

CERTIFICATION

I certify that this work, "EQUIPMENT DESIGN OF AN AGITATED BATCH LEACHING VESSEL FOR THE PRODUCTION OF CASTOR OIL" was carried out by OMITAYO ADESHEYE A. of the Chemical Engineering Department and has never been submitted elsewhere.

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DEDICATION

This design project is dedicated to the **OMITAYO's** family.

ABSTRACT

The objective of the work is to design an agitation vessel on the basis of production of 100,000 m³/year. An assumption of 250 working days /year and 10 working hour /day were made. And thus two batches /day of operation was obtained the weight of feed fed per batch and the weight of solvent used was also obtained. Material and Energy balances were also obtained around each unit making up the whole process.

A detailed design was also taken into consideration with regards to the agitated vessel. The cost of the agitated vessels was =N=2,545,699.50 using the formular for equipment costing for 1992.

2.1.1	Castor oil-----	3 - 5
2.2	Properties of castor oil-----	5 - 6
2.3	Extraction-----	6 - 7
2.4	Storage of castor oil-----	7
2.5	Uses of castor oil-----	7 - 8
2.6	Batch Stirred Tank-----	8
2.7	Choice of Solvent-----	9

CHAPTER THREE

3.0	Process design-----	10
3.1	Process description-----	10
3.2	Design consideration-----	11 - 12
3.3.1	Materials for construction-----	13
3.3.	Material balance -----	13
3.4.1	Around the crusher-----	13
3.4.2	Around the extractor-----	14
3.4.3	Around the filter-----	14 - 15
3.4.4	Around the distillation column-----	15 - 17
3.5	Energy balance-----	17
3.5.1	Around the extractor-----	17 - 19

CHAPTER FOUR

4.0	Sizing.....	21
4.1.0	The volume of the extractor.....	21 - 22
4.1.1	Area of the extractor.....	22 - 23
4.1.2	Height of the extractor.....	23 - 24
4.1.3	Height of the impeller above the bottom vessel.....	24
4.1.4	Agitator diameter.....	24
4.1.5	Area of extractor.....	24
4.1.6	Thickness of the vessel.....	24 - 25
4.2	The Stirrer.....	25
4.2.1	Critical stirrer speed.....	25 - 26
4.2.2	Power required for the stirrer.....	26
4.3	Heat of mixture.....	27
4.3.1	Thermal conductivity of mixture.....	27
4.3.2	Heat capacity of mixture.....	27
4.3.3	Pipe diameter for various streams.....	27 - 28
4.4	Calculating the Reynolds' number at 30°C, 50°C and 70°C.....	29
4.5	Calculating the Prandtl number at 30°C, 50°C, and 70°C.....	29 - 30
4.6	Approximate values of the heat transfer coefficient inside the extractor.....	30 - 31
4.7	Internal wall.....	31
4.7.1	The temperature of the internal wall.....	31 - 32
4.7.2	Viscosity at temperature of the internal wall.....	31 - 32

4.8 To calculate the actual heat transfer coefficient.....	34 - 35
4.9 The overall heat transfer coefficient.....	35 - 36
4.10 Time taken to heat the bulk mass.....	36 - 39
4.11 Amount of steam required to heat the bulk.....	39 - 40
4.12 Heat supplied by steam.....	40
4.13 The bulking pressure.....	40 - 41
4.14 Cost analysis.....	41
4.14.1 Cost of extractor.....	42 - 43
4.14.2 Cost of agitator.....	42
4.14.3 Cost of solvent.....	43
4.14.4 Cost of steam.....	43
4.14.5 Cost of pipes.....	43
4.15 Safety of the equipment design.....	44 - 46

CHAPTER FIVE

5.0 Conclusion and Recommendation.....	47
5.1 Conclusion.....	47
5.2 Recommendation.....	47

CHAPTER ONE

1.0 INTRODUCTION

The general term "plant design" includes all engineering aspects involved in the development of either a new, modified or expanded industrial plant.

It refers to the actual design of the equipment and facilities necessary for carrying out the process it however, requires the use of engineering principles and theories combined with a practical realization of the limit imposed by industrial conditions such as the equipment design of an agitated batch leaching oil vessel for the production of castor oil.

Castor oil is a pale amber viscous liquid derived from the seeds of the plant, *Ricinus communis* of the family *Euphorbiaceae* and it is sometimes known as ricinus oil, oil of palma christi, tangantangan oil and Neoloid.

The world's production of castor was 844 metric tonnes from 1961 to 1971 which increased to 907 metric tonnes in 1979 but decreased to 845 metric tonnes in 1980 and 67 metric tonnes from 1983 to 1984 and about 154 metric tonnes between 1993 and 1996.

The major importers of the seed and oil are the Brasil, India, China, USSR, Thailand and followed by the rest of the world (ie including Nigeria). Report however shows that about 10% of imported castor oil is used in paints and varnishes, 5% in lubricating and similar oil, 5% as fatty acid and except for a small amount used medicinally, the remaining quantity is utilised by industry for undefined products.

With great significance (ie. seed and oil)It is necessary to increase the production to a greater quantity.

And Nigeria being a producer (oil and seed) has the potential to expand, thus, generating foreign exchange for the country. It is widely cultivated in Ogun, Niger, Nasarawa, Kogi, Kaduna states to name a few. Moreover the facilities required are indigenous, thus making it cost effective.

CHAPTER TWO

2.0 LITRATURE REVEIW

2.1 CASTOR BEANS

Opinions differ as to whether castor plant originated in Africa, India, but at the present time it occurs in practically all tropical and sub tropical regions where it grow wild as a perennial. It is also widely found in temperate zones, but must be cultivated as an annual where there is frost.

In the frost free areas castor can attain height of 9 - 11 metres (30 - 36 ft). The seeds of the castor plant are encased in a spring outer shell and grown in clusters on spikes of the plant. The seeds are oval in shape and generally similar to, but larger than a common bean. The helium is at the end of the seed. Typical seed weight is between 0.1 and 1.2gramme. The seeds are molted dark and light brown, but both the making and size very considerably amount beans from different varieties. The seeds are poisonous and ingestion of only one seed can be fatal to humans.

The castor beans is made of approximately 75% kernel and 25% husk and about 2/3 of the weight of the kernel is oil. The bean also contains the enzyme lipase, which may be readily extracted from the seeds. It is insoluble in water and has been shown to catalyze the synthesis of triglycerides as well as the hydrolysis of the oil in the presence of water.

2.1.1 CASTOR OIL

It is a pale amber viscous liquid derived from the seeds of the plant, *Ricinus communis* of the family Eurphorbiacea and is consequently some times known as ricinus oil, oil of palma christi, tangantangan oil or Neoliod.

Virtually, odourless and tasteless castor oil can be obtained by careful handling of the seed and deodorization of the extracted oil, has long been available.

Although most widely known for it's medicinal properties, such use accounts for only a minute fraction of the total. The industrial uses of castor oil are many and varied.

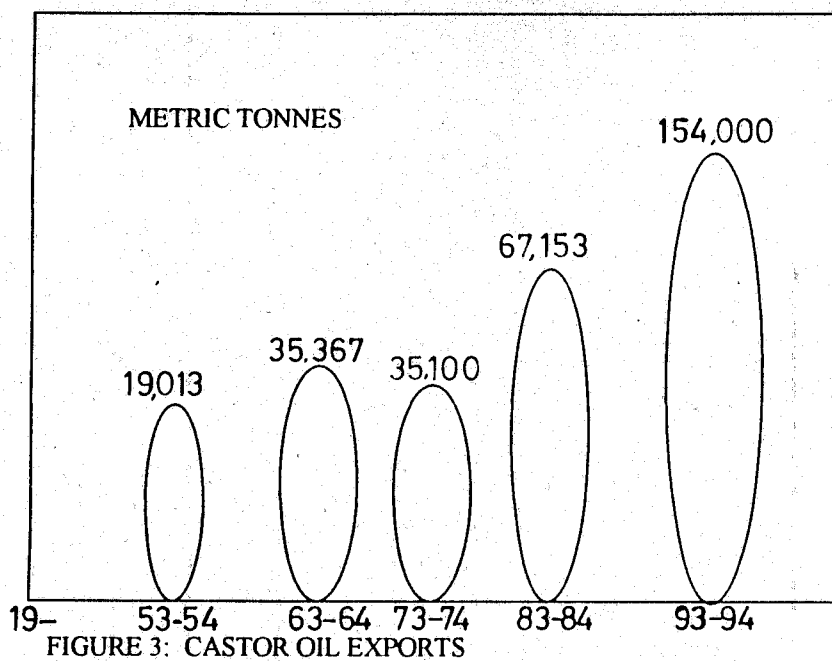


FIGURE 3: CASTOR OIL EXPORTS

From the two figures shown, it is seen that there's an increasing importance in castor seed and oil production. However, Nigeria on its own part produces a very minute quantity. otherwise, the major producers in the country such as in Ogun ,Kogi, Kaduna, Nasarawa States prefer to export the seeds other than produce the oil.

Research, show that only a few and not completely functional industries produce the oil in the country. For example the Integrated oil mills in Kaduna sponsored by the Raw Material and Research Development Council (RMRDC) does not produce all year round. And this reduces greatly the direct use of the oil to meet up with the demands. And this could be as a result of incompetent management and knowledge of what is available. It is however believed that the design when put into reality should be able to meet up to a reasonable quantity of the demand.

2.2 PROPERTIES OF CASTOR OIL

- (A) Castor oil as compared with other vegetable oils is low in tocopherol, containing about 0.05%, and is an extremely poor source of essential fatty acids.
- (B) Castor oil is one of the few naturally occurring glycerides that approaches being a pure compound since fatty acid portion are nearly nine-tenths ricinoleic. The average fatty acid composition of castor oil is ricinoleic 86%, oleic 8.5%, stearic 0.5%, - 2.0% and dehydroxy stearic acid 1- 2%.

