

Weight of head (W_h)

$$W_h := \frac{\pi}{4} \cdot D^2 \cdot h \cdot \rho_s$$

$W_h = 226.014 kg$

Weight of head = 2670

(3) Calculation of stresses:

(i) Axial tensile stress due to pressure

$$f_{ap} := \frac{P \cdot D_i}{4(t_s - C)}$$

$f_{ap} = 0.016 m^{-2} \cdot kg$

This is the same throughout the column height.

(ii) Circumferential stress due to pressure

$$C_p := 2 \cdot f_{ap}$$

$$C_p = 0.033\,m^{-2} \cdot kg$$

(iii) Compressive stress due to dead loads:

(a) Compressive stress due to weight of shell up to a distance x metre.

fds = Weight of shell / Cross-sectional area of shell

$$f_{ds} = \frac{\frac{\pi}{4} \cdot \left(R_c^{\,2} - D_i^{2}\right) \cdot \rho_s \cdot x}{\frac{\pi}{4} \cdot \left(R_c^{\,2} - D_i^{2}\right)}$$

Where D_i and R_c = Internal and external diameters of shell.

ρ_s = density of shell.

Also,

f_{ds} = Weight of shell per height of x X / $D_m(t_s\text{-}C)$

D_m = Mean diameter of the shell

t_s = thickness of the shell

C = Corrosion allowance

$$f_{ds} = \rho_s \cdot x$$

But $\rho_s = 7.7 \times 10^3\,m^{-3} \cdot kg$

$$f_{ds} := 0.77 \cdot x \quad \frac{kg}{m^2}$$

(b) Compressive stress due to weight of insulation at height x (m)

$$f_{dins} = \frac{\pi \cdot D_{ins} \cdot t_{ins} \cdot \rho_{ins} \cdot x}{\pi \cdot D_m \cdot \left(t_s - C\right)}$$

D_{ins} = Diameter of insulation

t_{ins} = Thickness of insulation

s = Density. of insulation

$$D_m := \frac{D_i + (D_i + 2 \cdot t_s)}{2}$$

Assuming that asbestos is the insulation material.

$\rho_{ins} := 0.000575 \frac{kg}{m^3}$ $t_{ins} := 0.075m$

$D_{ins} := D_i + 2 \cdot t_s + 2 \cdot t_{ins}$

$D_{ins} = 2.462\,m$

$D_m = 2.306\,m$

$$f_{dins} := \frac{\pi \cdot D_{ins} \cdot t_{ins} \cdot \rho_{ins} \cdot x}{\pi \cdot D_m \cdot (t_s - C)}$$

$f_{dins} = 4.604 \times 10^{-4} m^{-3} \cdot kg$

(c) Tensile stress due to wind loads in self supporting vessel

$$f_{wx} = \frac{M_w}{Z}$$

M_w = bending moment due to wind load = (wind load x distance)/2

$$M_w = \frac{0.7 \cdot P_w \cdot D_m \cdot x^2}{2}$$

Z = modulus for the area of shell

$$Z := \frac{\pi}{4} \cdot D_m^2 (t_s - C)$$

$$f_{wx} = \frac{0.7 \cdot P_w \cdot D_m \cdot x^2}{2 \cdot \frac{\pi}{4} \cdot D_m^2 \cdot (t_s - C)} = \frac{1.4 \cdot P_w \cdot x^2}{\pi\, D_m (t_s - C)}$$

P_W = wind pressure $\quad P_W = 219.42\,\frac{kg}{m^2}$

$$M_W = \frac{0.7 \cdot 219.42 \cdot 2.306}{2} \cdot x^2 = 177.09 \cdot x^2$$

But $\quad Z = 0.017\,m^3$

$$f_{wx} = \frac{177.09}{0.017} \cdot x^2 = 10604.2 \cdot x^2\,\frac{kg}{m^2}$$

Stress due seismic load are neglected.

Calculation of resultant longitudinal stress (upwind side)

Tensile:

$f_{tmax} = f_{wx} + f_{ap} - f_{ds}$

f_{wx} = Stress due to wind load.

f_{ap} = Axial tensile stress due to pressure.

f_{ds} = Stress due to dead loads.

$$f_{tmax} = 1.0604 \cdot x^2 + 163.33 - 0.77 \cdot x$$

$f_{tmax} := f \cdot J \qquad f_{tmax} = 0.081\,m^{-2} \cdot kg$

$$1.0604 \cdot x^2 - 0.77 \cdot x + 163.33 = 810$$

$$1.0604 \cdot x^2 - 0.77 \cdot x - 646.67 = 0$$

$a := 1.0604 \qquad b := -0.77 \qquad c := -646.67$

$$x := \frac{-b + \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a}$$

$x = 25.061 \quad m$

Calculation of resultant longitudinal stress (downwind side)(compressive)

$f_{tmax} = f_{wx} - f_{ap} + f_{ds}$

$f_{tmax} = 1.0604 \cdot x^2 - 163.33 + 0.77 \cdot x$

$a := 1.0604 \qquad b := 0.77 \qquad c := -163.33$

$$x := \frac{-b + \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a}$$

$x = 12.053$ m

$(f_{tmax}) = 152.91$ kg/cm^2 (therefore, compressive)

Hence $f_{cmax} = 0.125 \cdot E\left(\frac{t}{D_o}\right)$

E = Elastic modulus $E = 2 \cdot 10^6 \frac{kg}{cm^2}$

t = tensile stress = 6 mm

Do = external diameter = 2312 mm

$f_{cmax} := 0.125 \cdot 2 \cdot 10^6 \cdot \left(\frac{6}{2312}\right)$

$f_{cmax} = 648.789 \quad \frac{kg}{cm^2}$

$648.79 = 1.0604 \cdot x^2 - 163.33 + 0.77 \cdot x$

$1.0604 \cdot x^2 + 0.77 \cdot x - 812.12 = 0$

$a := 1.0604 \qquad b := 0.77 \qquad c := -812.12$

$$x := \frac{-b + \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a}$$

$x = 27.314$ m

Since the calculated height is greater than the actual column height. So it can be concluded that the design is safe thus design calculations are acceptable.

6.2.4 Detail mechanical design of the condenser

(a) Shell:

Shell material: Carbon steel (Corrosion allowance = 3 mm)

Number of shells = 1

Number of passes = 6

Working pressure = 1 atm

Design pressure = 1.1 x working pressure = 1.1 x 0.101 = 0.11N/mm^2

Temperature of the inlet = 64.6 ^oC

Temperature of the outlet = 64.6 ^oC

Permissible tensile stress $f := 95\frac{N}{mm^2}$

(b) Tube side:

Number of tubes = 1740

Outside diameter = 0.0191 m

Inside diameter = 0.0157 m

Length = 2.5 m

Pitch = 25.4*10^-3 m

Feed = water

Working pressure = 1 atm

Design pressure = 1.1 x working pressure = 1.1 x 0.101 = 0.11N/mm^2

Temperature of the inlet = 97 ^oC

Temperature of the outlet = 40 ^oC

shell side:

Thickness of shell (m) t_s

Design pressure $P := 0.11\frac{N}{mm^2}$

Diameter of the shell $D_i := 1219mm$

Permissible tensile stress $f := 95 \frac{N}{mm^2}$

Corrosion allowance $C := 3mm$

Joint efficiency ; Considering double welded butt joint with backing strip J = 85%

$J := 0.85$

$$t_s := \frac{P \cdot D_i}{(2 \cdot f \cdot J) - P}$$

$t_s = 0.831 \cdot mm$

Minimum thickness = 6.3 mm (Including corrosion allowance)

Therefore, $t_s = 8$ mm.

(2) Head: (Torrispherica head)

$$t_h = \frac{P \cdot R_c \cdot W}{2 \cdot f \cdot J}$$

th = thickness of head

Crown radius = outer diameter of the shell (R_c)

$R_c := 1219mm$

Knukle radius (R_k)

$R_k := 0.06 \cdot R_c$

$R_k = 73.14 \cdot mm$

W = stress intensification factor

$$W := \frac{1}{4}\left(3 + \sqrt{\frac{R_c}{R_k}}\right)$$

$W = 1.771$

$$t_h := \frac{P \cdot R_c \cdot W}{2 \cdot f \cdot J}$$

$t_h = 1.47 \cdot mm$

Therefore, minimum shell thickness should be = 10 mm

Since for the shell, there are no baffles, tie-nods and spacers are not required.

Flanges:

Loose type except lap-joint flange

Design pressure (P) = 0.11N/mm^2

Flange material: IS:2004-1962 class 2

Bolting steel: 5% Cr Mo steel.

Gasket material = asbestos compositon

Shell side diameter = 1219 mm

Shell side thickness = 10 mm

$d_i := 1219mm$ $\qquad$ $t_s := 10mm$

Outside diameter of shell (d_o)

$d_o := d_i + 2 \cdot t_s$ $\qquad$ $d_o = 1.239 \times 10^3 \cdot mm$

Determination of gasket width:

$$\frac{d_o}{d_i} = \left[\frac{Y - P \cdot m}{Y - P \cdot (m + 1)}\right]^{\frac{1}{2}}$$

Gasket material chosen is asbestos with a suitable binder for the operating conditions

Y = Yield stress $\qquad$ $Y := 25.5 \frac{N}{mm^2}$ $\qquad$ i.e (2.60*9.81)

$m := 2.75$

$$B := \frac{d_o}{d_i}$$

$$B := \left[\frac{Y - P \cdot m}{Y - P \cdot (m + 1)}\right]^{\frac{1}{2}} \qquad B = 1.002$$

d_i = inside diameter of gasket = outside diameter of shell = 1239 + 5 mm = 1244 mm.

d_o = outside diameter of the gasket = 1.004 (1244) = 1249 mm.

Minimum gasket width $\frac{1.249 - 1.244}{2} = 2.5 \times 10^{-3}$ m = 2.5 mm

But minimum gasket width = 6 mm

Therefore, G = 1.244 + 2(0.006) = 1.256 m.

G = diameter at the location of gasket load reaction.

Calculation of minimum bolting area:

Minimum bolting area (A_m) = $A_g = \frac{W_g}{S_g}$

S_g = Tensile strength of bolt material (MN/m^2)

Consider, 5% Cr-Mo steel, as design matrial for bolt at 64°C

But, $S_g := 138 \cdot 10^6 \ \frac{N}{m^2}$ $W_g := 0.6037 \cdot 10^6$ N

$$A_g := \frac{W_g}{S_g}$$

$A_g = 4.375 \times 10^{-3}$ m^2

Calculation for optimum bolt size:

$$g_1 = \frac{g_0}{0.707} = 1.415 \cdot g_0$$

g_1 = thickness of the hub at the back of the flange

g_0 = thickness of the hub at the small end = 10 + 2.5 = 12.5 mm.

Selecting bolt size M 18 x 2

R = Radial distance from bolt circle to the connection of hub and back of flange.

C_b = Bolt circle diameter

$d_i := 1.219$ m $g_0 := 0.0125$ m $R := 0.027$

$$C_b := d_i + \left[2 \cdot \left(1.415 \cdot g_0 + R\right)\right]$$

$C_b = 1.308$ m

Estimation of bolt loads:

Load due to design pressure (H) $H = \frac{\pi}{4} \cdot G^2 \cdot P$

$G := 1.256\text{m}$ $P := 0.11 \cdot 10^6 \frac{N}{m^2}$

$$H := \frac{\pi}{4} \cdot G^2 \cdot P$$

$$H = 1.363 \times 10^5 \cdot N$$

Load to keep the joint tight under operating conditions.

But $g := G$ $b := 0.006\text{m}$ (Gasket width)

$H_p := \pi \cdot g \cdot 2 \cdot b \cdot m \cdot P$ $H_p = 1.432 \times 10^4 \cdot N$

Total operating load (W_o)

$W_o := H + H_p$ $W_o = 1.506 \times 10^5 \cdot N$

Load to seat gasket under bolt - up condition = W_g

And $y := 25.5 \cdot 10^6 \frac{N}{m^2}$

$W_g := \pi \cdot g \cdot b \cdot y$ $W_g = 6.037 \times 10^5 \cdot N$

$W_g > W_o$ Therefore W_g is the controlling load.

Actual flange outside diameter (A)

$b_d := 0.015$ m (Bolt diameter)

$$A := C_b + b_d + 0.02$$

$A = 1.343$ m

Check for gasket width

A_b minimum bolt area

$A_b := 44 \cdot 1.54 \cdot 10^{-4}$ $A_b = 6.776 \times 10^{-3}$

$$\frac{A_b \cdot S_g}{\pi \cdot G \cdot N} = \frac{6.776 \cdot 10^{-3} \cdot 138}{\pi \cdot 1.256 \cdot 0.012} = 19.75 \frac{N}{mm^2}$$

$$2 \cdot y = 2 \cdot 25.5 = 51 \frac{N}{mm^2}$$

$\frac{A_b \cdot S_g}{\pi \cdot G \cdot N} > 2y$ i .e., bolting conditon is satisfied.