(C) Castor oil is the only major oil that is composed in the main of glycerides of a hydroxyl acid. Ricinoleic acid (12 - hydroxy - 9 - octadecanoic acid). $\text{CH}_3 (\text{CH}_2)_5 \text{CH} (\text{OH}) \text{CH}_2 \text{CH} = \text{CH} (\text{CH}_2) \text{COOH}$, has a neutralization value of 188.00 and exhibits and optical rotation. $(\alpha)_D$ of + 7.8, due to its asymmetric C - 12 atom (5, kirik O. 1964) It is the cis acid melting point 5.5°c (also reported as 17°c , indicating two polymorphic forms), that is ordinarily present in castor oil, the trans acid, melting point 53°c is also known

(D) Castor oil tastes some what acid and has excellent qualities. It is readily distinguished from other triglycerides by its high specific gravity, viscosity and acetyl value. Another distinguishing feature is its solubility in alcohol

One volume of oil dissolve in two volumes of 95% ethyl alcohol at room temperature and the oil is miscible in all proportions with absolute ethyl alcohol. Castor oil is soluble in polar organic solvents and relatively less soluble in aliphatic hydrocarbon, thus its slight solubility in petroleum ether can also be used to distinguish it from other triglycerides.

2,3 EXTRACTION

Castor oil can be obtained from the seed by expression or solvent extraction or by combination of both. Expression to usually accomplished by hydraulic presses at low temperature, hence the designation cold pressed castor oil. Expeller have also been used to effect continuous expression, they are favoured on account of their greater capacity and lower processing cost.

Cold pressing generally removes 25 - 30% of the oil, which is filtered to yield a bright and clear oil. The press cake containing 10 - 20% oil is them extracted by percolating a solvent usually heptane or sometimes petroleum ether through a bed of the cake.

The result miscella is stripped, by heating to remove the petroleum ether, yielding solvent free oil, which is usually filtered.

A direct solvent extraction process has been reported to have been applied successfully on a batch scale to either whole on decorticated beans to produce a quality castor oil. Essentially

the process consists of cracking and flaking most cooking, crisping by evaporative cooking and finally re-rolling the beans before extracting with petroleum ether at 69°C

The cake (called castor pomace) resulting from commercial extraction contains up to 2% oil and is used chiefly as fertilizer. Castor pomace is high in protein but is unfortunately highly toxic, precluding any edible use. The toxicity is attributed to three different agents.

- (1) A poison protein called ricin easily detoxified by most cooking.
- (2) A toxic alkaloid known as ricinine but considered a serious contaminant.
- (3) A very powerful heat-stable allergen and it is not easily destroyed in its entirety.

The 3 OH groups of Ricinoleic acid ($C_{17}H_{32}OH$) COOH) confer on castor oil the unique property of solubility in alcohol.

The proximate composition of castor seed ranges as follows

Oil => 45 - 51.8%

Moisture => 3.1 - 5.8%

Protein => 12 - 16%

Carbohydrate => 3.1 - 7%

Fibre => 23.1 - 27.2%

Ash => 2 - 2.2%

2.4 STORAGE OF CASTOR OIL

Crude castor oil is generally not stored for a long period. The colour and acidity of crude castor stored at high atmospheric temperature do not increase appreciably after 1 month storage. Refined castor oil can be stored for up to 6 months to 1 year with little change in colour and acidity. Both crude and refined castor oils can be stored for 1 - 2 years without accumulation of peroxides in significant amounts or increasing the oxidative rancidity.

2.5 USES OF CASTOR OIL

- (1) Paints
- (2) Varnishes

- (3) Protective coverings
- (4) Chemicals e.g sebacic and undecylenic acid used for:
 - (a) Manufacturing plasticisers
 - (b) Nylon fibres
- (5) Heptal and undecylenic acid obtained by decomposition of castor oil at temperature of about 450°C and used in.
 - (a) Perfumery
 - (b) Bactericide/Fungicide.
- (6) However owing to their bacterial action, sodium ricinoleate and sulphuric ricinoleate are important ingredients of tooth paste formation.
- (7) Hydraulic brake fluid
- (8) Lubricant for locomotive, marine and airplane engines.
- (9) Printing inks
- (10) Soap making especially transparent soap
- (11) Medicinally, hydrogenated castor oil is used in the manufacture of ointment bases.
 - (a) Chemical contraceptive (as a result of Ricinoleic acid – the highest acid % in castor oil) to lower surface tension finally resulting in the disruption of sperms.
 - (b) Oil is used in pharmacy as a strong laxative
- (12) Cake due to its richness in protein, carbohydrate, Ca, K, Mg and Fe is used in fertilizer.
- (13) Waxes, polishes, carbon papers, candles are other products from castor oil

2.6 THE BATCH STIRRED TANK

In so far as the controlling rate in the mass transfer is the rate of transfer of material into or from the interior of the solid particles, rather than the rate of transfer to or from the surface of the particles. The main function of the agitator is to supply unexhausted solvent to the particles while they reside in the tank long enough for the diffusive process to be completed.

The agitator does this most efficiently if it just gently circulates the solid across the tank bottom or barely suspends them above the bottom. After leaching has proceeded to the desired

degree, the solids may be separated by setting and decantation of the extract or by external filter centrifuges or thickness.

2.7 CHOICE OF SOLVENT

The boiling point of petroleum ether is 69°C and the oil solubility in the solvent is used to distinguish it from other triglycerides.

CHAPTER THREE

3.0 PROCESS DESIGN

3.1 PROCESS DESCRIPTION

This involves the drying, cracking, winnowing and crushing of the castor seed into a small size to allow easy percolation of the solvent and also to obtain the highest yield as obtained from the laboratory experiment.

The crushed sample is charged into the extractor, the solvent is allowed to pass over the mass. The extract and the raffinate enters into the filter press where they are being separated. The extract (oil and solvent) goes into the distillation column (i.e after separation by the filter press).

In the column, the castor oil is separated from the solvent and the oil pumped into the storage tank while the solvent is recovered and recycled for further use.

RAW MATERIALS AND PROPERTIES

The raw materials for the production of castor oil are:

- (a) Castor seed
- (b) Solvent (Petroleum ether)

3.22 PROPERTIES OF THE SOLVENT

- (a) Boiling point - $60-80^{\circ}\text{c}$
- (b) Odour - Pungent
- (c) Formular - C_6H_6
- (d) Thermal conductivity - $0.102 \text{ w/m}^{\circ}\text{c}$
- (e) Density - 659 kg/m^3
- (f) Heat capacity - 0.527 kj/kg k

3.22 PROPERTIES OF THE CASTOR SEED

- Density = 1500 kg/m^3
- Thermal conductivity = $0.198 \text{ m}^{\circ}\text{c}$
- Heat capacity = $1.675 \text{ kj/kg}^{\circ}\text{k}$

3.2 DESIGN CONSIDERATION

Basis: Production per year = $100,000\text{m}^3 / \text{year}$

But. Density = Mass per volume

Density of oil (from experiment) = 0.972 kg/m^3

Volume = $100,000 \text{ m}^3/\text{year}$

Therefore, mass of oil = Density x Volume

$$= 0.972 \times 100,000$$

$$= 97200 \text{ kg /yr.}$$

However, assume that, there are:

- (i) 250 working days per year
- (ii) 10 working hours per day.
- (iii) Extraction time of 5 hours per batch

EQUIPMENT DESIGN OF AN AGITATED BATCH
LEACHING VESSEL FOR THE PRODUCTION OF
CASTOR OIL.

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Hence, the number of batches /day is

$$\left[\frac{10}{5} \right] \frac{\text{hrs}}{\text{day}} \times \frac{\text{batch}}{\text{hrs}} = 2 \text{ batches/day}$$

2 batches / day

$$\begin{aligned} \text{Production / day} &= \frac{97200 \text{ kg}}{250 \text{ yr}} \times \frac{\text{yr}}{\text{days}} \\ &= 388.80 \text{ kg / days} \end{aligned}$$

388.80 kg/days

$$\text{Production / batch} = \frac{388.80 \text{ kg}}{2 \text{ day}} \times \frac{\text{day}}{\text{batch}}$$

194.40 kg/batch

194.40 kg/batch

To determine the mass of feed. From the laboratory experiment

0.02kg of cast seed produces 0.00926 kg of oil

194.40 kg of oil will be obtained from

$$\text{i.e } 0.00926 \text{ kg of oil} = 0.02 \text{ kg of feed}$$

$$194.40 \text{ kg of oil} = \left[\frac{194.40 \times 0.02}{0.00926} \right] \text{ kg of feed}$$

$$\Rightarrow 419.87 \text{ kg of feed /batch}$$

419.87 kg of feed/batch

Let the ratio of the solvent to feed be;

3 : 1

Such that, the ratio of the mass of solvent (represented as a) to the feed

Will be

$$3 = 1$$

$$a \text{ kg} = 419.87 \text{ kg}$$

$$\Rightarrow \left[\frac{419.87 \times 3}{1} \right] \text{ kg} = a$$

$$\Rightarrow 1259.61 \text{ kg of solvent}$$

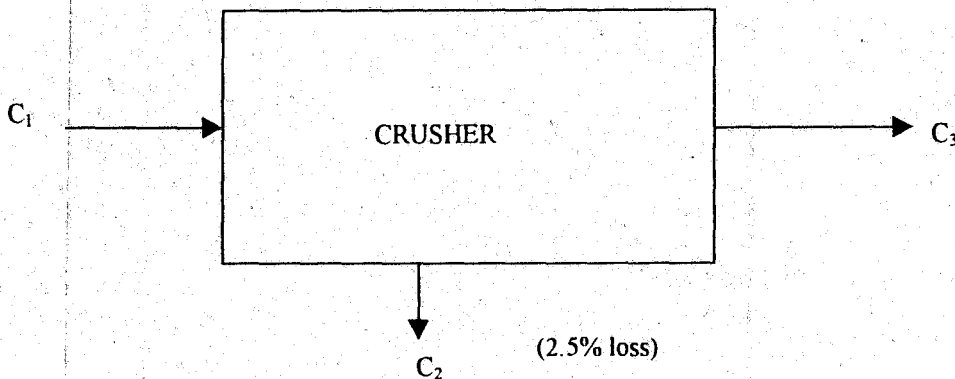
1259.61 KG OF SOLVENT

3.3.1 MATERIALS FOR CONSTRUCTION

The material chosen for construction is steel. This is because of its ability to withstand vibration, stress and much more its resistance to corrosion and strength. However, it is not susceptible to deformation until life spans exceeds.

3.3 MATERIAL BALANCE

3.3.1 AROUND THE CURSHER



Assumption: 2.5% loss of material during crushing

$$C_1 (1 - 0.025) = 419.87$$

$$0.975 C_1 = 419.87$$

$$C_1 = \frac{419.87}{0.975}$$

$$C_1 = 430.64\text{kg}$$

430.64KG

However 2.5% loss of material becomes

$$\frac{2.5}{100} \times 430.64 = 10.77 \text{ kg} = C_2$$

But recall that Material In = Material out

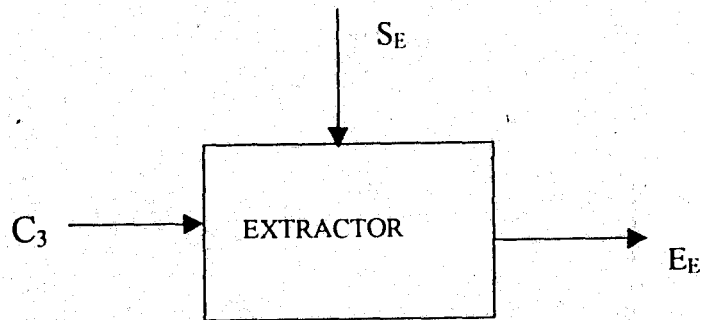
$$\Rightarrow C_1 = C_1 + C_3$$

$$\Rightarrow 430.64 = 10.77 + 419.87$$

$$430.64/\text{kg} = 430.64/\text{kg}$$

430.64KG
(BALANCE)

3.42 AROUND THE EXTRACTOR



Where C_3 = Feed; from the crusher. (kg)

S_E = Weight of Solvent entering the crusher. (kg)

E_E = Weight of Solvent + material (kg)

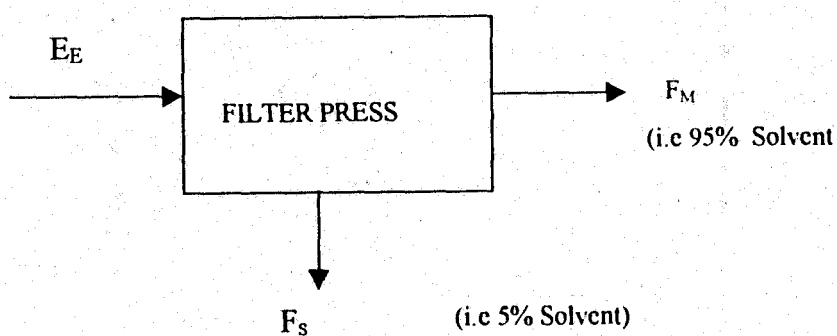
Material In = Material out

$$C_3 + S_E = E_E$$

$$419.87 + 1259.61 = E_E$$

$$E_E = 1679.48 \text{ kg}$$

1679.48KG

3.4.3 AROUND THE FILTER

Where E_E = Weight of Solvent + Solid material (kg)

F_S = Weight of Solid material after extraction (kg)

F_M = Weight of the mixture (Solvent + oil) (kg)

But, Weight of Solvent = 1259.61 kg

$$F_M \quad (95\% \text{ of Solvent}) \quad = \quad 0.95 \times 1259.61$$

$$= \quad 1196.63\text{kg}$$

1196.63KG

$$F_S \quad (5\% \text{ of Solvent}) \quad = \quad 0.05 \times 1259.61$$

$$= \quad 62.98\text{kg}$$

62.98KG

But recall that 194.40 kg of oil is obtained

From 419.87 kg of feed

Therefore,

$$F_M \quad = \quad 1196.63 + 194.40 = 1391.03 \text{ kg}$$

$$F_S \quad = \quad 62.98 + (419.87 - 194.40)$$

$$= \quad 62.98 + 225.47$$

$$= \quad 288.45 \text{ kg}$$

288.45kg

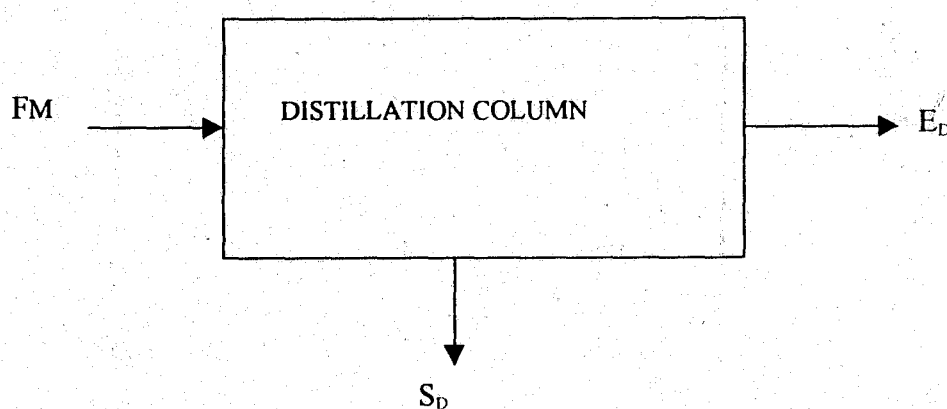
$$\Rightarrow \quad = \quad E_E \quad = \quad F_S + F_M$$

$$\Rightarrow \quad = \quad 1679.48 \quad = \quad 288.45 + 1391.03$$

1679.48KG
(Balanced)

$$1679.48\text{kg} \quad = \quad 1679.48 \text{ kg}$$

3.4.4 AROUND DISTILLATION COLUMN



Where F_M = Weight of the mixture (Solvent + oil) kg

S_D = Weight of the Solvent (kg)

E_D = Weight of the oil (kg)

However, the property of petroleum ether holds for the fact that above 0.02% of the residue is contained in the extract. i.e contained in the 95% of the initial Solvent.

But, recall that the weight of the solvent is obtained as 1259.61 kg
For 95% of the Solvent i.e 0.95×1259.61

$$\Rightarrow 1196.63\text{kg}$$

1196.63kg

i.e Weight of solvent entering the distillation column

.. $0.02\% \times \text{Weight of the solvent} = \text{Weight of the residue in the solvent}$

$$\Rightarrow 0.02\% \times 1196.63$$

$$= 0.24\text{kg}$$

0.24kg

... 99.98% will be the percentage of the pure solvent entering the distillation column i.e

99.98% x Weight of the solvent

$$99.98\% \times 1196.63$$

$$= 1196.39\text{ kg}$$

1196.39kg

$$F_M = 1391.03\text{kg (not of solvent + oil)}$$

$$S_D = 1196.39\text{kg (not of pure solvent)}$$

But, Material In = Material out

$$F_M = S_D + E_D$$

$$\text{OR } E_D = F_M - S_D$$

$$= 1391.03 - 1196.39$$

$$= 194.64\text{kg}$$

Recall, the 0.02% of residue contained in the extract.

$$E_D = 0.24\text{kg}$$

$$E_D = (194 - 0.24)\text{kg}$$

$$= 194.40\text{kg}$$

194.40kg

3.5 ENERGY BALANCE

3.5.1 AROUND THE EXTRACTOR

Recall,

$$\text{Heat Input} + \text{Heat due to water} = \text{Heat output}$$

For, heat Input;

Castor Seed

$$M_f C_{pf} DT = H_f$$

$$\text{Where } M_f = \text{Weight of feed} = 419.87\text{kg}$$

$$C_{pf} = \text{Heat capacity of feed } 1.675\text{kJ/kg}^\circ\text{k}$$

$$T_2 = 27^\circ\text{c} \quad T_1 = 25^\circ\text{c}$$

$$H_f = 419.87 \times 1.675 (27 - 25)$$

$$= 703.28 \times 2$$

$$= 1406.56\text{kJ}$$

1406.56kJ

Solvent

$$M_s C_{ps} DT = H_s$$

Where,

$$M_s = \text{Mass of solvent} = 1259.61\text{kg}$$

$$C_{ps} = \text{Heat capacity of solvent} = 0.527\text{kJ/kg}^\circ\text{k}$$

$$DT = \text{Temperature change}$$

$$T_1 = 15^\circ\text{c}$$

$$T_2 = 25^\circ\text{c}$$

$$H_s = 1259.61 \times 0.527 (25 - 15)$$

$$= 1259.61 \times 0.527 \times 10$$

$$= 6638.14 \text{ kJ} \quad 6638.14 \text{ kJ}$$

Heat output.