Flange moment calculations:

(a) For operating conditions:

$W_o = W_1 + W_2 + W_3$

$B := 1.239$ $P := 0.11 \cdot 10^6$

$W_1 := \frac{\pi}{4} \cdot B^2 \cdot P$ = Hydrostatic end force on area inside of flange.

Where, B = outside shell diameter

$W_1 = 1.326 \times 10^5$ N

But, $H := 1.363 \cdot 10^5$

$W_2 := H - W_1$ $W_2 = 3.675 \times 10^3$ N

W_3 = gasket load = W_Q - H = H_p

$W_3 := H_p$ $W_3 := 1.432 \cdot 10^4$ N

$W_o := W_1 + W_2 + W_3$

$W_o = 1.506 \times 10^5$ N

Mo = Total flange moment = $W_1a_1+W_2a_2+W_3a_3$

$C := 1.308$ $B = 1.239$ $G := 1.256$

$a_1 := \frac{C - B}{2}$ $a_1 = 0.034$

$a_3 := \frac{C - G}{2}$ $a_3 = 0.026$

$a_2 := \frac{a_1 + a_3}{2}$ $a_2 = 0.03$

$M_o := W_1 \cdot a_1 + W_2 \cdot a_2 + W_3 \cdot a_3$

$M_o = 5.059 \times 10^3$ J

(b) For bolting up condition:

Mg = total bolting moment = W a3

$W = \dfrac{A_m + A_b}{2} \cdot S_g$ $\quad A_m := 4.375 \cdot 10^{-3}$ $\quad A_b := 67.76 \cdot 10^{-4}$

$W := \dfrac{A_m + A_b}{2} \cdot S_g$ $\quad W = 7.694 \times 10^5$

$M_g := W \cdot a_3$ $\quad M_g = 2 \times 10^4$ J

$M_g > M_o$ Therefore, M_g is the moment under operating conditions

$M := M_g$ $\quad M = 2 \times 10^4$ J

Calculation of the flange thickness:

$$t^2 = \frac{M \cdot C_f \cdot Y}{B \cdot S_{fo}}$$

C_f = Bolt pitch correction factor = $\sqrt{\dfrac{B_s}{2 \cdot d + t}}$

B_s = Bolt spacing $\quad$ n = number of bolts $\quad n := 44$

$B_s := \dfrac{\pi C}{n}$ $\quad B_s = 0.093$ m

Let $C_f := 1$

S_{fo} = Nominal design stresses for the flange material at design temperature.

$S_{fo} := 100 \cdot 10^6$

$K := \dfrac{A}{B}$ = Flange diameter / Inner shell diameter

$K = 1.084$

But, $Y := 24$ $d := 36 \cdot 10^{-3}$ m

$$t := \sqrt{\frac{M \cdot C_f \cdot Y}{B \cdot S_{fo}}} \qquad t = 0.062 \quad m$$

$$C_f := \sqrt{\frac{B_s}{2 \cdot d + t}} \qquad C_f = 0.834$$

Let t = 60 mm = 0.06 m

Tube sheet thickness:

$$T_s = G_c \cdot \sqrt{\frac{K \cdot P}{F}}$$

Gc = mean gasket diameter.

P = design pressure.

K = factor = 0.25 (when cover is bolted with full faced gasket).

F = permissible stress at design temperature.

$G_c := 1.256$ $K := 0.25$ $F := 95 \cdot 10^6$ $P = 1.1 \times 10^5$

$$T_s := G_c \cdot \sqrt{\frac{K \cdot P}{F}} \qquad T_s = 0.021 \quad m$$

Channel and channel cover

But, $K := 0.3$ for ring type gasket

$$T_h := G_c \cdot \sqrt{\frac{K \cdot P}{F}} \qquad T_h = 0.023 \quad m$$

Consider corrosion allowance = 0.004 m

$T_h = 0.004 + 0.023 = 0.027$ m

Saddle support

Material: Low carbon steel

Total length of shell: 4.877 m

Diameter of shell: 1.239 m

Knuckle radius $r_o := 0.06 \cdot d_o$ $r_o = 0.074\,\text{m}$

Total depth of head (H)

$$H := \sqrt{\frac{d_o \cdot r_o}{2}} \qquad H = 0.215\,\text{m}$$

Let $D := d_o$

$$R := \frac{D}{2} \qquad R = 0.027$$

Distance of saddle center line from shell end = A

$A := 0.5 \cdot R$ $A = 0.31\,\text{m}$ $A := 0.31$

Longitudinal bending moment

$$M_1 = Q \cdot A \cdot \left(1 - \frac{1 - \frac{A}{L} + \frac{R^2 - H^2}{2 \cdot A \cdot L}}{\frac{1+4 \cdot H}{3 \cdot L}} \right)$$

$W := 12681.25\text{kg}$ (Weight of shell and its contents)

$L := 4.877$ $H := 0.214$ $R := 0.62$

$$Q := \frac{W}{2} \cdot \left(L + \frac{4 \cdot H}{3} \right) \qquad Q = 3.273 \times 10^4 \text{kg} \quad \text{m}$$

$$M_1 := Q \cdot A \cdot \left[1 - \left[\frac{1 - \left(\frac{0.31}{4.877} + \frac{0.62^2 - 0.214^2}{2 \cdot 0.31 \cdot 4.877} \right)}{\frac{1+4 \cdot 0.214}{3 \cdot 4.877}} \right] \right]$$

$M_1 = 96.703\text{kg} \cdot \text{m}$

Bending moment at center of the span

$$M_2 := \frac{Q \cdot A}{4} \cdot \left[\frac{1 + \frac{2 \cdot \left(R^2 - H^2\right)}{L}}{\frac{1+4 \cdot H}{3 \cdot L}} - 4 \cdot \frac{A}{L} \right]$$

$I_2 = 2.213 \times 10^4 \,\text{kg} \quad \text{m}$

tresses in shell at the saddle

)At the topmost fibre of the cross-section

$I_1 := 96.703 \qquad K_1 := 1 \qquad K_2 := K_1 \qquad t := 0.008$

$$:= \frac{M_1}{K_1 \cdot \pi \cdot R^2 \cdot t} \qquad f_1 = 1.0096 \frac{\text{kg}}{\text{cm}^2}$$

he stress is well within the permissible values

) Stress in the shell at mid point

$$2 := \frac{M_2}{K_1 \cdot \pi \cdot R^2 \cdot t} \qquad f_2 = 229.058 \frac{\text{kg}}{\text{cm}^2}$$

) Axial stress in the shell due to internal pressure

$$f_p := \frac{P \cdot D}{4 \cdot t} \qquad f_p = 425.906 \frac{\text{kg}}{\text{cm}^2}$$

$$f_2 + f_p = 754.964 \frac{\text{kg}}{\text{cm}^2}$$

he sum f2 and fp is well within the permissible values.

6.2.5 Piping design

Jsing the standard nominal pipe and schedule 40, a 1.61in pipe of internal diameter on he schedule was selected.

ssumed diameter $d := 41 \,\text{mm}$

ensity of steam oil vapour mixture is assumed as that of steam $\rho_{so} := 995 \frac{\text{kg}}{\text{m}^3}$

team oil vapour mass flow rate $M := 58.169 \frac{\text{kg}}{\text{hr}}$

Viscosit $\mu := 0.8 \frac{\text{N} \cdot \text{s}}{\text{m}^2}$

Volumetric flow rate in m^3/hr

$V := \frac{M}{\rho_{so}}$ $\quad V = 0.058 \quad \frac{m^3}{hr}$

Vilumetric flow rate in ft^3/min

$V_f := \frac{V}{1} \cdot \left(\frac{3.2808}{1}\right)^3 \cdot \frac{1}{60}$ $\quad V_f = 0.034 \quad \frac{ft^3}{mir}$

Volumetric flow rate in m^3/sec

$V_s := \frac{V}{3600}$ $\quad V_s = 7.809 \times 10^{-7} s \cdot \frac{m^3}{s}$

Pipe sizing was performed in accordance with Darcy Rational relation for compressible vapors and gases.

$Re := \frac{50.6 \cdot V_s}{d \cdot \mu}$ $\quad Re = 2.505 \times 10^{-5}$

This is equivalent to a laminar regime

From the Chart the friction factor Γ was calculated as

$\Gamma := \frac{64}{Re}$ $\quad \Gamma = 2.555 \times 10^6$

$g := 9.81 \quad \frac{m}{sec}$

Assuming a length of 1.5m between the coulum extractor and the condenser $L := 1.5$

$\Delta P_1 := \frac{\Gamma \cdot L \cdot V_s^2}{2 \cdot g}$ $\quad \Delta P_1 = 5.151 \times 10^{-5} \quad \frac{N}{m^2}$

A long radius screwed 90o elbow was selected to link the tank still and the condenser. From the chart at 1.61in, the resistance coefficient K was 0.46

$K := 0.46$

$\Delta P_2 := \frac{\Gamma \cdot K \cdot V_s^2}{2 \cdot g}$ $\quad \Delta P_2 = 1.58 \times 10^{-5} \quad \frac{N}{m^2}$

$\Delta P_t := \Delta P_2 + \Delta P_1 \qquad \Delta P_t = 6.73 \times 10^{-5} \; \frac{N}{m^2}$

The pressure drop is insignificant thus the pipe selection is acceptable.

$1.61\text{in} = 0.041\,\text{m}$

41mm internal diameter and outer diameter 48mm are adequate.

To calculate the minimum pipe thickness assuming a ccorrosion allowance of 3mm.

$P := 0.10133 \qquad D_o := 48 \qquad f := 81 \qquad c := 3$

$$t := \left(\frac{P \cdot D_o}{2f - P}\right) + c \qquad t = 3.03$$

t = thickness(mm)

P = design pressure(N/mm^2)

f = design stress (81N/mm^2,stainless steel)

c = corrosion allowance (mm)

D_o = outer diameter (mm)

Having consider the general piping system for the column extractor and the condenser, the piping arrangement for the separator is also considered below.

6.2.6 Piping Arrangement for the separator

To minimise entrainment by the jet of the liquid entering the vessel, the inlet velocity for a seperator should keep below 1 m/s.

Let inlet velocity of separator $\quad V_{inlet} := 1 \cdot \frac{m}{s}$

Density of oil $\quad \rho_d := 876.2 \frac{kg}{m^3}$ $\qquad$ Flow rate of oil $\quad F_d := 11.853 \frac{kg}{hr}$

Density of water $\quad \rho_c := 992.65 \frac{kg}{m^3}$ $\qquad$ Flow rate of oil $\quad F_c := 50 \frac{kg}{hr}$

$$\text{Flow\_Rate} := \left(\frac{F_d}{\rho_d} + \frac{F_c}{\rho_c}\right)$$

$\text{Flow\_Rate} = 3.691 \times 10^{-4} s^{-1}$

$$\text{Area\_of\_pipe} := \frac{\text{Flow\_Rate}}{V_{inlet}}$$

$$\text{Area\_of\_pipe} = 1.775 \times 10^{-5} \cdot m^2$$

$$\text{Pipe\_diameter} := \sqrt{\frac{4(\text{Area\_of\_pipe})}{\pi}}$$

$$\text{Pipe\_diameter} = 0.013$$

Take the position of the interface as half-way up the vessel and the light liquid off-take as at 90% of the vessel height , then

$Z_1 := 98\% \cdot H_{sep}$ $\quad Z_1 = 1.434$

$Z_3 := 90\% \cdot H_{sep}$ $\quad Z_3 = 1.317$

Where,

$Z._1$ = height from datum to the light liquid overflow, m

$Z._2$ = height from datum to the heavy liquid overflow, m

$Z._3$ = height from datum to the interface, m

Since Z_1 and Z_3 are known, Z_2 can be calculated as follows:

$$(Z_1 - Z_3) \cdot \rho_d \cdot g + Z_3 \cdot \rho_c \cdot g = Z_2 \cdot \rho_c \cdot g$$

$$Z_2 = \frac{\rho_d \cdot Z_1 - \rho_d \cdot Z_3 + Z_3 \cdot \rho_c}{\rho_c}$$

$$Z_2 := \frac{(Z_1 - Z_3) \cdot \rho_d}{\rho_c} + Z_3$$

$$Z_2 = 1.42$$

Drain values should be fitted at the interface so that any tendency for an emulsion to form can be checked; and the emulsion accumulating at the interface drained off periodically as necessary.

CHAPTER SEVEN

7.0 EQUIPMENT OPTIMIZATION

In optimizing any equipment, 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 reactor or equipment must be an economical one. This is because for any chemical plant set up, the primary objective is to maximize profits.

7.1 EQUIPMENT OPTIMIZATION

The optimization of the storage tank, which is used in the storage of product produced from this plant designed is carried out as shown below.

7.1.2 OPTIMIZATION OF THE CONVERTER USING THE PRINCIPLE OF MINIMIZING THE LENGTH AND DIAMETER

The storage tank can also be optimized using the fact that, in order to minimize cost of construction of the storage tank, the length and diameter of the tank must be kept at minimum.