The heat Output will be the total heat output of the mixture

Total mass of the mixture (feed + solvent)

$$= (419.87 + 1259.61) \text{ kg}$$

$$= 1679.48 \text{ kg}$$

Heat capacity of the mixture (C_p mix)

$$= 0.814 \text{ kJ / kg k}$$

$$\Rightarrow T_1 \text{ mix} = \frac{15 + 25}{2} = \frac{40}{2} = 20^\circ\text{C}$$

$$T_2 \text{ mix} = 70^\circ\text{C}$$

$$H \text{ mix} = 1679.48 \times 0.814 (70 - 20)$$

$$= 1679.48 \times 0.81 \times 50$$

$$= 68354.84 \text{ kJ}$$

By difference,

$$\text{Heat due to water} = \text{Heat output} - \text{Heat input}$$

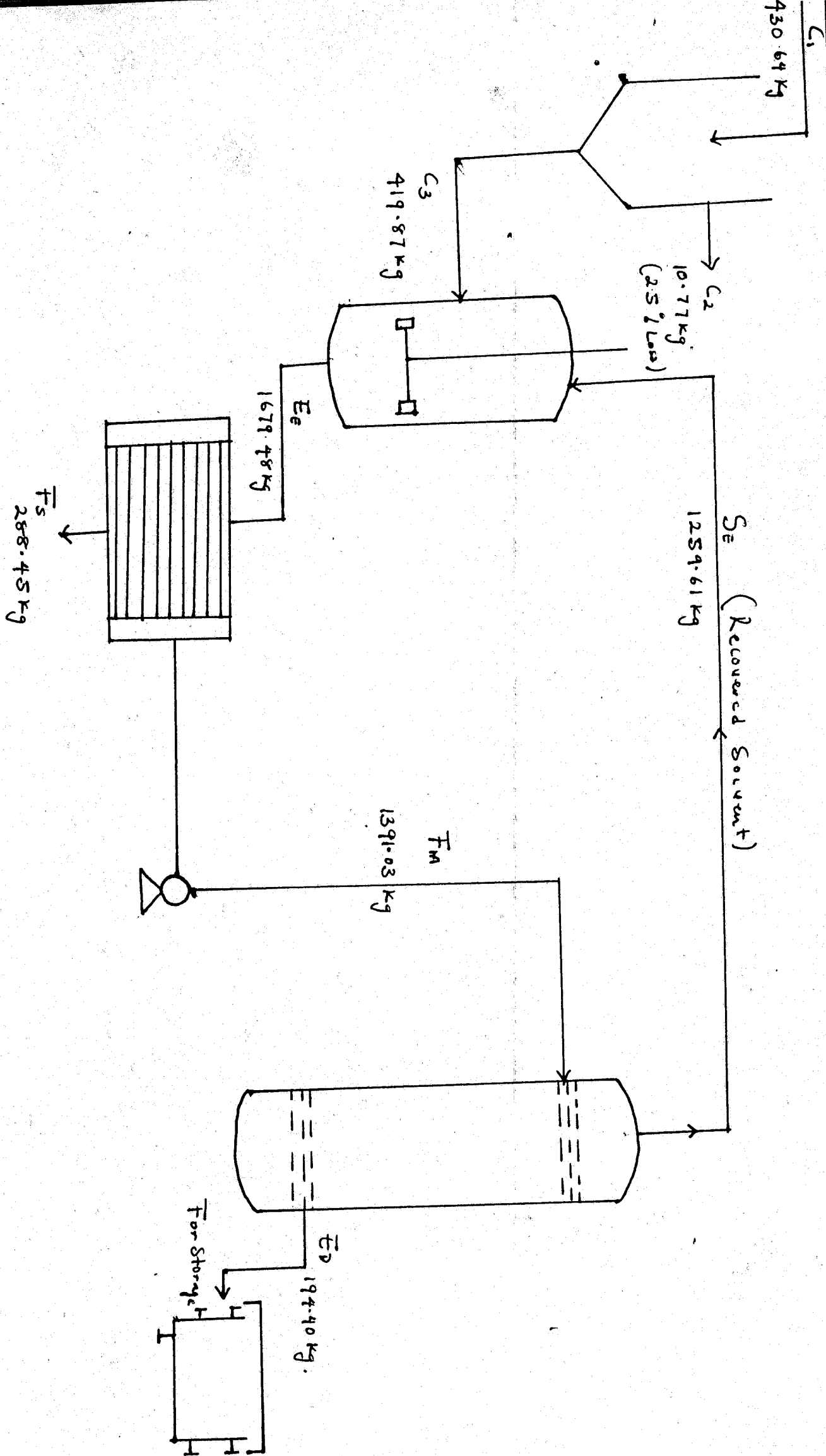
$$= 68359.89 - (1906.56 + 6638.14)$$

$$= 68359.84 - 8049.70$$

$$\text{Heat due to water} = 60310.14 \text{ kJ}$$

However, in summary

Total Heat input	Total Heat output
Feed => 1406.56 kj	
Solvent => 6638.14 kj	68359.84
Heat due to water => 60310.14 kj	
Total => 68354.84 kj	68359.84 kj



CHAPTER FOUR

DETAILED DESIGN OF THE EXTRACTOR UNIT

4.0 SIZING

4.1.0 THE VOLUME OF THE EXTRACTOR

Recall that, Density = $\frac{\text{Mass}}{\text{Volume}}$

$$\text{Likewise } \rho_{\text{mix}} = \frac{W_f \rho_f + W_s \rho_s}{W_f + W_s}$$

Transport
Phenomena
By
Bryan Bird

Where,

$$W_f = \text{Weight of the feed} = 149.87\text{kg}$$

$$\rho_f = \text{Density of the feed} = 1500 \text{ kg/m}^3$$

$$W_s = \text{Weight of the solvent} = 1259.61\text{kg}$$

$$\rho_s = \text{Density of the solvent} = 659 \text{ kg/m}^3$$

$$\rho_{\text{mix}} = \frac{(419.87 \times 1500) + (1259.61 \times 659)}{419.87 + 1259.61}$$

$$\Rightarrow \frac{629805 + 830082.99}{1679.48}$$

$$\Rightarrow \frac{1459887.99}{1679.48}$$

$$\rho_{\text{mix}} = 869.25 \text{ kg/m}^3$$

Density of
mixture
869.25 kg/m³

Hence, from the above definition of density, the volume of the Mixture, V_{mix} is given as

$$V_{\text{mx}} = \frac{\text{Total mass}}{\text{Density of the mixture}}$$

$$\text{Total mass (Wf + Ws)} = 1679.48\text{kg}$$

$$\text{Density of the mixture } (\rho_{\text{mix}}) = 869.25\text{kg/m}^3$$

$$V_{\text{mix}} = \frac{1679.48}{869.25}$$

$$V_{\text{mix}} = 1.93\text{ m}^3$$

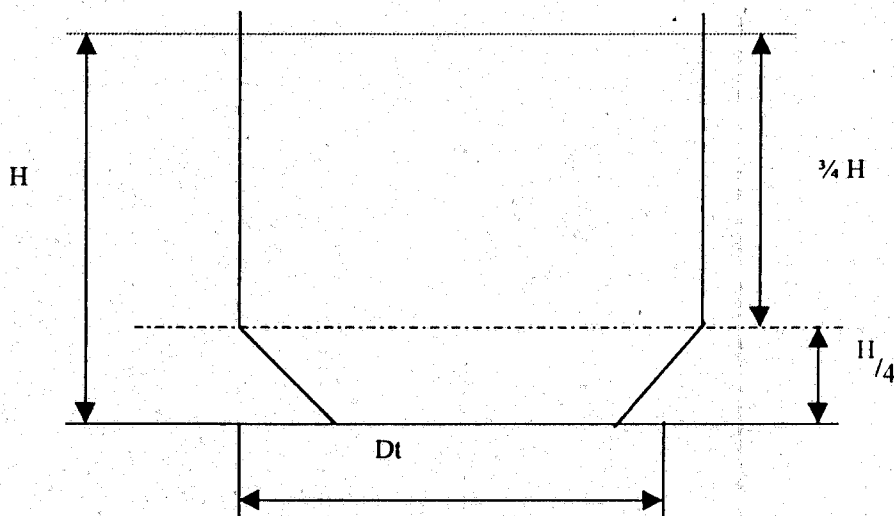
However, putting into construction the safety factor, ie. As 22% ie. 1.22

$$\begin{aligned} \text{Total volume (V}_T) &= 1.93 + 1.22 \\ &= 3.15\text{ m}^3 \end{aligned}$$

Volume of mixture
1.93m³

Total Volume
3/15m³

4.1.1 THE AREA OF THE EXTRACTOR



Total volume = Volume of the cylindrical part + Volume.

Of the hemispherical part.

$$\text{But, } r = \frac{Dt}{2}, \quad h = Dt, \quad V_T = 3.15\text{ m}^3$$

$$= 3.15\text{ m}^3$$

$$\text{Volume of the hemisphere} = \frac{4}{3} \pi r^3 \times \frac{1}{2}$$

$$\text{Volume of the cylinder} = \pi r^2 h$$

$$\text{Volume of the hemisphere} = \frac{2}{3} \pi \left[\frac{Dt}{2} \right]^3 \times \frac{1}{2} = \frac{1}{12} \pi Dt^3$$

$$\text{Volume of cylinder} = \pi \left[\frac{Dt}{2} \right]^2 Dt = \frac{1}{4} \pi Dt^3$$