Since the storage tank is a tubular type, it is said to have a cylindrical shape.

That is, the total surface area of the storage tank is given as

$$A_r = 2\cdot\pi\cdot r^2 + 2\cdot\pi\cdot r\cdot H$$

and $r = \frac{D}{2}$

where r = "radius of the reactor tube"

D = "diameter of the reactor"

H = "height of the reactor"

π = "pie, a constant"

So, the formula becomes

$$A_r = 2\cdot\pi\cdot r^2 + 2\cdot\pi\cdot r\cdot H$$

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

$$A_r = 2\cdot\pi\cdot\frac{D^2}{4} + 2\cdot\pi\cdot\frac{D}{2}\cdot H$$

$$A_r = \pi\cdot\frac{D^2}{2} + \pi\cdot D\cdot H$$

One can now say that the area of the reactor is a function of the diameter and length of the reactor. That is, mathematically,

$$A_r = f(D,H)$$

where $A_r = \pi\cdot\frac{D^2}{2} + \pi\cdot D\cdot H$ is the objective function and D = minimum and H = minimum are the constraints that are to be minimized.

so that the equation of A_r becomes

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

Noting that the volume of the tank is given as

$$V_r = \pi\cdot r^2\cdot H$$

with $r = \frac{D}{2}$

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

$$V_r = \pi \cdot \frac{D^2}{4} \cdot H$$

Making H the subject of the formula in the above equation,

$$H = \frac{4 \cdot V_r}{\pi \cdot D^2}$$

substituting the expression of H into the equation of total area of the tank which is a function of distance, D, and height ,H, it is obtained that

$$f(D,H) = \pi \cdot \frac{D^2}{2} + \pi \cdot D \cdot \frac{4 \cdot V_r}{\pi \cdot D^2}$$

Simplifying,

$$f(D,H) = \pi \cdot \frac{D^2}{2} + \pi \cdot \frac{4 \cdot V_r}{\pi \cdot D}$$

Now, it can be observed that the term of H has disappeared. That is to say that the total surface area is now a function of only the diameter, D. As such, the expression can be rewritten as

$$f(D) = \pi \cdot \frac{D^2}{2} + \pi \cdot \frac{4 \cdot V_r}{\pi \cdot D}$$

Since the aim here is to optimize, it may either be maximizing or minimizing. In this case, the aim is to maximize buy to minimize the dimension of the tank so that the size can be less, consequently, the profit can be much.

Differentiating the above equation,

$$\frac{d}{dD} f(D) = \pi \cdot D - \frac{4}{D^2} \cdot V_r$$

To optimize, the differential will be equated to zero, that is,

$$\frac{d}{dD}f(D) = \pi \cdot D - \frac{4}{D^2} \cdot V_r = 0$$

Taking the last two expressions,

$$\pi \cdot D - \frac{4}{D^2} \cdot V_r = 0$$

simplifying and making D the subject of the formula

$$\pi \cdot D = \frac{4}{D^2} \cdot V_r$$

$$D^2 \cdot D = \frac{4 \cdot V_r}{\pi}$$

$$D^3 = \frac{4 \cdot V_r}{\pi}$$

$$D = \sqrt[3]{\frac{4 \cdot V_r}{\pi}}$$

- The above expression is now the optimized diameter of the reactor.

Using the relatioship between the height of the reactor and the diameter given as

$$H = \frac{4 \cdot V_r}{\pi \cdot D^2}$$

Substituting for D in this expression yields

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

Simplifying,

$$H = \frac{V_r^{\frac{1}{3}}}{\pi^{\frac{1}{3}}} \cdot \sqrt[3]{2^2}$$

Numerically, with

$V_r := 45m^3$

$$D := \sqrt[3]{\frac{4 \cdot V_r}{\pi}} \qquad D = 3.855m$$

$$H := \frac{V_r^{\frac{1}{3}}}{\pi^{\frac{1}{3}}} \cdot \sqrt[3]{2^2} \qquad H = 3.855m$$

Thus, it, therefore, means that the optimum diameter and height of the tank are the same and have the same value of $D = 3.855m$ and $H = 3.855m$.

Taking cost as the objective function, which is always the primary objective of any set-up, the optimum dimension is almost given as $H = 2 \cdot D$

CHAPTER EIGHT

8.0 SAFETY AND QUALITY CONTROL

In designing a plant, safety is one of the major criteria for selection of the best alternative along with economic viability. Safety becomes even more pertinent when the materials involved are hazardous because value should be placed on the operating personnel and the equipment handled. Safety measures are then recommended to fit into the plant design. Since essential oil is a volatile substances the following recommendation are important in handling it.

8.1 General Recommendations

Written procedures detailing requirements for proper handling, safety equipment, first aid training, unloading and loading procedures are good practice and in many cases, required by law. They should include detailed instructions for handling and reporting spills. Considerable care should be taken when transferring essential oil to maintain high product quality. These same careful practices will ensure the health and safety of workers, and ensure that no essential oil is allowed to escape into the air, soil or water. An above ground tank must be used whenever a large volume of essential oil is to be stored at a customer or terminal site. Storage tanks should be large enough to contain a minimum of 150% of the normal delivery volume. The tank should be monitored closely during the initial filling with essential oil to check for leaks not detected during water testing.

Storage tanks may be mounted horizontally or vertically. All local regulations concerning above ground storage tanks should be reviewed and all permits obtained before installing a bulk storage system. Bulk storage containers should be constructed of either mild, or stainless steel. Storage tanks should not be constructed of , nor contain, any non compatible plastic components. The storage tanks exterior should be cleaned, primed and painted with a white or aluminum colored paint to aid in keeping the tank and its contents cool.

A storage tank pads or saddles

Saddles used to support horizontal tanks may be constructed of reinforced concrete or steel. The design of the concrete pad or saddle foundation (if horizontal) should be based on at least the total weight of the tank filled with essential oil.

B Dikes

All storage tanks should be diked to contain the tank contents in the event of a spill or tank rupture. They should be large enough to contain the tank's volume, and an additional appropriate volume as safety factor. (Containment volumes and diking requirements are often defined and mandated by individual states and localities. Regulations must be reviewed prior to construction.)

Dikes may be constructed of concrete or concrete treated with an essential oil resistant. Where diking does not apply, essential oil resistant buckets or other appropriate portable spill containers should be used.

C Piping

Carbon or stainless steel is the material of choice for piping. Transfer pipes are typically 2-inch in diameter, but may be as large as 6-8 inches for barge and vessel deliveries. Fittings may be carbon steel or stainless steel, and may be threaded, flanged or welded. Threaded piping is only recommended for sizes less than 3/4" in diameter. It is essential that the pipe be threaded two full turns before applying threading compound or Teflon® tape to eliminate the possibility of contaminating the interior of the pipe. All pipes should be free of oils and any other contaminants prior to being placed in service.

D. Drain Lines

Storage tanks should be equipped with a flanged and valve outlet drain at the floor level to allow the tank complete drainage if necessary. This outlet should be located such that it can be tied into a pump.

E. Valves

Ball, gate, globe or plug valves are suitable for use with essential oil. Construction may be steel. Ball valves should have Monel balls and stems, and seats should be carbon filled PTFE, and globe valves should have 13% chrometrim and hard-faced Satellite seats. Valve stems may be packed with PTFE or graphite impregnated PTFE. Ball, gate or plug valves are generally preferred where full line flow is desired. Globe valves are used where throttling is necessary.

F. Pumps

Pumps may be either positive displacement or centrifugal type, and can be constructed of steel, cast iron, or bronze. All packing must be made of essential oil resistant materials such as PTFE. Pumps used for drumming should supply essential oil at a rate of approximately 50gpm. The pump should be located so that a positive head pressure is always maintained on the suction side.

8.2 Hazards

To identify hazards present in this design, a material and equipment inventory was taken.

8.2.1 Material inventory

For the material inventory, we have as follows:

(1) Essential oil, which is volatile at high temperature

(2) Terpens (hydrocarbons), which is a volatile flammable liquid.

(3) Steam, which enhances corrosion.

8.2.2 Equipment inventory

1. **Reactor (column extractor)**

Allows for batchwise extraction of essential oil at temperature of 100°C, with an endothermic reaction by using steam for the extraction followed by condensation to 40 °C .

With the material and equipment inventory the following hazards were identified as present in the design.

A. Explosion

This is a sudden release of energy as a pressure or a blast wave. It usually occurs on ignition of vapour cloud and also by a pressure build up that leads to the sudden release from the extraction column.

B. Fire

This is the combustion of material in air the material forms a mixture with air, which would burn once ignited with careless handling.

C. Burning

As a result of loading and off loading of the residue after each batch operation may expose one to the burns. This can be caused by the steam or hot leafy materials (residue).

Other means of ensuring the safety and quality of process industry (e.g. essential oil plant), is by proper maintenance of the equipment involved in optimizing process, also the layout of the plant should be such that there be reduction in the number of auxiliary equipment and short distance between the feed and the processing section i.e. pipe reduction the use of natural flow instead of an auxiliary equipment can be part of the optimization i.e. use of gravity instead of the use of pump material for fabrication also places an important role in process optimization, because a high maintenance price thus the use of a high graded materials for fabrication.

8.3 General Quality Control Measures

Maintaining product quality in accordance with acceptable standard has been a major role for industrial instrumentation since its inception decades ago with the ever growing interest in speeding up production, one becomes increasingly aware of the fact that rejects as well as acceptable products can be produced at very high rates. Below are some of the measures:

8.3.1 General safety measures

1. All materials of construction should be well selected on the basis of corrosion resistance and structural strength. This is to avoid the collapse of any equipment or structures.
2. All pipelines carrying flammable materials must be installed with flame traps.
3. Relief valves should be installed along all lines carrying gases and vapour.
4. Automatic controllers should be installed to control temperature, pressure, and flow rates of the material or equipment involved.
5. A badly maintained plant is a potential hazards. Ensure that a competent staff is responsible for recognizing maintenance and repairs on a planned basis.
6. Signs and placards warning of the hazardous materials should be placed all over the plant.
7. Foam fire extinguishers or those using carbon dioxide should be widely and easily available and ready for immediate use at all times.
8. Plant layout should be such that:
    i. The storage facilities should be placed away from the plant.
    ii. All electrical installation should be earthed and insulated and should be kept away from the processing unit.
    iii. Exit and escape route: - the concept of quality control analysis has been greatly achieved by statistical quality control method. The

general intent of SQC is that of sampling units and parts being produced and essentially determining trends in deviation from production as continuously (affordable and achievable) as possible. There are many important statistical tests, which can be used to determine the quality of products.

8.3.2 Quality control measures

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The concept of quality control analysis has been greatly achieved by statistically quality control (SQC) method. The general intent of SQC is that of sampling units and parts being produced and essentially determining trends in deviation from production as continuously (affordable and achievable) as possible.

There are many important statistical tests, which could be used to determine the quality of products, among techniques is the t-test hypothesis. There are three common hypotheses and their corresponding t – equations are given below.

Hypothesis A:

$\mu = \mu_0$ (one sample test)

dF = n-1

$$t = \frac{\bar{x} - Mo}{s(X)}$$

Hypothesis B:

N1 – N2 = 0 (two sample test – matched pairs)

dF =n-1

$$t = \frac{\bar{x} - O}{s(X)}$$

N1 = N2 (two sample test)

dF =ni+n2-2

$$t = \frac{\bar{x}_1 - X_2}{s(X)}$$

Where:

$$s(x) = s(x) / \sqrt{n}$$

$$s(x) = s(x)\sqrt{{}^{1}\!/_{n1} + {}^{1}\!/_{n2}}$$

$$s(x) = \sqrt{\frac{\Sigma\left(\bar{x} - x_1\right)^2 + \Sigma\left(\bar{x}_2 - x_2\right)}{n1 + n2 - 2}}$$

$$s(x) = \sqrt{\frac{\Sigma(x_1 - x)^2}{n - 1}}$$

df = degree freedom

n = number of observations

However, before a statistical test is applied, the level of significance is generally selected. It is customary to prescribe significance of 95% or more before rejecting a specific hypothesis.

CHAPTER NINE

9.0 PROCESS CONTROL AND INSTRUMENTATION

9.1 Introduction

In the design of an industrial plant, the methods which will be used, for plant operation and control help determine many of design variables, for example, the extent of instrumentation can be a factor in choosing the type of process and setting the labor requirements. It should be remembered that maintenance work would be necessary to keep the installed equipment and facilities in good operating condition. The importance of such factors which are directly related to plant operation and control must be recognized and take into proper account during the development of a design project.

Processes may be controlled more precisely to give more uniform and higher – quality products by the application of automatic control, often leading to higher profits. Therefore, any process with an input and output which may be flow, pressure, liquid level, temperature, composition or any other inventory, environmental or quality variable that is to be held at a desired value must have some measure of control applied to it.

Change in output may occur:

1. Randomly as caused by changes in weather or raw material quality.
2. Diurnally with ambient temperature
3. Manually when operators change production rate.
4. Stepwise when equipment is switched in or out of service, or
5. Cyclically as a result of oscillations in other control loops.

Variation in any of the ways stated above would drive the output (controlled variable) further away from the set point (desired value) thus requiring a corresponding variable to bring it back (manipulative variable).

There are various control methods used in chemical engineering such as feed forward control, feed back control and cascade control. For example figure 9.1 below shows a typical feed forward control system for a condenser (heat exchanger).

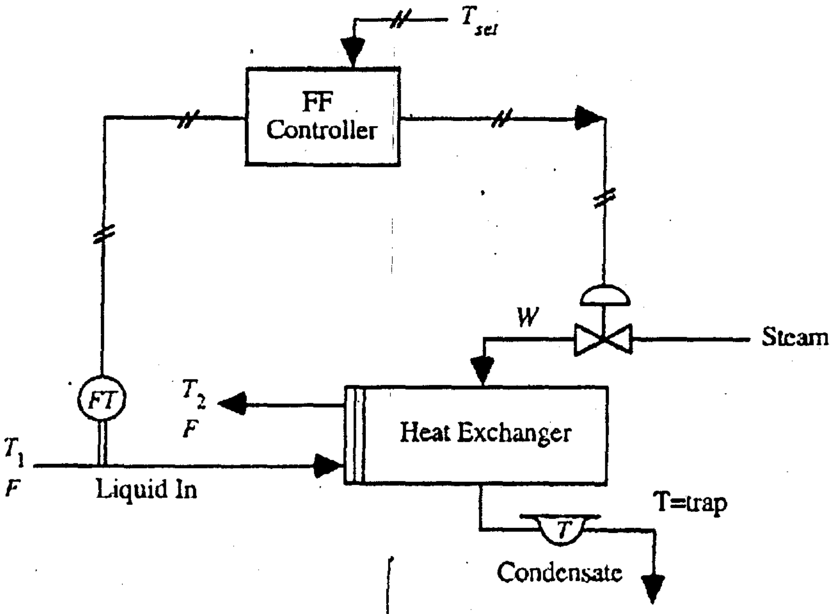

Figure 9.1 Feed forward control for a shell and tube heat exchanger (condenser).

But a cascade control system is recommended for this design. This is explained explicitly below.

9.2 Cascade Control

Cascade control can improve control system performance over single-loop control whenever either:

(1) Disturbances affect a measurable intermediate or secondary process output that directly affects the primary process output that we wish to control; or

(2) The gain of the secondary process, including the actuator, is nonlinear.

In the first case, a cascade control system can limit the effect of the disturbances entering the secondary variable on the primary output. In the second case, a cascade control system can limit the effect of actuator or secondary process gain variations on the control system performance. Such gain variations usually arise from changes in operating point due to set point changes or sustained disturbances.

A typical candidate for cascade control is the shell and tube heat exchanger (condenser) of figure 9.2

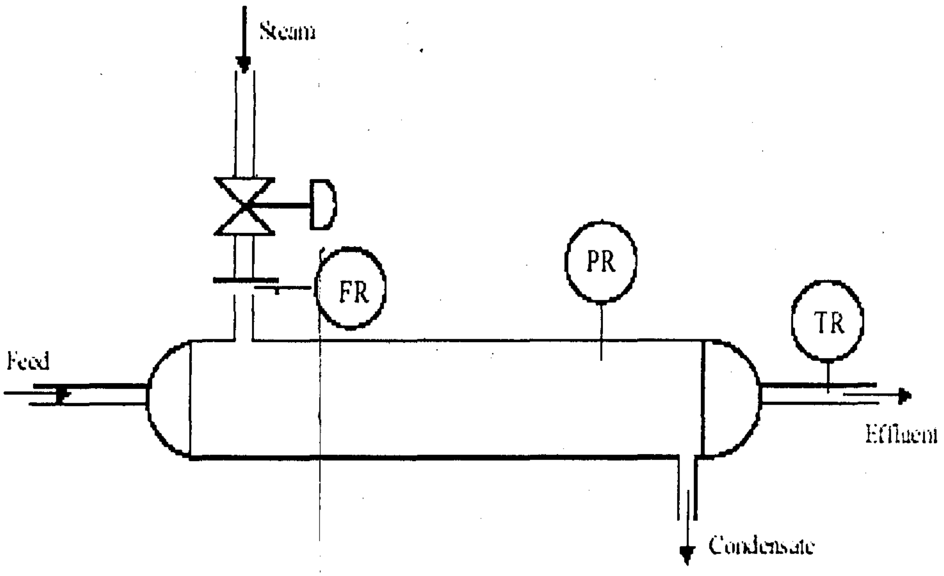

Figure 9.2 A shell and tube heat exchanger.

The primary process output is the temperature of the tube side effluent stream. There are two possible secondary variables, the flow rate of steam into the exchanger and the steam pressure in the exchanger. The steam flow rate affects the effluent temperature through its effect on the steam pressure in the exchanger. The steam pressure in the exchanger affects the effluent temperature by its effect on the condensation temperature of the steam. Therefore, either the steam flow rate or the steam pressure in the exchanger can be used as the secondary output in a cascade control system. The choice of which to use depends on the disturbances that affect the effluent temperature. If the main disturbance is variations in the steam supply pressure, due possibly to variable steam demands of other process units, then controlling the steam flow with the control valve is most likely to be the best choice. Such a controller can greatly diminish the effect of steam supply pressure variations on the effluent temperature. However, it is still necessary to have positive control of the effluent temperature to be able to track effluent temperature set point changes and to reject changes in effluent temperature due to feed temperature and flow variation. Since there is only one control effort, the steam valve, steam position, traditional cascade control uses the effluent temperature controller to adjust the set point of the steam flow controller, as shown in Figure 9.3

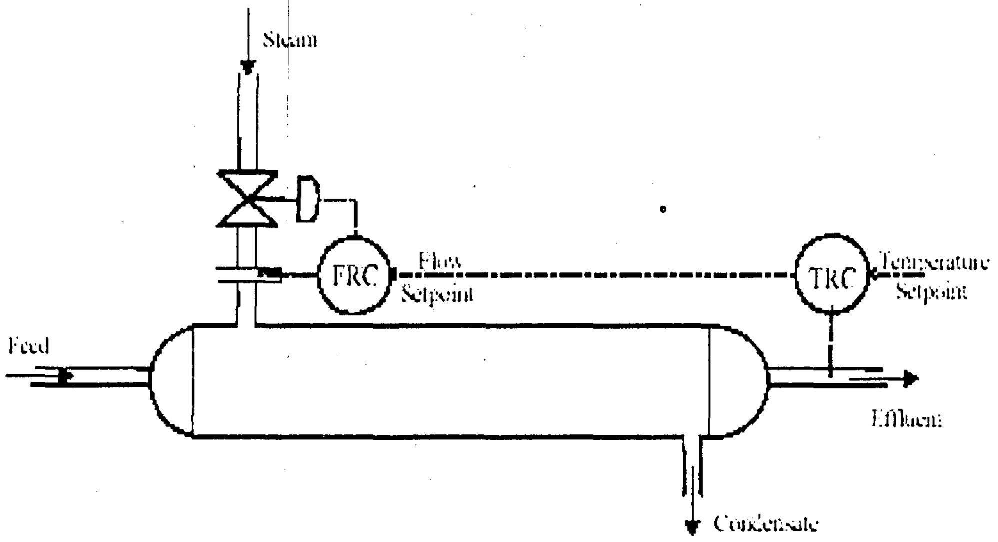

Figure 9.3 Cascade control of effluent temperature via steam flow control.

If feed flow and temperature variations are significant, then these disturbances can beat least partially compensated by using the exchanger pressure rather than the steam flow as the secondary variable in a cascade loop, as shown in Figure 9.4 below.

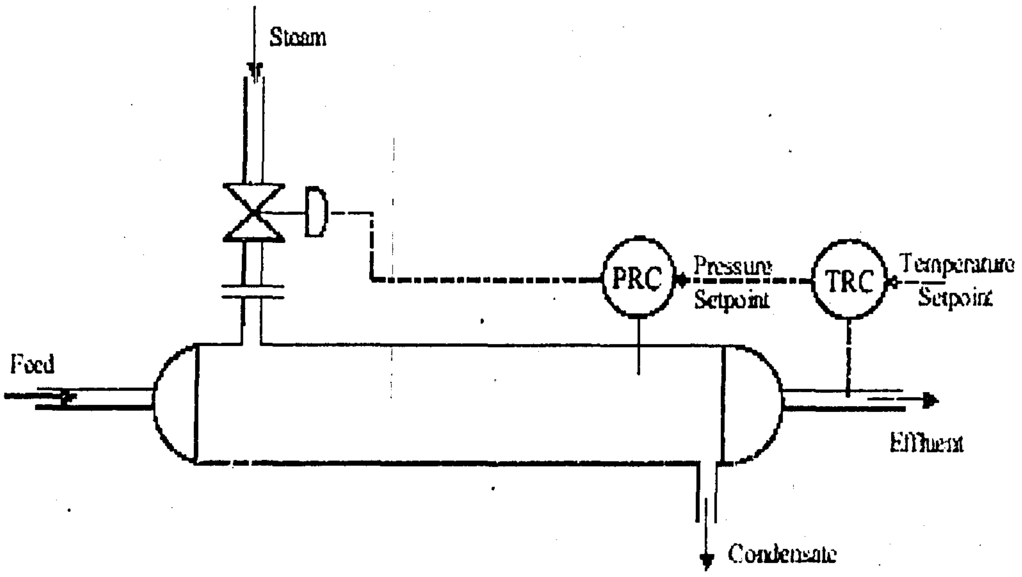

Figure 9.4 Cascade control of effluent temperature via shell side pressure control.

The trade-off in using the configuration of Figure 9.2 rather than that of Figure 9.1 is that the inner control loop from the steam pressure to the valve stem position may not suppress variations in valve gain as well as with an inner loop that uses the valve to control the steam flow rate. This consideration relates to using a cascade control system to suppress the effect of process uncertainty, in this case the valve gain, on the control of the primary

process variable, the effluent temperature. We will have a lot more to say about using cascade control systems to suppress process uncertainty in the following sections. To repeat, cascade control has two objectives.

The first is to suppress the effect of disturbances on the primary process output via the action of a secondary, or inner control loop around a secondary process measurement.

The second is to reduce the sensitivity of the primary process variable to gain variations of the part of the process in the inner control loop.

As we shall demonstrate, cascade control can be usefully applied to any process where a measurable secondary variable directly influences the primary controlled variable through some dynamics. We will also demonstrate that despite frequent literature statements to the contrary, inner loop dynamics do not have to be faster than the outer loop dynamics.

However, the traditional cascade structure and tuning methods must be modified in order for cascade control to achieve its objectives when the inner loop process has dynamics that are on the order of, or slower than, the primary process dynamics.

9.3 Importance of Cascade Control

A cascade control system is a multiple-loop system where the primary variable is controlled by adjusting the set point of a related secondary variable controller. The secondary variable then affects the primary variable through the process. The primary objective in cascade control is to divide an otherwise difficult to control process into two portions, whereby a secondary control loop is formed around a major disturbances thus leaving only minor disturbances to be controlled by the primary controller.

The use of cascade control is described in many texts on process control applications.

The advantages of cascade control are all somewhat interrelated . They include:

1. Better control of the primary variable
2. Primary variable less affected by disturbances
3. Faster recovery from disturbances
4. Increase the natural frequency of the system
5. Reduce the effective magnitude of a time-lag
6. Improve dynamic performance
7. Provide limits on the secondary variable

Cascade control is most advantageous on applications where the secondary closed loop can include the major disturbance and second order lag and the major lag is included in only the primary loop. The secondary loop should be established in an area where the major disturbance occurs. It is also important that the secondary variable respond to the disturbance. If the slave loop is controlling flow and the disturbance is in the heat content of the fluid, obviously the flow controller will not correct for this disturbance.

There is only one master controller and usually only one slave controller and only one manipulated variable. See Figure (9.2), (9.3), and (9.4). However, some applications can benefit from the use of more than one slave controller. There will be a separate secondary variable and manipulated variable associated with each slave controller in the system if the slave loops are in parallel as shown in Figure (9.4). Another configuration, shown in Figure (9.5), is the operation of a cascade system.