$$\text{Hence, } VT = \frac{1}{12} \pi Dt^3 + \frac{1}{4} \pi Dt^3$$

$$3.15 = \pi Dt^3 \left[\frac{1}{12} + \frac{1}{4} \right]$$

$$= \frac{1}{3} \pi Dt^3$$

$$3.15 = \frac{1}{3} \times 3.142 Dt^3$$

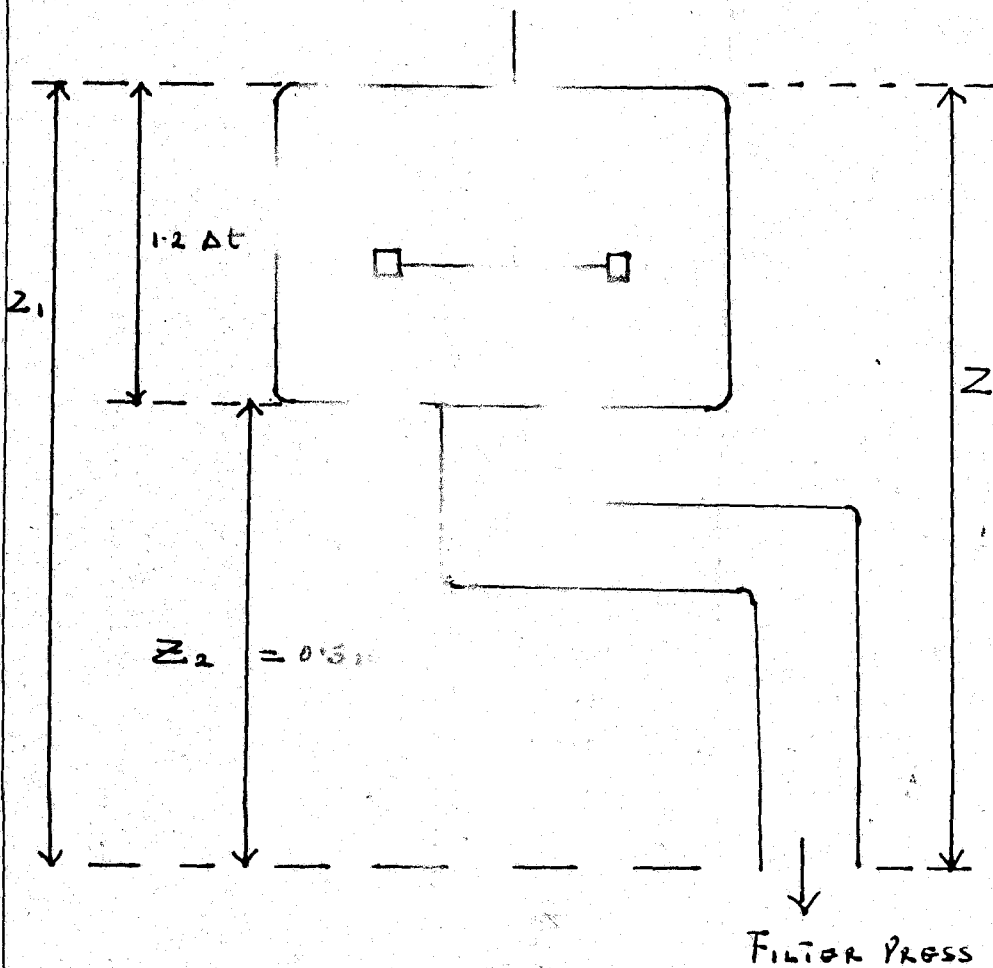
$$3.15 = 1.047 Dt^3$$

$$Dt^3 = \frac{3.15}{1.047} = 3.01$$

$$Dt = 1.44 \text{ m}$$

Width of
Extractor
1.441m

4.1.2 HEIGHT OF THE EXTRACTOR



$$H = 1.2 D_t, \quad \text{but} \quad D_t = 1.441 \text{ m}$$

$$H = 1.2 \times 1.441 = 1.7292 \text{ m}$$

$$\text{Height of the extractor base i.e } Z_z = 0.5 \text{ m}$$

$$\text{Total height, } Z_1 = 1.7292 + 0.5$$

$$= 2.2292 \text{ m}$$

Height of
extractor H
= 1.7292m

Total
Height of
extractor
Z₁ =
2.2292m

Plant
Design and
cost by
Chopey

4.1.3 HEIGHT OF THE IMPELLER ABOVE THE BOTTOM VESSEL (H_i)

From the literature, $\frac{H_i}{D_t} = 0.30$

$$H_i = D_t \times 0.30 = 1.441 \times 0.30$$

$$= 0.4323 \text{ m}$$

4.1.4 THE AGITATOR DIAMETER (D_i)

For the 2 blade paddle at 45°

$$\frac{D_t}{D_i} = 2.83$$

$$\frac{D_t}{2.83} = D_i = \frac{1.441}{2.83} = 0.509 \text{ m}$$

4.1.5 THE AREA OF THE EXTRACTOR (A_i)

Recall, Volume = Area x height

$$\text{Area} = \frac{\text{Volume}}{\text{Height}} = \frac{3.15}{1.729}$$

$$= 1.822 \text{ m}^2$$

Area of
exttractor
1.822m²

4.7.6 THICKNESS OF THE VESSEL

From the literature

$$\frac{2}{3} W_b = \text{Thickness of Vessel}$$

$$W_b = \text{Width of the bath}$$

$$W_b = D_t \times 0.10$$

Chemical
Engineering
Design (Vol. 6)
Richardson &
Coulson

Chemical
Engineering
Design
(Vol.6) by
Richardson
& Coulson

$$= 1.441 \times 0.10$$

$$= 0.1441\text{m}$$

Hence, thickness of the vessel

$$= \frac{2}{3} \times 0.1441 = 0.0961\text{m}$$

Thickness of
Vessel =
0.0961m

4.2 THE STIRRER

4.2.1 THE CRITICAL STIRRER SPEED

From the dimensionless variation.

$$N_c D^{0.85} = S V^{0.1} D_p^{0.2} (g D_p / \rho)^{0.45} B^{0.13}$$

Where, N_c = Critical Stirrer Speed

D_a = D_i = Agitator diameter = 0.509m

S = Shape factor for a 2 blade paddle = 8

g = Acceleration due to gravity = 9.8 kg/m^2

V = Kinematic viscosity of the solvent.

$$= \frac{0.00039}{649} = 6.0 \times 10^{-7}$$

D_p = Average particle size = $0.85 \times 10^{-3}\text{m}$

$$D\rho = \text{Density difference} = \rho_r - \rho_s$$

$$= (1500 - 659) = 841\text{kg/m}^3$$

ρ_{mix} = Density of mixture = 869.25kg/m^3

$$B = 100 \times \frac{\text{Weight of feed}}{\text{Weight of solvent}} = 100 \times \frac{419.87}{1259.01}$$

Therefore,

$$N_c (0.509)^{0.85} = 8 (6.0 \times 10^{-7})^{0.1} \left[\frac{9.8 \times 8.41}{869.25} \right] \left[0.85 \times 10^{-3} \right]^{0.45} \left[33.33 \right]^{0.13}$$

$$Nc(0.563) = 8 \times 0.239 \times 9.48 \times 0.415 \times 1.577$$

$$Nc(0.563) = 1.186$$

$$Nc = \frac{1.186}{0.563} = 2.107 \text{ rps}$$

4.2.2 POWER REQUIRED FOR STRIRER

Using the information,

$$P = \frac{N_p N_c^3 D_a^5 \rho}{0.1g}$$

Where $N_p =$ Power number for 2 blade = 2.5

$N_c =$ Critical stirrer speed = 2.107 rps

$D_a =$ Di = Agitator diameter = 0.509

$g =$ Acceleration due to gravity = 9.8 m/sec^2

$\rho =$ Density of the mixture = 869.25 kg/m^3

$$P = \frac{2.5 (2.107)^3 (0.509)^5 (869.25)}{0.1 \times 9.8}$$

$$= \frac{2.5 \times 9.354 \times 0.0342 \times 869.25}{0.98} = \frac{695.197}{0.98}$$

$$= 709.39 \text{ w} \quad \text{or} \quad 0.7094 \text{ kw}$$

The extractor is fully jacketed to prevent heat loss to the environment.

However, the thickness of the vessel is 0.0961m in which is equipped

With a diameter blade of 0.509 m paddling at 360° . The mixture be

Will be heated from 30°C to 70°C before extractor proceeds.

The volume of the extracting unit is given by 3.15 m^3 with a height of 1.73m and diameter of 1.441m

4.3 HEAT OF MIXTURE

4.3.1 THERMAL CONDUCTIVITY OF

MIXTURE (K mix)

Therefore,

$$K_{\text{mix}} = \frac{W_s K_s + W_f K_f}{W_s + W_f}$$

Where

$$K_s = \text{Thermal conductivity of solvent} = 0.102 \text{ W/m}^0\text{c}$$

$$W_s = \text{Weight of solvent} = 1259.61 \text{ kg}$$

$$K_f = \text{Thermal conductivity of feed} = 0.198 \text{ K/m}^0\text{c}$$

$$W_f = \text{Weight of feed} = 419.87 \text{ kg}$$

$$K_{\text{mix}} = \frac{(1259.61 \times 0.102) + (419.87 \times 0.198)}{1259.61 + 419.87} = \frac{211.614}{1679.48}$$

$$K_{\text{mix}} = 0.126 \text{ W/M}^0\text{c}$$

4.2.3 HEAT CAPACITY OF MIXTURE (Cp mix)

$$C_{pf} = \text{Heat capacity of the feed} = 1.675 \text{ kg/kg}^0\text{k}$$

$$W_f = \text{Weight of feed} = 419.87 \text{ kg}$$

$$C_{ps} = \text{Heat capacity of solvent} = 0.527 \text{ kj/kg k}$$

$$W_s = \text{Weight of solvent} = 1259.61 \text{ kg}$$

$$C_p \text{ mix} = \frac{(1.675 \times 419.87) + (0.527 \times 1259.61)}{419.87 + 1259.61}$$

$$= \frac{703.282 + 663.814}{1679.48} = \frac{1367.096}{1679.48}$$

$$C_p \text{ mix} = 0.814 \text{ kj/kg k}$$

4.2.4 PIPE DIAMETER FOR VARIOUS STREAMS

$$\text{Diameter of Pipe (dp)} = 293 a^{0.53} \rho^{0.37}$$

$$\text{Where } G = \text{Flow rate in kg/s}$$

$$D_p = \text{diameter of the Pipe}$$

$$\rho = \text{Density of mixture}$$

However, assume the flow rate of the mixture to be 15 kg/s. Therefore,

$$G = \frac{15}{\text{mass of mixture}} \times \text{mass of feed}$$

$$= \frac{15}{1679.48} \times 419.87 = \frac{6298.05}{1679.48}$$

$$\therefore G_f = \underline{3.75 \text{ kg/s}}$$

For Solvent

$$G = \frac{15}{1679.48} \times 1259.61 = \frac{18899.15}{1679.48}$$

$$G_s = \underline{11.25 \text{ kg/s}}$$

For each Pipe diameter we have.