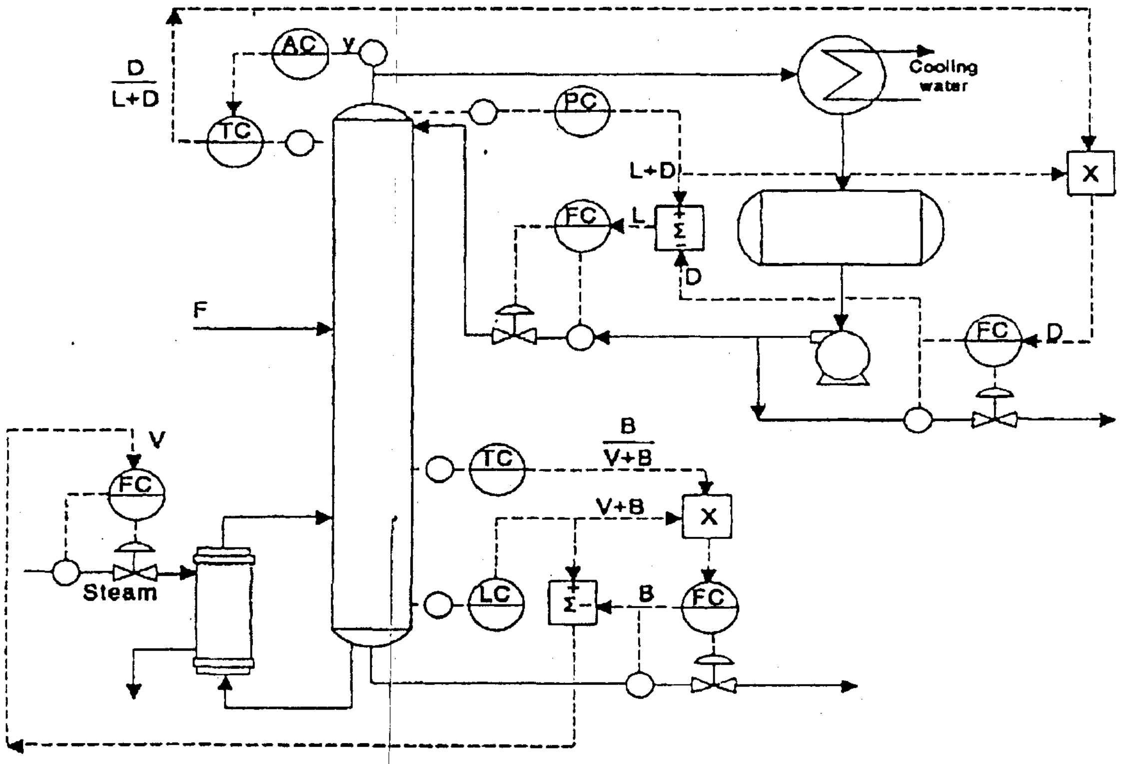

Figure 9.5 Cascade control system for the extraction column and the condenser.

9.4 Instrumentation and Control Objectives

The key objectives adhered to in the specification of the instrumentation and control schemes are:

1. **Safe plant operation**
   - i. To keep the process variables within known safe operations limits.
   - ii. To defect dangerous situations as they develop and to provide alarms and automatic shut – down systems
   - iii. To provide interlocks and alarms to prevent dangerous operation procedures.
2. **Production rate:** To achieve the design producer output
3. **Product quality:** To maintain the product composition within the specific quality standards.

4. **Cost:** They operate at the lowest production cost, but not to the detriment of the product quality.

In the plant design some of the variables needed to be monitored and controlled are, the flow rate, temperature, pressure and composition.

i. **Flow rates/feed ratio control:** a feed ratio controller is applied between the methane stream and the oxygen stream with the aim of maintaining a complete conversion of methane to the desired products. This is necessary to avoid excess oxygen being built up in the reactor.

ii. **Temperature control reaction:** temperature is controlled by regulating the flow rate of the reaction into it. This can also be controlled by heat transfer. The reaction is exothermic. It produces heat, which tends to raise reaction temperature thereby increasing reaction rate and producing more heat. This positive feedback is countered by negative feedback in the cooling system, which removes more heat as reactor temperature rises. The temperature controller, which in turn operates the coolant value, to counter the rise or drop in temperature in the sector.

iii. **Pressure control:** pressure sensing is quite straightforward with the aid of pneumatic instrumentation such as Bourdon gauge, diaphragms and bellows. These sensors measure absolute pressure and pressure differences between two levels. Therefore, pressure control is achieved by manipulating the airflow rate in the compressor to avoid deviation from set point.

iv. **Composition control:** first requirement here is to establish proper stoichiometry of the reactants in propositions needed to satisfy the reaction chemistry and also the desired output product. This is achieved by setting input flow rates in ratio to one another, or a composition measurement (analyzer) can be used to trim the ratios to the right proportion

TABLE 9.1: Controls Limits For the column extractor.

Control loop	Controller	Set-point and tolerance limit	Function
a. Cascade	1. Flow Control	50 ± 0.0005kg/hr	Controls flow rate of water flow to the reactor
	2. Temperature Control	97 ± 5°C	By manipulating steam and essential oil flow
	2. Pressure Control	1.0 ± 0.0005 atm	manipulating air flow

TABLE 9.2: Controls Limits For the condenser.

Control loop	Controller	Set-point and tolerance limit	Function
a. Cascade	1. Flow Control	50 ± 0.0005kg/hr	Controls flow rate of oil and water mixture
	2. Inlet temperature Control.	97 ± 5°C	By manipulating water and essential oil flow
	3. Outlet temperature control	35 ± 5°C	By manipulating water and essential oil flow.
	2. Pressure Control	1.0 ± 0.0005 atm	manipulating air flow

TABLE 9.3: Controls Limits For the boiler.

Control loop	Controller	Set-point and tolerance limit	Function
a. Cascade	1. Flow Control	50 ± 0.0005kg/hr	Controls flow rate of water flow to reactor
	2. Temperature Control	97 ± 5°C	By manipulating water and essential oil flow.
	2. Pressure Control	1.0 ± 0.0005 atm	manipulating air flow
a. Cascade	1. Flow Control	50.23 ± 0.0005kg/hr	Controls flow rate of plug flow reactor

9.5 Electrical Design/Instrumentation

The main aim of process instrumentation and automation is to ensure process stability at optimum technological condition, high productivity at minimum energy utilization and process safety. The functional schematic diagram of the design process is presented in Figure 9.6

The column extractor

Analysis of the proposed production technology shows that for efficient operation of this unit the automation process must guarantee the designed temperature and steam flow rate regimes. Temperature and flow rate (pressure gauge) sensors are installed before and after the packed bed. The automation involves regulation of the steam flow rate and stabilization of the temperature regime. The steam flow rate is monitored either manually or with the aid of digital pressure gauge. The signal is sent to the control board from where secondary signal is sent to the regulatory mechanism to allow more or reduce the flow from the steam generator. The same procedure is applied for the temperature sensor (digital thermometer or visual observation). A signal from the control board is sent to the regulatory mechanism to maintain the required steam temperature.

The Condenser

The regulated parameters are the temperature of the coolant. Increase in the temperature of the outlet water mean increased temperature of the crude condensate. The installed temperature gauge will sent signal to the control board for increase in the coolant flow rate.

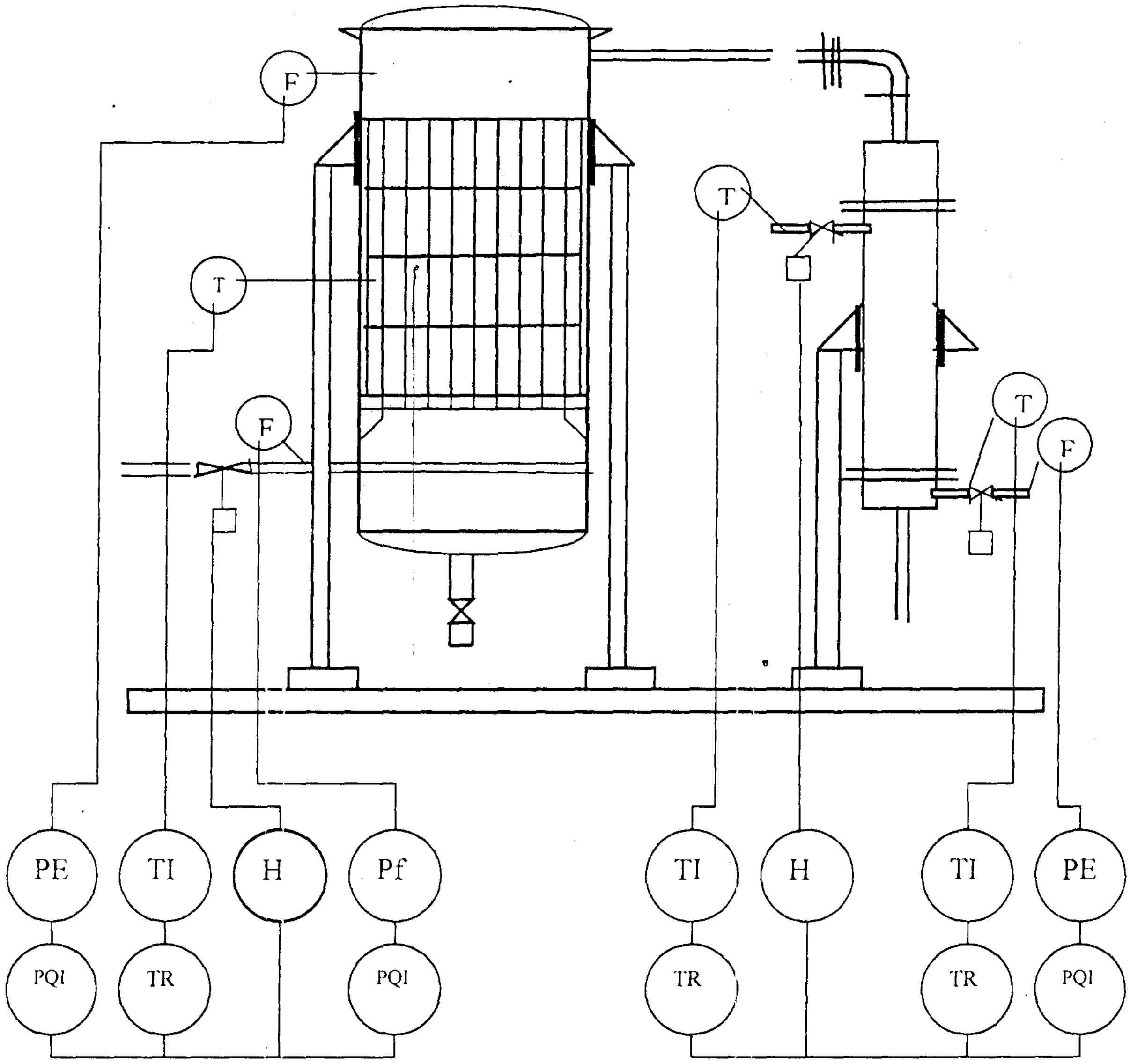

Fig 9.6: Functional schematic Process Instrumentation and Control (National Research Institute for Chemical Technology Zaria, 2004)

Key: T – temperature, P – pressure, F – flow rate, E – electrical signal, I – indicator, H – manual control, Q – quantity, R – registration, f – ratio.

9.6 Operability Study

An "operability study" is a structured technique for identifying potential malfunction beforehand. Critical examination in process design, inevitably leads to a safer, more reliable and more profitable process. These studies are based on sets of "keywords" which stimulates thoughts. It is essential to formulate unambiguously, the design objectives, to which the key words are applied in a systematic way.

In operability studies the thoughts are about deviations from the design conditions and the design intention. The set of key words contains two sub-sets: "property words" which focus attention on the design conditions and the design intention; and the second sub-set of "guide words" which focus attention onto possible deviations. The Chemical Industries Association has published a Guide to Hazard and Operability Studies which recommends the seven guide words explained.

Table 10.1: A list of guide words.

NO or NOT	The complete negation of these intentions	No part of the intentions is achieved but nothing else happens
MORE, LESS	Quantitative increases or decreases	These refer to quantities and properties such as flow rates and temperatures as well as activities like "ABSORB" and "REACT"
AS WELL AS	A qualitative increase	All the design and operating intentions are achieved together with some additional activity
PART OF	A qualitative decrease	Only some of the intentions are achieved; some are not
REVERSE	The logical opposite of the intention	This is mostly applicable to activities, for example reverse flow or chemical reaction.
OTHER THAN	Complete substitution	No part of the original objective achieved; different thing happen.

Efficient to use only NO, MORE and LESS, with a layer set of property words should be chosen beforehand accordingly.

Operability Studies are generally carried out in industry by a small team of specialists, directed by an experienced group-leader. The exercise is of the brain-storming type and only those deviations which would lead to hazardous outcomes are recorded for further action. Initially the inexperienced chemical engineer will find it more effective to record all causes of deviations, their consequences and action. In addition it is more appropriate to use a process follow-sheet with only the basic control loops. This enables those who are not experienced instruments which are included on the final diagram. A further benefit of keeping complete records of the operability study is that operating instructions and procedures for start-up, shut-down and carrying out cyclic operations can be drawn up by reference to the operability study. Furthermore, if the significance of deviations in measured variables is understood, simple fault-finding strategies can be included in the design report. The operability study in this design project differs from that of an industrial process design in that normally every vessel and pipeline must be covered by an industrial operability study. In this design report the operability study is restricted to the scrubber section only.

9.6.1 Operability study of the column extractor

Vessel: Column extractor

Intention: to take in steam, this would react with lemon grass for the extraction of the essential oil.

Table 10.2 intention to extract essential oil at 100°c.

NO/NOT	Flow	Blockage of the line failure of the control valve.	No essential oil would be produced.
MORE		Control valve stock open	Excess essential oil will be produced along with the floral water anhydride
LESS OF		Partial blockage of the line. Failure of the control valve	Less essential oil would be produced.
PART OF		Partial blockage of the line. Failure of the control valve	Less essential oil would be produced..
REVERSE		Blockage of the line failure of the control valve.	No essential oil would be produced.

CHAPTER TEN

10.0 ENVIRONMENTAL ACCEPTABILITY

Essential oil is one of the most volatile oil known, so extreme caution should be taken in its production, handling and usage in order to avoid the side effect to user and the environment.

10.1 Identification of Possible Pollutants

Any project involving new technology or hazardous material requires a rational approach of assessing whether it is methodologically sound in order to identify systematically all possible pollutants. Suitability or acceptability of any process plant depends on its impact to the life, properties and environment.

10.2 Treatments of Any Possible Pollutants

Therefore to make this process suitable and acceptable to the environment, there is need for these pollutants to be controlled. Presently, the following measures can be used to control possible pollutants from essential oil plant.

i. Absorption process this is used in based on dissolution of poisonous impurities liquid (physical absorption), or selective absorption using chemical active absorbent such as water, solutions of NaOH, Na_2CO_3 and $KMnO_4$ the major equipment used in absorption purification process is packed bed absorption reactor

ii. Catalyzed conversion of pollutants in this method, the pollutants are converted to fewer sometimes harmless and products in presence of a catalyst. These products are than concentrated removed from the gas stream or passed to the atmosphere.

· The major advantage of this process is its high purification coefficient of about 99%. Depending on the operating condition.

iii. Absorption using solid absorbents: the purification technique based on selective removal of poisonous impurities from the gas, using solid absorption can be physical or chemical (chemisorptions) process. Commonly used absorbents include highly porous materials such as activated coal, silica gel, synthetic zeolite, etc.

Absorption of gaseous impurities could be performed using the batch reaction with the absorbent placed on the grid. The flue gases are passed to top-down at a velocity determined by the hydraulic resistance of the absorbent layer with the absorbent lose their absorptive due to saturation of their active sites by the solute gas (impurities) they can therefore be regenerated by passing through them hot water vapour air or inert gas-Nitrogen.

10.3 Waste Water Treatment

This is carried out by using both physically and chemical treatments. The physical treatment involves the removal of large floating or suspended particles from the waste water. This is achieved by gravity settling. This is further processed by filtration to clarify the effluents. The next stage is the chemical treatment. It involves the neutralization of acids and alkali, conversion of ions to poorly soluble compounds, co-precipitation of inorganic substances, oxidation, Electrolysis, catalytic oxidation, etc. these methods are mainly used to deactivate and remove the impurities of inorganic compounds.

10.4 Thermal Pollution Control

The waste heat should be reclaimed by raising the thermal potentials of the gas, by setting up cogeneration technology; the water heat could be converted to mechanical power.

CHAPTER ELEVEN

11.0 START-UP AND SHUT DOWN

11.1 Start-Up

1. Only responsible, well-trained and well-supervised employees should be entrusted with the starting-up process. A worker should be present during the entire time of combustion and it should proceed only during daytime or with adequate lighting. A written copy of the procedures should be readily available.

2. The operation should be conducted with no leakage of oil fumes or liquid. However, because of possible accidental emissions, workers responsible for the entire process should exercise extreme care and wear proper safety equipment.

3. Fill entire extraction column (reactor) with lemon grass and start boiler.

4. No smoking or flames are permitted in the area due to certain situations.

5. Check all transfer lines and hoses to make sure they are dry and free of contamination. Inspect equipment for signs of deterioration or other conditions which might cause a leak. Do not continue if there is any question about the condition of any equipment.

6. Carefully vent the delivery vessel to zero gauge pressure and cautiously disconnect the air and discharge lines. Be prepared with a suitable container to collect any product remaining in the line. Have appropriate supplies to contain or clean up any possible leakage that may occur.

7. Close all valves and replace all caps and blind flanges on the delivery vessel. Make certain that the dome cover is fastened securely and electrical grounding wires are removed. Flush hoses with water and wash down area where any vapors or leakage may have occurred.

8. Adjust controls to set point.

9. Turn all valves to automatic position

11.2 Shut-Down

1. Turn all valves to manual position

2. Put burner off by isolating

3. Isolate all pumps, and stop cooling water and steam supply to heat exchangers and boilers respectively.

4. Discharge reactors content.

5. Flush all line with air to inert the system

CHAPTER TWELVE

12.0 SITE FOR PLANT LOCATION AND SITE SELECTON, AND PLANT LAYOUT

12.1 Site for Plant Location and Site Selection

The geographical location of the final plant can have strong influence on the success of the industrial venture. Considerable care must be exercised in selecting the plant site, and many different factors must be considered. Primarily the plant must be located where the minimum cost of production and distribution can be obtained but, other factors such as room for expansion and safe living conditions for plant operation as well as the surrounding community are also important. The location of the plant can also have a crucial effect on the profitability of a project. The choice of the final site should first be based on a complete survey of the advantages and disadvantages of various geographical areas and ultimately, on the advantages and disadvantages of the available real estate. The various principal factors that must be considered while selecting a suitable plant site, are briefly discussed in this section. The factors to be considered are:

1. Raw material availability.
2. Location (with respect to the marketing area.)
3. Availability of suitable land.
4. Transport facilities.
5. Availability of labors.
6. Availability of utilities (Water, Electricity).
7. Environmental impact and effluent disposal.
8. Local community considerations.
9. Climate.
10. Political strategic considerations.

11. Taxations and legal restrictions

12.1.1 Raw materials availability

The source of raw materials is one of the most important factors influencing the selection of a plant site. This is particularly true for the sulfuric acid plant because large volumes of sulfur is consumed in the process which will result in the reduction of the transportation and storage charges. Attention should be given to the purchased price of the raw materials, distance from the source of supply, freight and transportation expenses, availability and reliability of supply, purity of raw materials and storage requirements.

12.1.2 Market location

The location of markets or intermediate distribution centers affects the cost of product distribution and time required for shipping. Proximity to the major markets is an important consideration in the selection of the plant site, because the buyer usually find it advantageous to purchase from near-by sources. In case of sulfuric acid plant, the major consumers are fertilizer industries and hence the plant should be erected in close proximity to those units.

12.1.3 Availability of suitable land

The characteristics of the land at the proposed plant site should be examined carefully. The topography of the tract of land structure must be considered, since either or both may have a pronounced effect on the construction costs. The cost of the land is important, as well as local building costs and living conditions. Future changes may make it desirable or necessary to expand the plant facilities. The land should be ideally flat, well drained and have load-bearing characteristics. A full site evaluation should be made to determine the need for piling or other special foundations

12.1.4 Transport

The transport of materials and products to and from plant will be an overriding consideration in site selection. If practicable, a site should be selected so that it is close to at least two major forms of transport: road, rail, waterway or a seaport. 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. If possible the plant site should have access to all three types of transportation. There is usually need for convenient rail and air transportation facilities between the plant and the main company head quarters, and the effective transportation facilities for the plant personnel are necessary.

12.1.5 Availability of labours

Labors will be needed for construction of the plant and its operation. Skilled construction workers will usually be brought in from outside the site, but there should be an adequate pool of unskilled labors available locally; and labors 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 labors for recruitment and training.

12.1.6 Availability of utilities

The word "utilities" is generally used for the ancillary services needed in the operation of any production process. These services will normally be supplied from a central facility and includes Water, Fuel and Electricity which are briefly described as follows:

(i) Water: - The water is required for large industrial as well as general purposes, starting with water for cooling, washing, steam generation and as a raw material in the. The plant therefore must be located where a dependable water supply is available namely lakes, rivers, wells, seas. If the water supply shows seasonal fluctuations, it's desirable to construct a reservoir or to drill several standby wells. The temperature, mineral content, slit and sand content, bacteriological content, and cost for supply and purification treatment must also be considered when choosing a water supply. Demineralized water, from which all the minerals have been removed is used where pure water is needed for the process use, in boiler feed. Natural and forced draft cooling towers are generally used to provide the cooling water required on site.

(ii) Electricity: - Power and steam requirements are high in most industrial plants and fuel is ordinarily required to supply these utilities. Power, fuel and steam are required for running the various equipments like generators, motors, turbines, plant lightings and general use and thus be considered as one major factor is choice of plant site.

12.1.7 Environmental impact and effluent disposal

Facilities must be provided for the effective disposal of the effluent without any public nuisance. In choosing a plant site, the permissible tolerance levels for various effluents should be considered and attention should be given to potential requirements for additional waste treatment facilities. As all industrial processes produce waste products, full consideration must be given to the difficulties and cost of their disposal. The disposal of toxic and harmful effluents will be covered by local regulations, and the appropriate authorities must be consulted during the initial site survey to determine the standards that must be met.

12.1.8 Local community considerations

The proposed plant must 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.

12.1.9 Climate

Adverse climatic conditions at site will increase costs. Extremes of low temperatures will require the provision of additional insulation and special heating for equipment and piping. Similarly, excessive humidity and hot temperatures pose serious problems and must be considered for selecting a site for the plant. Stronger structures will be needed at locations subject to high wind loads or earthquakes.

12.1.10 Political and strategic considerations

Capital grants, tax concessions, and other inducements are often given by governments to direct new investment to preferred locations: such as areas of high unemployment. The availability of such grants can be the overriding consideration in site selection.

12.1.11 Taxation and legal restrictions

State and local tax rates on property income, unemployment insurance, and similar items vary from one location to another. Similarly, local regulations on zoning, building codes, nuisance aspects and others facilities can have a major influence on the final choice of the plant site.

12.2 Plant Layout

After the flow process diagrams are completed and before detailed piping, structural and electrical design can begin, the layout of process units in a plant and the equipment within these process unit must be planned. This layout can play an important part in determining construction and manufacturing costs, and thus must be planned carefully with attention being given to future problems that may arise. Thus the economic construction and efficient operation of a process unit will depend on how well the plant and equipment specified on the process flow sheet is laid out. The principal factors that are considered are listed below:

1. Economic considerations: construction and operating costs.
2. Process requirements.
3. Convenience of operation.
4. Convenience of maintenance.
5. Health and Safety considerations.
6. Future plant expansion.
7. Modular construction.
8. Waste disposal requirements

12.2.1 Economic considerations: operating costs

The cost of construction can be minimized by adopting a layout that gives the shortest run of connecting pipe between equipment, and least amount of structural steel work. However, this will not necessarily be the best arrangement for operation and maintenance.

12.2.2 Process requirements

An example of the need to take into account process consideration is the need to elevate the base of columns to provide the necessary net positive suction head to a pump.

12.2.3 Convenience of operation

Equipment that needs to have frequent attention should be located convenient to the control room. Valves, sample points, and instruments should be located at convenient positions and heights. Sufficient working space and headroom must be provided to allow easy access to equipment.

12.2.4 Convenience of maintenance

Heat exchangers need to be sited so that the tube bundles can be easily withdrawn for cleaning and tube replacement. Vessels that require frequent replacement of catalyst or packing should be located on the out side of buildings. Equipment that requires dismantling for maintenance, such as compressors and large pumps, should be places under cover.

12.2.5 Health and safety considerations

Blast walls may be needed to isolate potentially hazardous equipment, and confine the effects of an explosion. At least two escape routes for operators must be provided from each level in process buildings.

12.2.6 Future plant expansion

Equipment should be located so that it can be conveniently tied in with any future expansion of the process. Space should be left on pipe alleys for future needs, and service pipes over-sized to allow for future requirements.

12.2.7 Modular construction

In recent years there has been a move to assemble sections of plant at the plant manufacturer's site. These modules will include the equipment, structural steel, piping and instrumentation. The modules are then transported to the plant site, by road or sea. The advantages of modular construction are:

1. Improved quality control.
2. Reduced construction cost.
3. Less need for skilled labors on site.

The disadvantages of modular construction are:

1. Higher design costs & more structural steel work.
2. More flanged constructions and possible problems with assembly on site.

12.2.8 Waste disposal requirements

In a plant layout, the permissible tolerance levels for various waste should be considered and attention should be given to potential requirements for additional waste treatment facilities. As all industrial processes produce waste products, full consideration must be given to the difficulties and cost of their disposal. The disposal of toxic and harmful effluents will be covered by local regulations, and the appropriate authorities must be consulted during the initial site survey to determine the standards that must be met.

A detailed plant layout is drawn as shown in figure 12.1 below. Although this plant layout is just a reference plant layout. There may be changes in actual plant layout by the industrialist or whoever is setting up the plant to produce essential oil. Below are the key words for the plant layout.