Solvent

$$D_p = 2.93 (11.25)^{0.53} (659)^{0.37}$$

$$\Rightarrow 2.93 \times 3.61 \times 0.091$$

$$\Rightarrow 0.9625 \text{ m}$$

$$\text{or } dp = \underline{96.25 \text{ mm}}$$

Feed

$$D_p = 2.93 (3.75)^{0.53} (1500)^{0.37}$$

$$= 2.93 \times 2.015 \times 0.067$$

$$= 0.3956 \text{ m}$$

$$\text{or } dp = \underline{39.56 \text{ mm}}$$

For the mixture

$$dp = 293 (15)^{0.53} (869.25)^{0.37}$$

$$= 293 \times 4.200 \times 0.0818$$

$$dp = \underline{100.66 \text{ mm}}$$

4.3 CALCULATING THE REYNOLD'S AT 30°C, 50°C AND 70°C (SINCE THE MIXTURE IS HEATED FROM 30 – 70 BY STEAM AT 100°C)

Reynold's Number is given by the formular

$$N_{re} = \frac{\rho N D_i^2}{\mu}$$

Where ρ = Density of mixture = (869.25 kg/m^3)

N = Speed of agitator = 2.107 rps

D_i = Impeller diameter = 0.509

μ = Viscosity of mixture at 30°C = $2.90 \text{ m}^2/\text{s}$

“ “ at 50°C = $2.40 \text{ m}^2/\text{s}$

“ “ at 70°C = $2.10 \text{ m}^2/\text{s}$

$$N_{re} (30^\circ\text{C}) = \frac{869.25 \times 2.107 \times (0.509)^2}{2.90}$$

$$= 163.62$$

$$N_{re} (50^\circ\text{C}) = \frac{869.25 \times 2.107 \times (0.509)^2}{2.40}$$

$$= 197.71$$

$$N_{re} (70^\circ\text{C}) = \frac{869.25 \times 2.107 \times (0.509)^2}{2.10}$$

$$L = 225.96$$

4.4 CALCULATING THE PRANDTL NUMBER AT 30°C, 50°C AND 70°C OF THE MIXTURE

Recall that Prandtl Number (N_{pr}) is given by

$$N_{pr} = \frac{C_p \mu}{K}$$

Where C_p = the heat capacity of the mixture = $0.814 \text{ kJ/kg}^\circ\text{C}$

= Viscosity of the mixture at 30°C = $2.90 \text{ m}^2/\text{s}$

= Viscosity of the mixture at 50°C = $2.90 \text{ m}^2/\text{s}^2$

$$K = \text{Thermal conductivity of the mixture (kmix)} = 0.216 \text{ w/m}^\circ\text{c}$$

Therefore,

$$N_{pr} (30^\circ\text{c}) = \frac{0.814 \times 2.90}{0.216} = \frac{2.361}{0.216} = 10.931$$

$$N_{pr} (50^\circ\text{c}) = \frac{0.814 \times 2.40}{0.216} = \frac{1.954}{0.216} = 9.046$$

$$N_{pr} (70^\circ\text{c}) = \frac{0.814 \times 2.10}{0.216} = \frac{1.709}{0.216} = 7.914$$

4.5 THE APPROXIMATE VALUES OF THE HEAT TRANSFER COEFFICIENT INSIDE THE EXTRACTOR

Using,

$$H_i (\text{mix}) = 0.73 (N_{pc})^{0.66} (N_{pr})^{0.34} \left(\frac{k}{D_t}\right)$$

Where,

$$N_{re} = \text{Reynolds number at } 30^\circ\text{c } 50^\circ\text{c and } 70^\circ\text{c}$$

$$N_{pr} = \text{Prandtl number at } 30^\circ\text{c, } 50^\circ\text{c and } 70^\circ\text{c}$$

$$K = \text{Thermal conductivity of the mixture} = 0.216 \text{ W/m}^\circ\text{c}$$

$$D_t = \text{Diameter at the extractor} = 1.441\text{m}$$

$$H_i (30^\circ\text{c}) = 0.73 (163.62)^{0.659} (10.93)^{0.339} \left[\frac{0.216}{1.441}\right]$$

$$\Rightarrow 0.73 \times 28.77 \times 2.25 \times 15$$

$$= 7.09 \text{ kw/m}^\circ\text{c}$$

$$h_i (50^\circ\text{c}) = 0.73 (197.71)^{0.659} (9.046)^{0.339} \left[\frac{0.216}{1.441}\right]$$

$$= 0.73 \times 32.59 \times 2.11 \times 15$$

$$7.53 \text{ kw/m}^\circ\text{c}$$

ACKNOWLEDGEMENT

Firstly, I will like to acknowledge the lord Jesus Christ whose word is "YE" and "AMEN". My sincere gratitude to my parents. Chief and Mrs Omitayo and to my brothers and sisters, Bosun, Sesan, kumbi, kemi and Niran.

Thank you to all the lecture in the chemical engineering department and BIG UPS to my friends and class mates.

I love you all.

TABLE OF CONTENTS.

	PAGE.
Title page-----	i
Certification-----	ii
Dedication-----	iii
Acknowledgement-----	iv
Abstract-----	v
Table of contents-----	vi - viii

CHAPTER ONE

1.0	Introduction -----	1
1.1	Problem statement-----	2
1.2	Scope of work-----	2
1.2.1	Process design-----	2
1.2.2	Chemical engineering design-----	2
1.2.3	Economic evaluation and safety considerations-----	2
1.2.4	Instrumentation and control-----	2

CHAPTER TWO

2.0	Literature review-----	3
2.1	Castor beans-----	3

And owing to this peculiar economic importance attached to castor seed and its oil, below shows the round figure of castor seed production between the year 1994 -1996.

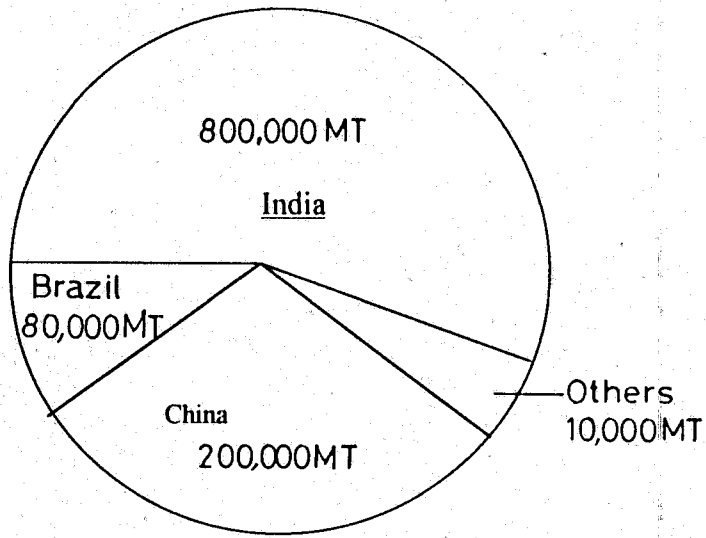


FIGURE: Shows worldwide castor seed production.

From above, it shows that India is the major producer of castor seed of about 800,000 metric tonnes (MT), China 200,000 MT, Brazil (80,000 MT) and others of about 10,000 MT including Nigeria.

Furthermore the below chart show the increasing importance attached to castor seed and its oil in the last decades.

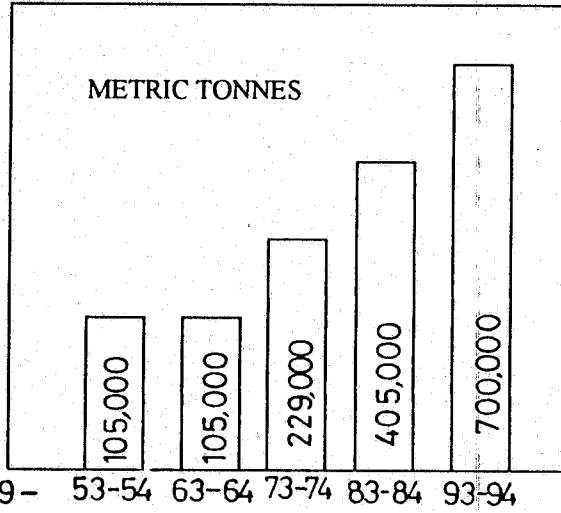


FIGURE 2: CASTOR SEED PRODUCTION

$$\begin{aligned}
 h_i (70^\circ\text{c}) &= 0.73(225.96)^{0.659} (7.914)^{0.339} \left[\frac{0.216}{1.441} \right] \\
 &= 0.73 \times 35.59 \times 2.02 \times 15 \\
 &= 7.87 \text{ kw/m}^2\text{c}
 \end{aligned}$$

4.7 THE INTERNAL WALL

4.7.1 THE TEMPERATURE OF THE INTERNAL WALL

Using,

$$T_{\text{true}} = T_s - \left[\frac{(T_s - T_a)}{1 + h_s/n_i} \right]$$

Where,

- T_w = Temperature of the wall
- T_s = Temperature of the steam = 100°c
- T_b = Bulk temperature (i.e Temperature of mixture)
- h_s = Heat transfer coefficient of steam = $5.673 \text{ W/m}^2\text{c}$
- h_i = Approximate heat transfer coefficient in the vessel

(1) For $T_o = 30^\circ\text{c}$, Them

$$T_{\text{true}} = 100 - \left[\frac{100 - 30}{1 + \frac{5.673}{7.09}} \right] = 100 - \left[\frac{70}{1 + 0.80} \right]$$

$$= 100 - 38.89 = 61.11$$

$$\underline{T_w = 61.11^\circ\text{c}}$$

(2) For $T_b = 50^\circ\text{c}$

$$T_{\text{true}} = 100 - \left[\frac{100 - 50}{1 + \frac{5.673}{7.53}} \right] = 100 - \left[\frac{50}{1 + 0.753} \right]$$

$$= 100 - 28.52 = 71.48$$

$$T_w = 71.48^\circ\text{C}$$

$$(3) \text{ For } T_b = 70^\circ\text{C}$$

$$\text{True} = 100 - \left[\frac{(100 - 70)}{1 + \frac{5.673}{7.87}} \right] = 100 - \left[\frac{80}{1 + 0.721} \right]$$

$$= 100 - 17.43 = 82.57$$

$$T_w = 82.57^\circ\text{C}$$

4.7.2 VISCOSITY AT TEMPERATURE OF THE INTERNAL WALL

From the chemical Engineer's Hand Book, the following was obtained ie.