Plant layout keywords

A --- Production unit (factory)

B --- Generator house

C --- Maintenance section

D --- Fire service station

E --- Safety block

F --- Quality control unit

G --- Exit security

H --- Utility station

I --- Product storage unit

J --- Raw material storage unit

K--- Waste/effluent disposal unit

L --- Area for future expansion

M --- Car park

N --- Car park

O --- Clinic

P --- Common room

Q --- Canteen

R --- Exit security post

S --- Security office

T --- Entrance security post

U --- Administrative block

V --- Car park

W --- Access road.

CHAPTER THIRTEEN

13.0 COST ESTIMATION EQUIPMENT AND ECONOMIC ANALYSIS

Acceptable plant design must present a process that is capable of operating under conditions, which will yield profit. Since net profit equals total value minus all expenses, it is essential that the chemical engineer be aware of the many different types of cost involved in the manufacturing processes. Capital must allocate for the direct, plant expenses, such as those for raw material, labour and equipment. Besides direct expenses many others indirect expenses are incurred, and these must be included if a complete analysis of the total cost is to be obtained. Some examples of these indirect expenses are administrative salary, product distribution cost and cost for interplant communication. A capital investment is required for every industrial process and determination of necessary investment is an important part of a plant design process. The total investment for any process consist of fixed capital investment for practical equipment and facilities in the plant plus working capital, which must be available to pay salaries, keep raw material and products on hand, and handle other special items requiring the direct cost outline.

When the cost for any type of commercial process is to be determined, sufficient accuracy has to be provided for reliable decision. There are many factors affecting investment and production cost. These are;

1. source of equipment
2. price fluctuation
3. company policies
4. operating and rate of production
5. governmental policies

Before an industrial plant can be put into operation, a large sum of money must be supplied to purchase and install the necessary machinery and equipment.

13.1 Costing of Equipment

The cost were based on cost data of 2002 which were available in Dollars

Exchange rate ER 145Naira = 1Dolla

Therefore $ER := 145Naira$

Costing of the column extractor

Purchase cost PC is given by the relation below

$M\Omega S := 1100 \qquad F_c := 1$

$$PC_{extr} := \frac{M\Omega S}{280}\left(101.9\cdot D_{extr}{}^{1.066}\cdot H_{extr}{}^{0.802}\cdot F_c + 2.18\right)\cdot ER$$

$$PC_{extr} = 3.16\times 10^4\cdot Naira$$

Costing of the of the condenser

$$PC_{cond} := \frac{M\Omega S}{280}\left(101.3\cdot A_{condenser}{}^{0.65}\cdot F_c\right)\cdot ER$$

$$PC_{cond} = 2.014\times 10^4\cdot Naira$$

Costing of the boiler

$$PC_{boil} := \frac{M\Omega S}{280}\left(101.3\cdot A_{boiler}{}^{0.65}\cdot F_c\right)\cdot ER$$

$$PC_{boil} = 5.382\times 10^3$$

Costing of the separator

$$PC_{dec} := \frac{M\Omega S}{280}\left(101.9\cdot D_{sep}{}^{0.65}\cdot H_{sep}{}^{0.802}\cdot F_c\right)\cdot ER$$

$$PC_{dec} = 3.149\times 10^4\cdot Naira$$

Costing of pumps

$$Cost\_pump = 4.65\cdot G^{0.4}$$

Note that all flow rates are converted into galloon/yr

Cost of pump A

Flow rate of water(exluding the 35% allowance)

Water flow rate per/yr

$F_{water} := F_4 \cdot \left(7392 \frac{hr}{yr}\right)$ $\qquad F_{water} = 3.696 \times 10^5 \cdot \frac{kg}{yr}$

Volumetric flow rate of water

$V_{water} := \frac{F_{water}}{\rho_{water}}$ $\qquad V_{water} = 369.6 m^3 \cdot yr^{-1}$

$V_{water} = 9.764 \times 10^4 \cdot \frac{gal}{yr}$

$Cp_A := 4.65 97640^{0.4} ER$ $\qquad Cp_A = 6.678 \times 10^4 \cdot Naira$

Cost of pump B

Flow rate of oil(exluding the 35% allowance); Oil flow rate per annum

$F_{oil} := F_{6a} \left(7392 \frac{hr}{yr}\right)$ $\qquad F_{oil} = 8.762 \times 10^4 \cdot \frac{kg}{yr}$

Volumetric flow rate of oil

$V_{3p} := \frac{F_{oil}}{\rho_{oil}}$ $\qquad V_{3p} = 0.011 m^3 \cdot hr^{-1}$

$V_{3p} = 2.642 \times 10^4 \cdot \frac{gal}{yr}$

$Cp_B := 1.65 \times 26420^{0.4} \cdot ER$ $\qquad Cp_B = 1.405 \times 10^4 \cdot Naira$

Cost of pump C

Flow rate of water(exluding the 35% allowance)

Water flow rate per/yr $\qquad F_{4b} := 80 \frac{kg}{hr}$

$F_{water} := F_{4b} \cdot \left(7392 \frac{hr}{yr}\right)$ $\qquad F_{water} = 5.914 \times 10^5 \cdot \frac{kg}{yr}$

Volumetric flow rate of water

$V_{water} := \frac{F_{water}}{\rho_{water}}$ $\qquad V_{water} = 591.36 m^3 \cdot yr^{-1}$ $\qquad V_{water} = 1.562 \times 10^5 \cdot \frac{gal}{yr}$

$Cp_C := 4.65\,156200^{0.4}ER$ $\qquad Cp_C = 8.059 \times 10^4 \cdot \text{Naira}$

$TC_p := Cp_A + Cp_B + Cp_C$ $\qquad TC_p = 1.614 \times 10^5 \cdot \text{Naira}$

Costing of the storage tanks

Equation for carbon steel as presented by Bridgewater is as below

$C = 4.44V^{0.61}$

Tank A: Oil storage tank

Volume of tank allowing for 35% safety allowance as calculated in sizing.

Volume of tank $\qquad V_3 := 11.25m^3 yr^{-1}$ $\qquad V_3 = 6.181 \times 10^4 m^{-3} \cdot gal \cdot yr^{-1}$

$Ct_A := 4.44\,2972^{0.61}ER$ $\qquad Ct_A = 8.459 \times 10^4 \cdot \text{Naira}$

Tank B: Water storage tank

Volume of tank allowing for 35% safety allowance as calculated in sizing.

Volume of water $\qquad V_w := 9.969m^3 yr^{-1}$ $\qquad V_w = 5.477 \times 10^4 m^{-3} \cdot gal \cdot yr^{-1}$

$Ct_B := 4.44\,2634^{0.61}ER$ $\qquad Ct_B = 7.858 \times 10^4 \cdot \text{Naira}$

Total cost of storage tanks

$TC_s := Ct_A + Ct_B$ $\qquad TC_s = 1.632 \times 10^5 \cdot \text{Naira}$

Total cost of pumps and storage tanks

$TC_{ps} := TC_p + TC_s$

$TC_{ps} = 3.246 \times 10^5 \cdot \text{Naira}$

Total cost of equipments

$PC_{equip} := PC_{dec} + PC_{boil} + PC_{extr} + PC_{cond} + TC_{ps}$

$PC_{equip} = 4.132 \times 10^5 \cdot \text{Naira}$

13.2 ECONOMIC ESTIMATION OF TOTAL CAPITAL INVESTIMENT

The total capital investiment can be given by

$T_{inv} = TFC + WC + TLC$

where, TFC =total fixed cost

WC=working capital

TLC=total land

13.2.1 Total fixed cost

The factorial method can be used with the relationship below

Total physical plant cost (Direct cost)

$PPC := 3.40PC_{equip}$

$PPC = 1.405 \times 10^{6} \cdot Naira$

Fixed Capital cost (Indirect cost)

$TFC := 3.45PPC$

$TFC = 4.847 \times 10^{6} \cdot Naira$

Working capital

$WC := 0.12 \cdot TFC$

$WC = 5.816 \times 10^{5} \cdot Naira$

Total land cost

$TLC := 0.01 \cdot TFC$

$TLC = 4.847 \times 10^{4} \cdot Naira$

$T_{inv} := TLC + WC + TFC$

$T_{inv} = 5.477 \times 10^{6} \cdot Naira$

13.2.2 Operating cost

This is divided into Fixed and Variable operating cost

Let the plant life be 4yrs $n := 4yr$

13.2.2.1 Fixed operating cost

Direct labour cost

$Lb_{c} := 0.05TFC$

$Lb_{c} = 2.423 \times 10^{5} \cdot Naira$

Plant maintenace and repairs

$M_c := 0.06TFC$

$M_c = 2.908 \times 10^5 \cdot \text{Naira}$

Insurance

$Ins_c := 0.011TFC$

$Ins_c = 5.332 \times 10^4 \cdot \text{Naira}$

Local taxes

$Ltx_c := 0.014TFC$

$Ltx_c = 6.786 \times 10^4 \cdot \text{Naira}$

Royalties and licences fee

$Roy_c := 0.1 \cdot TFC$

$Roy_c = 4.847 \times 10^5 \cdot \text{Naira}$

Laboratory cost

$Lab_c := 0.02Lb_c$

$Lab_c = 4.847 \times 10^3 \cdot \text{Naira}$

Supervision

$S_c := 0.14Lb_c$

$S_c = 3.393 \times 10^4 \cdot \text{Naira}$

Plant overhead cost

$POH_c := 0.3Lb_c$

$POH_c = 7.27 \times 10^4 \cdot \text{Naira}$

GENERAL EXPENSES

i administrative

$ADM_c := 0.25Lb_c$

$ADM_c = 6.059 \times 10^4 \cdot \text{Naira}$

ii. Research and development

$RAD_c := 0.015 \cdot TFC$

$RAD_c = 7.27 \times 10^4 \cdot \text{Naira}$

Total fixed operating cost

$TFO_c := RAD_c + ADM_c + POH_c + Lab_c + Roy_c + Ltx_c + Ins_c + M_c + Lb_c + S_c$

$TFO_c = 1.384 \times 10^6 \cdot Naira$

Annual fixed operating cost

$$TFO_{annum} := \frac{TFO_c}{n}$$

$$TFO_{annum} = 3.459 \times 10^5 \cdot \frac{Naira}{yr}$$

13.2.2.2 Variable operating cost

Cost of raw materials CRMc

$$Ginger\_Rhizome\_cost = F_1 \cdot \frac{0.002ER}{kg}$$

$$Ginger\_Rhizome\_cost = 85.937 \cdot \frac{Naira}{hr}$$

$$Water\_cost := F_4 \cdot \frac{0.001ER}{kg}$$

$$Water\_cost = 7.25 \cdot \frac{Naira}{hr}$$

$CRM_c := Ginger\_Rhizome\_cost + Water\_cost$

$$CRM_c = 93.187 \cdot \frac{Naira}{hr}$$

$$ACRM := \left(CRM_c\right) \cdot \left(7392 \frac{hr}{yr}\right)$$

$$ACRM = 6.888 \times 10^5 \cdot \frac{Naira}{yr}$$

Miscellaneuos

$Ms_c := 0.05Lb_c$

$Ms_c = 1.212 \times 10^4 \cdot Naira$

Utilities cost

$Ut_c := 3Lb_c$

$Ut_c = 7.27 \times 10^5 \cdot Nair\varepsilon$

Shipping and packaging negligible

$SAP_c := 0 \qquad SAP_c = 0 \cdot Nair\varepsilon$

Total variable operating cost

$TVO_c = SAP_c + Ms_c + ACRM$

Annual variable operating cost

$$TVO_{annum} := \frac{SAP_c + Ms_c + Ut_c}{n} + ACRM$$

$$TVO_{annum} = 8.736 \times 10^5 \cdot \frac{Naira}{yr}$$

Total annual operating cost

$AOC_c := TFO_{annum} + TVO_{annun}$

$$AOC_c = 1.22 \times 10^6 \cdot \frac{Naira}{yr}$$

13.2.3 Profit analysis

Annal sales of product or revenue (A_{sp})

Sales of ginger rhizome essential oil

$$Oil_{sales} := F_{6a} \cdot \frac{0.4 \cdot ER}{kg} \qquad Oil_{sales} = 687.495 \cdot \frac{Naira}{hr}$$

Saving from selling of residue for Animals consumption

$$RES_{sales} := F_{62} \cdot \left(0 \cdot \frac{ER}{kg}\right) \qquad RES_{sales} = 0 \cdot \frac{Naira}{hr}$$

Annual sales of product

$$As_p := \left(RES_{sales} + Oil_{sales}\right) \cdot \left(7392 \frac{hr}{yr}\right)$$

$$As_p = 5.082 \times 10^6 \cdot \frac{Naira}{yr}$$

Profit before tax (PBT)

$PBT := As_p - AOC_c$

$$PBT = 3.862 \times 10^{6} \cdot \frac{Naira}{yr}$$

Annual depreciation (Depr)

let S = Salvage Value after n years of the plant. Assume plant life of 4 yrs

Then $S := 20 \cdot 10^{4} Naira$

$$Depr := \frac{T_{inv} - S}{n}$$

$$Depr = 1.319 \times 10^{6} \cdot \frac{Naira}{yr}$$

Tax payable (TP)

Assume tax ratio of 20% and depreciation is tax allowable, hence $Tax\_ratio := 0.1$

$$TP := (PBT - Depr) \cdot Tax\_ratio$$

$$TP = 2.543 \times 10^{5} \cdot \frac{Naira}{yr}$$

Profit after tax (PAT)

$$PAT := PBT - TP$$

$$PAT = 3.608 \times 10^{6} \cdot \frac{Naira}{yr}$$

Net income (NIN)

$NIN := PAT + Depr$ $NIN = 4.927 \times 10^{6} \cdot \frac{Naira}{yr}$

Pay back period (PBP)

$PBP := \frac{T_{inv}}{NIN}$ $PBP = 1.112 \cdot yr$

Return on investment (ROI)

$ROI := \frac{PAT + Depr}{T_{inv}} \cdot 100$ $ROI = 82.524$

The essential oil plant is profitable with rate of return on investment (ROI) of 81.24%. Annual profit after tax (PAT) of approximately 3.4 million and pay back period of 1 year.