Temperature ($^\circ\text{C}$)	Viscosity (μ) k_p
30.0	0.30
64.54	0.23
50.0	0.25
73.91	0.21
70.0	0.22
84.03	0.19

However using

$$\text{Viscosity} = \frac{\mu_b}{\mu_w}$$

$$\text{For } T_w = 61.11^\circ\text{C}, T_b = 30^\circ\text{C}, \mu_b = 0.30$$

μ_w is obtained by interpolation

$$30.0 \quad \equiv \quad 0.30$$

$$61.11 \quad \equiv \quad x$$

$$64.54 \quad \equiv \quad 0.23$$

$$\frac{30.00 - 61.11}{30.00 - 64.54} \quad \equiv \quad \frac{0.30 - x}{0.30 - 0.23}$$

$$\frac{31.11}{34.59} = \frac{0.30 - X}{0.07}$$

$$2.1777 = \frac{10.362 - 39.54 X}{10.362 - 2.178 = 34.540 X}$$

$$8.184 = 34.54 X$$

$$\mu_w = \frac{8.184}{34.54} = 0.237$$

$$\therefore \mu_{\text{viscosity}} = \frac{0.30}{0.237} = 1.266$$

For $T_w = 71.48^\circ\text{C}$, $T_b = 50^\circ\text{C}$, $\mu_b = 0.25$

Following suite (ie by interpolation)

$$50.00 = 0.25$$

$$71.48 = Y$$

$$73.91 = 0.21$$

$$\frac{50 - 71.48}{50 - 73.91} = \frac{0.25 - Y}{0.25 - 0.21}$$

$$\frac{-21.48}{-23.91} = \frac{0.25 - Y}{0.25 - 0.21}$$

$$0.8592 = 5.9775 - 23.91Y$$

$$5.1183 = 23.91Y$$

$$\mu_{\text{viscosity}} = \frac{0.25}{0.214} = 1.168$$

$$\text{For } T_w = 82.57^\circ\text{C}, T_b = 70^\circ\text{C}, \mu_b = 0.22$$

$$70.00 = 0.22$$

$$82.57 = Z$$

$$84.03 = 0.19$$

$$\frac{70.00 - 82.57}{70.00 - 84.03} = \frac{0.22 - Z}{0.22 - 0.19}$$

$$\frac{-12.57}{-14.03} = \frac{0.22 - Z}{0.03}$$

$$0.3771 = 3.087 - 14.03Z$$

$$2.7095 = 14.03Z$$

$$\mu_{\text{viscosity}} = \frac{0.22}{0.193} = 1.14$$

4.8 TO CALCULATE THE ACTUAL HEAT TRANSFER COEFFICIENT (ACTUAL h_i)

$$h_i = 0.74 \text{Re}^{0.67} \text{Pr}^{0.33} \mu_{\text{vis}}^{-0.24} \frac{K_{\text{mix}}}{D_t}$$

Where,

h_i = Actual Coefficient heat transfer

Re = Reynolds number at 30°C , 50°C & 70°C

μ_{vis} = Viscosity at temperature of the internal wall

K_{mix} = Thermal conductivity of the mixture

D_t = Diameter of the extractor

$$h_i (30^\circ\text{C}) = 0.74 (163.62)^{0.67} (10.931)^{0.33} (1.266)^{-0.24} \times \frac{0.216}{1.441}$$

$$= 0.74 \times 30.428 \times 2.202 \times 0.945 \times 0.150$$

$$= 7.028 \text{ kw/m}^0\text{c}$$

$$h_i (50^\circ\text{c}) = 0.74 (197.71)^{0.67} (9.046)^{0.33} (0.963)^{-0.24} \times 0.150$$

$$= 0.74 \times 34.541 \times 2.068 \times 0.945 \times 0.150$$

$$= 7.635 \text{ kw/m}^0\text{c}$$

$$h_i (70^\circ\text{c}) = 0.74 (225.96)^{0.67} (7.914)^{0.33} (1.140)^{-0.24} \times 0.150$$

$$= 0.74 \times 37.77 \times 1.979 \times 0.969 \times 0.150$$

$$= 8.040 \text{ kw/m}^0\text{c}$$

Plant Design and
Economies by
Chohey

4.8 THE OVERALL HEAT TRANSFER COEFFICIENT

From,

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{x}{k} + \frac{1}{h_s}$$

Where,

U = Overall heat transfer coefficient

H_i = Actual heat transfer coefficient

X = Thickness of Vessel (Assumptive) = 5mm

K = Thermal conductivity of the mixture (kmix)

H_s = Heat transfer of steam

Therefore,

At 30°c

$$\frac{1}{u} = \frac{1}{7.028} + \frac{5 \times 10^{-3}}{0.216} + \frac{1}{5.673}$$

$$\frac{1}{u} = 0.142 + 0.023 + 0.176$$

$$= 0.341$$

$$\therefore U = (\text{at } 30^{\circ}\text{c}) = 2.93 \text{ kw/m}^{\circ}\text{c}$$

At 50°c

$$\frac{1}{u} = \frac{1}{7.653} + \frac{5 \times 10^{-3}}{0.216} + \frac{1}{5.673}$$

$$\frac{1}{u} = 0.131 + 0.023 + 0.176$$

$$\frac{1}{U} = 0.33$$

$$\therefore U = (\text{at } 50^{\circ}\text{c}) = 3.03 \text{ kw/m}^{\circ}\text{c}$$

At 70°c

$$\frac{1}{u} = \frac{1}{8.040} + \frac{5 \times 10^{-3}}{0.216} + \frac{1}{5.673}$$

$$\frac{1}{u} = 0.124 + 0.023 + 0.176$$

$$\frac{1}{U} = 0.323$$

$$\therefore U = (\text{at } 70^{\circ}\text{c}) = 3.10 \text{ kw/m}^{\circ}\text{c}$$

4.10 TIME TAKEN TO HEAT THE BULK MASS

This is the time required to heat the feed and the solvent in the extractor from a temperature of 30°c to 70°c for extractor to proceed.

The heat is supplied by the steam at 100°c

Using,

$$T \text{ (hrs)} = \frac{WC^p}{U_i A_i} \log e \left[\frac{T_s - T_{bi}}{T_s - T_{br}} \right]$$

W = Total weight of the material
(Weight at feed + Weight of solvent)

$$419.87 \text{ kg} + 1259.61 \text{ kg} = 1679.48 \text{ kg}$$

$$\begin{aligned} C_p &= C_{p \text{ mix}} = \text{Specific heat capacity of the mixture} \\ &= 0.814 \text{ kJ/kgK} \end{aligned}$$

$$A_i = \text{Area of the extractor} = 1.822 \text{ m}^2$$

$$U_i = \text{Overall heat transfer coefficient}$$

$$T_{bf} \text{ and } T_{bi} = \text{Bulk temperature (}^\circ\text{C) at beginning}$$

And end of the time (hrs)

However, the graph of U versus bulk temperature (Appendix shows the following by locating U at temperatures of 30°C, 50°C and 70°C

$$\text{From (30}^\circ\text{C - 38}^\circ\text{C) } U \text{ at mid point} = 0.7989 \text{ kW/m}^2\text{C}$$

$$\text{From (38 - 46}^\circ\text{C) } U \text{ at mid point} = 0.8019 \text{ kW/m}^2\text{C}$$

$$\text{From (46}^\circ\text{C - 54}^\circ\text{C) } U \text{ at mid point} = 0.8055 \text{ kW/m}^2\text{C}$$

$$\text{From (54}^\circ\text{C - 62}^\circ\text{C) } U \text{ at mid point} = 0.8100 \text{ kW/m}^2\text{C}$$

$$\text{From (62}^\circ\text{C - 70}^\circ\text{C) } U \text{ at mid point} = 0.8163 \text{ kW/m}^2\text{C}$$

However, substituting the above into the formular

$$\text{For T (30 - 38}^\circ\text{C) } = \frac{1679.48 \times 0.814}{0.7989 \times 1.822} \log e \left[\frac{100 - 30}{100 - 38} \right]$$

$$= \frac{1367.10}{1.46} \log \left[\frac{70}{62} \right]$$

$$= 936.37 \log e (1.13)$$

$$= 936.37 \times 0.053$$

$$= 49.70 \text{ Secs}$$

$$= 0.014 \text{ hrs}$$

REFERENCES

CALCULATIONS

RESULTS

$$\text{For } T (38 - 46^\circ\text{c}) = \frac{1679.48 \times 0.814}{0.8019 \times 1.822} \log e \left[\frac{100 - 38}{100 - 46} \right]$$

$$= \frac{1367.10}{1.46} \log e \left[\frac{62}{54} \right]$$

$$= 936.37 \log e (1.148)$$

$$= 936.37 \times 0.060$$

$$= 56.18 \text{ Secs}$$

$$= \mathbf{0.016 \text{ hrs}}$$

$$\text{For } T (46 - 54^\circ\text{c}) = \frac{1679.48 \times 0.814}{0.8055 \times 1.822} \log e \left[\frac{100 - 46}{100 - 54} \right]$$

$$= \frac{1367.10}{1.46} \log e \left[\frac{54}{46} \right]$$

$$= 930.00 \log e (1.174)$$

$$= 930.00 \times 0.07$$

$$= 64.76 \text{ Secs}$$

$$= \mathbf{0.018 \text{ hrs}}$$

$$\text{For } T (54 - 62^\circ\text{c}) = \frac{1679.48 \times 0.814}{0.8100 \times 1.822} \log e \left[\frac{100 - 54}{100 - 62} \right]$$

$$= \frac{1367.10}{1.46} \log e \left[\frac{46}{38} \right]$$

$$\Rightarrow 926.33 \log e (1.210)$$

$$\Rightarrow 926.33 \times 0.083$$

$$= 76.86 \text{ Secs}$$

$$= 0.021 \text{ hrs}$$

$$\text{For } T (62 - 70^\circ\text{c}) = \frac{1679.48 \times 0.814}{0.8163 \times 1.822} \left[\frac{\log e \frac{100 - 62}{100 - 70}}{\log e \frac{100 - 62}{100 - 70}} \right]$$

$$= \frac{1367.10}{1.49} \log \left[\frac{38}{30} \right]$$

$$\Rightarrow 919.18 \log e (1.27)$$

$$\Rightarrow 919.18 \times 0.103$$

$$= 94.37 \text{ Secs}$$

$$= 0.026 \text{ hrs}$$

Hence, the total time required to heat from 30°c to 70°c becomes.

$$(0.14 + 0.016 + 0.018 + 0.012 + 0.026) \text{ hrs}$$

$$0.095 \text{ hrs}$$

Total time
from 30°c to 70°c =
0.095 hrs

4.1.1 AMOUNT OF STEAM REQUIRED TO HEAT THE BULK

Using,

$$M_s = \frac{U A D T}{Y_s}$$

Where,

$$U = \text{Overall heat transfer at } 70^\circ\text{c} = 2.87 \text{ kw/m}^2\text{c}$$

$$A = \text{Area of the extractor} = 1.822 \text{ m}^2$$

$$D T = \text{Difference in steam } (T_s) \text{ and bulk } (T_b) \text{ Temperature } (D T = T_s - T_b)$$

$$= (100 - 70)^\circ\text{c} = 30^\circ\text{c}$$

$$Y_s = 2412.03 \text{ kJ/kg}$$

$$M_s = \frac{2.87 \times 1.82 \times 30}{2412.03} = \frac{156.70}{2412.03}$$

$$= 0.065 \text{ kg/s}$$

Recall the time required to heat from 30°C - 70°C in seconds ie.

$$(0.95 \times 3600) \text{ secs}$$

$$= 342.00 \text{ secs.}$$

$$M_s = (0.065 \times 342.00) \text{ kg} \times \text{s}$$

$$= 22.23 \text{ kg}$$

Amount of steam required is = 22.23kg

4.12 HEAT SUPPLIED BY STEAM

Using,

$$Q_s = U A D T$$

Where Q_s = Heat supplied by steam

U = Overall heat transfer coefficient at 70°C

DT = Difference in temperature (30°C)

A = Area of the extractor

$$Q_s = 2.87 \times 1.822 \times 30$$

$$= 156.70 \text{ joules}$$

Heat supplied by steam = 156.70j

4.13 THE BUCKLING PRESSURE

For short closed vessels, long vessels, with soften ranges , the

critical buckling pressure is given by:

$$P_c = K_c E \left(\frac{t}{D_o} \right)$$

Where P_c = Buckling pressure

K_c = Function of the diameter and thickness of

the vessel

$$E = \text{Young Modulus for steel} = 2.4 \times 10^{11}$$

$$t = \text{Thickness of the wall}$$

$$D_o = \text{External diameter}$$

$$\begin{aligned} \text{Recall that, } D_o &= (2 \times t) + D_i \\ &= (2 \times 8 \times 10^{-3}) + 1.441 \\ &= 0.016 + 1.441 \\ &= 1.457\text{m} \end{aligned}$$

$$K_c \quad (\text{From the graph i.e } D_o/t \text{ / } L/D_o)$$

$$\text{Where } L = \text{length of vessel}$$

$$t = \text{thickness of the vessel}$$

$$\text{Hence, } \frac{L}{D_o} = \frac{1.129}{1.457} = 1.187\text{m}$$

$$\text{Likewise } \frac{D_o}{t} = \frac{1.457}{5 \times 10^{-3}} = 291.40$$

However, from the graph of collapse coefficient of cylindrical shell (Brown well and Young 1959) in Chemical Engineering Design (Volume 6)

$$K_c \quad \text{at} \quad \frac{D_o}{t} = 291.40 \quad \text{and} \quad \frac{L}{D_o} = 1.187$$

$$K_c = 38.42$$

Buckling Pressure;

$$P_c = 38.42 \times 2.4 \times 10^{11} \left[\frac{5 \times 10^{-3}}{1.457} \right]$$

$$\begin{aligned} P_c &= 38.42 \times 2.4 \times 10^{11} \times 5.43 \times 10^{-3} \\ &= 3.164 \times 10^{10} \text{ N/m}^2 \end{aligned}$$

4.14 COST ANALYSIS

Chemical plants are built to make a profit, and an estimate of the investment required and the cost of production are needed before the profitability of a project can be assessed. However, costing analysis is based upon cost index and scale up factor.

Chemical
Engineering
Design vol.6
by
Richardson &
Coulson.

Using the costing formula for equipment for 1992. i.e.

$$C_e = CS^n$$

Where,

$$C_e = \text{Purchased equipment cost (Pound Sterling)}$$

$$C = \text{Cost constant (obtained from table)}$$

$$S = \text{Characteristic size parameter, (in units, obtained from table)}$$

$$n = \text{Index for that type of equipment}$$

4.14.1 COST OF EXTRACTOR

For carbon steel,

$$C = \text{£}8,000$$

$$S = 3.15 \text{ m}^3$$

$$n = 0.40$$

$$C_e = 8,000 (3.15)^{0.40}$$

$$= 8,000 \times 1.58$$

$$= \text{£}12,659.43$$

4.14.2 COST OF AGITATOR

$$C = \text{£}3,200$$

$$S = 0.7094 \text{ kw}$$

$$n = 0.5$$

$$C_e = 3,200 (0.7094)^{0.5}$$

$$= 3,200 \times 0.8423$$

$$= \mathbf{£2,695.23}$$

4.14.3 COST OF SOLVENT

Weight of solvent = 1259.61 kg

From table, Petroleum Ether is £0.25 / kg of solvent.

$$\Rightarrow 0.25 \times 159.61 \text{ kg}$$

$$= \mathbf{£314.90}$$

4.14.4 COST OF STEAM

Cost of steam = £6.0 / ton

Weight of steam = 0.065 kg/s

$$\text{Quantity of steam used} = 0.065 \text{ kg/s} \times 4.5 \times 3600 \text{ secs}$$

$$\Rightarrow 1053 \text{ kg}$$

But 1 ton = 1000 kg

Quantity of steam used = 1.053 tons

Cost of steam = 6 x 1.053

$$= \mathbf{£6.32}$$

4.14.5 COST OF PIPES

For carbon steel, using 15 - 350 mm $\times (0.055)^{0.55}$

$$\text{Diameter cost} = £27 (0.055)^{0.55} / \text{m}$$

Cost for solvent pipe = £27 $(0.055)^{0.55} \times 96.25 \text{ mm}$

$$= 5.48 \times 96.25$$

$$= \mathbf{£527.19}$$

$$\begin{aligned} \text{Cost of feed pipe} &= \text{£}27 (0.055)^{0.55} \times 39.56\text{mm} \\ &= 5.48 \times 39.56 \\ &= \text{£}216.68 \end{aligned}$$

$$\begin{aligned} \text{Cost of discharge pipe} &= \text{£}27 (0.055)^{0.55} \times 100.66\text{mm} \\ &= 5.48 \times 100.66 \\ &= \text{£}551.34 \end{aligned}$$

TABLE 2: TOTAL COST => £1 = N=150

	COST IN POUNDS (£)	COST IN NAIRA (=N=)
Extractor	12,659.43	1,898,914.5
Agitator	2,695.23	404,284.50
Solvent	314.90	47,235.00
Steam	6.32	948.00
Pipes		
(a) Solvent	527.19	79,078.50
(b) Feed	216.68	32,502.00
(c) Discharge	551.34	82,701.00
TOTAL COST	16,971.09	2,545,699.50

4.15 SAFETY OF THE EQUIPMENT DESIGN

In design, safety factors were put into consideration to avoid unpleasant process conditions.

However, in the course of this design, a safety factor of 22% was considered during sizing of the reactor. This will account for any sudden increase in the volume of the mixture

In piping, welded pipes should be used instead of flanged and screwed connections.

Variable – speed electric motors should be installed for agitators and pumps.

An automatic high-level shuts offs on storage and process tanks should be installed.

Install advanced process control schemes for key process parameters such as temperature and flow.

Install alarms and other instrumentation to avoid overflow of the mixture (solvent or feed)

The pressure exceeding (over pressure) the system is one of the most serious hazard which might lead to failure of vessel which inturn can result into a disaster. In other to avoid extractor failure, the buckling pressure for the vessel was determined in other not to exceed it.

A distilling plant for recycling and reuse of solvent was installed.

Steam was used as a source of heat because it is practically safe as the temperature can not exceed the saturation temperature at the supply pressure.

Pipes were also used in the delivery of solvent round the whole plant in other to control entry and exit of solvent from obvious source fitted to vent lines of the solvent to prevent propagation of flame through vent since the solvent is flammable.

The solvent used should be stored in low pressure vessels instead of atmospheric storage tanks as it is flammable and when exposed to open flame might lead to fire out break.

Loading of the solvent (petroleum ether) containing vessel should be via dip pipes instead of splash loading.

The raw materials purchased should contain low impurity level and should also be purchased in clean and renewable containers.

Taking into consideration the safety of workers, in other to prevent accidents, the following safety measures were considered.

- (1) Plant operating personnel should be properly trained on how to operate the plant and also provided with protective wares such as nose cover, booths, gloves, overall etc.
- (2) Plant operators should also be trained on possible solution or action whenever there is an unpleasant occurrence in the factory. Such as first aid to victims and fire out breaks.

Filters should also be changed based upon pressure drop measurement rather than operator preferences.

The reflux ratio for the distillation column should be optimized to improve separation.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

After due consideration of conditions and assumptions it is concluded that the reactor designed can produce 100,000 m³ of castor oil per year under the conditions of 250 working days per year, 10 working hours per day of 2 batches per day from 419.87 kg/ batch of feed and 1259.61 kg of solvent.

5.2 RECOMMENDATION

It is however recommended that;

- (1) The conversion of the batch process to continuous process should be investigated.
- (2) Greater production of oil should be enhanced i.e above 100,000 m³ /yr.
- (3) Such design condition should be experimented on another seed containing oil