CHAPTER FOURTEEN

14.0.0 CONCLUSION AND RECOMMENDATION

14.1.0 CONCLUSION

The major objective of this design is to develop a cost effective, environmentally friendly process that takes into consideration the technological development of a viable economy and market structure. Hence a plant to produce 100,000 litre per year of essential oil has so far been designed. Based on the design, the basic equipment were properly sized and specified after carrying out detail material and energy balances around each of the units and hence the overall plant. Safety and effective waste disposal measures were considered and thus the plant can be said to be environmentally acceptable. From the economic analysis as calculated above, the equipment cost of the plant is N416, 000. The profit after tax was found to be 3.5 million naira per annum, with pay back period of approximately one year. Hence the plant designed so far can be said to be economically viable with rate of return on investment (ROI) of 81.24%.

14.2.0 RECOMMENDATION

For any intending industrialist or government the following recommendations are of paramount importance.

1. The safety of life and property should of paramount in the design implementation.
2. Experience mechanical engineer or contractor should be consulted for the construction.
3. Well trained personnel should keep proper statistic of technological parameters on order to prevent any unwanted accident.
4. For the operational services, well trained personnel should be employed.
5. The industrialist should ensure that a good maintenance culture is put in place.
6. The design should be properly supervised by personnel of adequate technical know how.

7. Double or triple column extractor should be considered to avoid production halt when one column develop fault(s) ; or in case of future expansion , the double or triple extractors can be working simultaneously.
8. Expansion of the plant from small scale production to large scale production should not be delayed since there is high demand for this product.

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APPENDICES

APPENDIX A

Drawing of the equipment in essential oil plant.

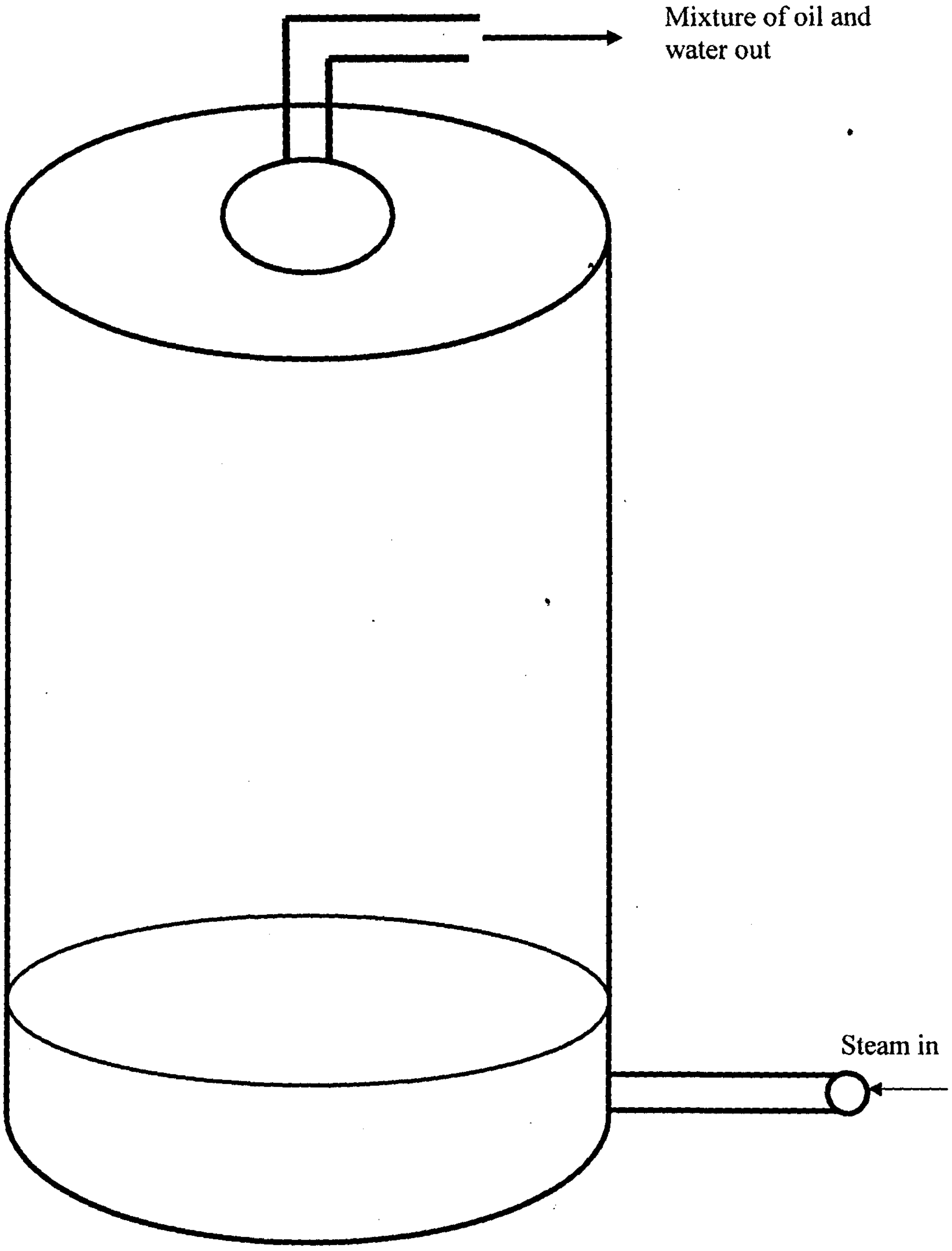

FIGURE 30: COLUMN EXTRACTOR

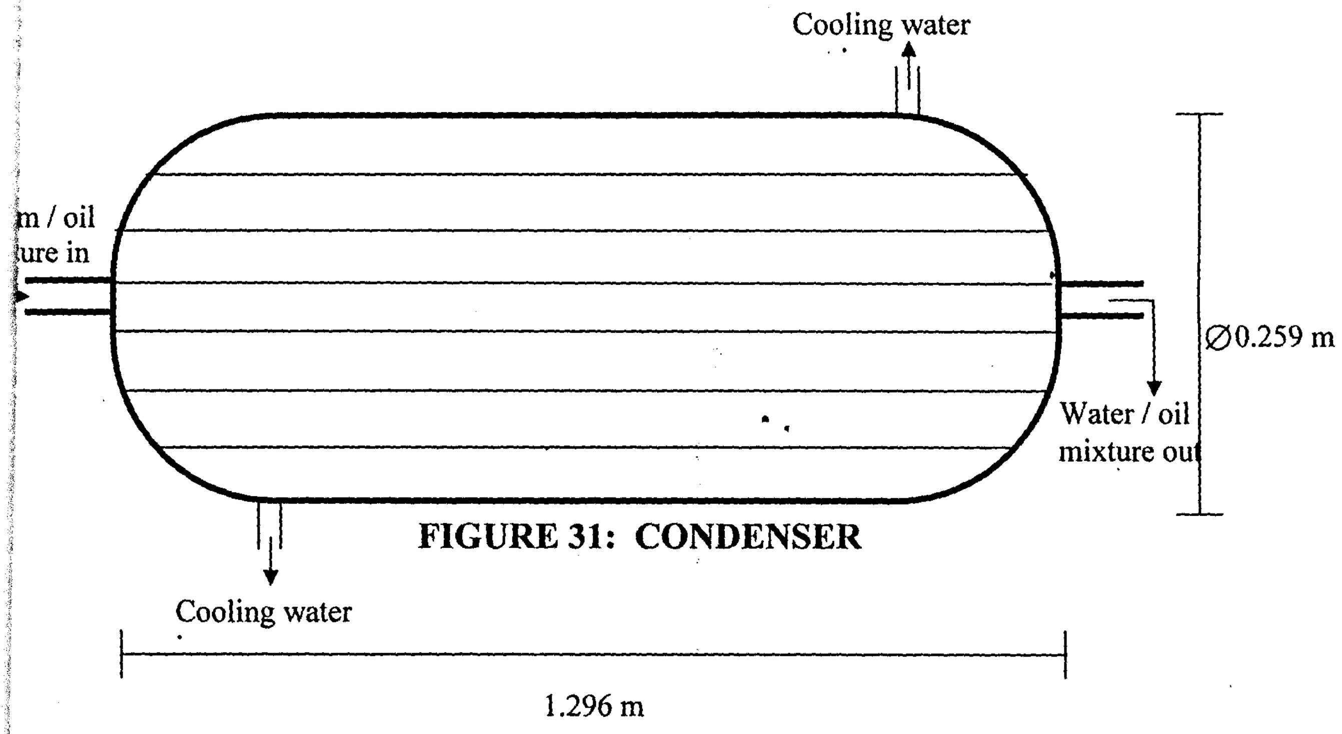

FIGURE 31: CONDENSER

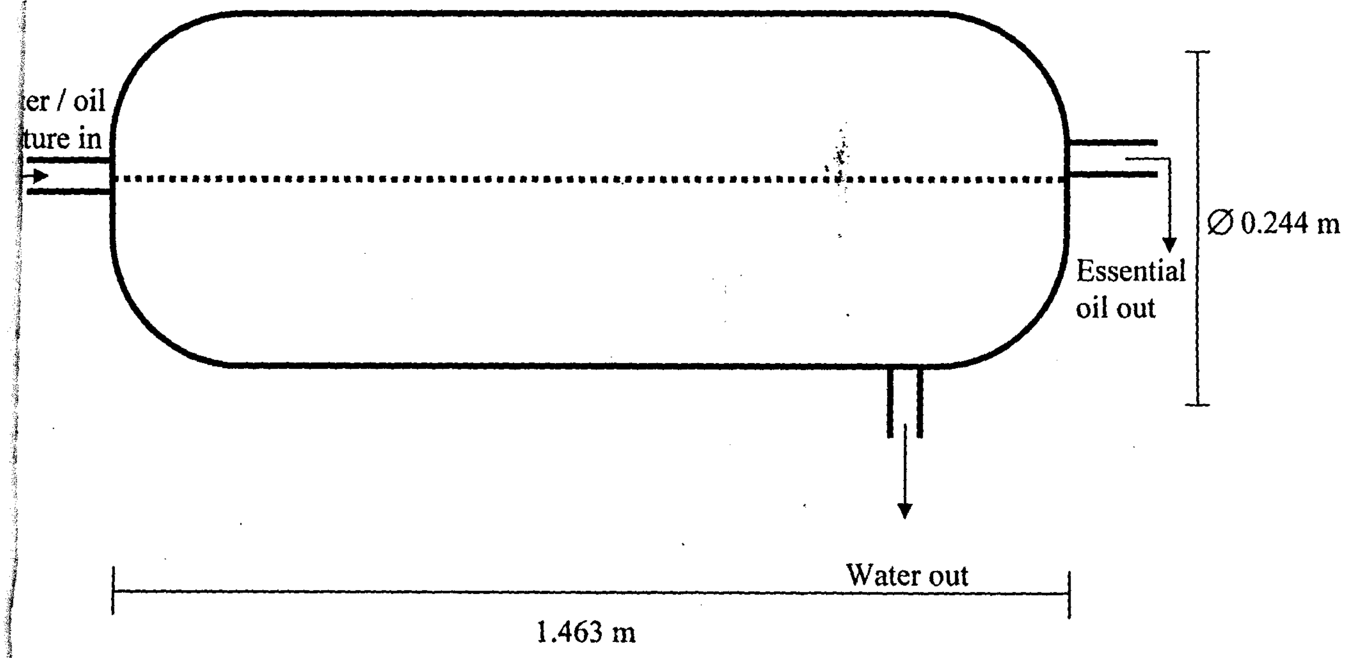

FIGURE 32: HORIZONTAL SEPARATOR