

DESIGN OF A BATCH AGITATED VESSEL TO PRODUCE 6000 TONS PER
ANNUM OF FORMULATED BIO-INSECTICIDE FROM NEEM KERNELS

BY

UWAGWU NICHOLAS IWELUEGIM

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CERTIFICATION

This is to certify that this work , "Design of a Batch Agitated Vessel to Produce 6000 tons per Annum of Formulated Bio-insecticide From Neem Kernels", was done by Uwagwu Nicholas Iweluegim and submitted to the Chemical Engineering Department of the Federal University of Technology, Minna, in partial fulfillment of the requirements for the award of Bachelor of Engineering (B. Eng.) degree in Chemical Engineering.

Dr. J.O. Odigure

Head of Dept.

Signature and Date

External Examiner

Signature and Date

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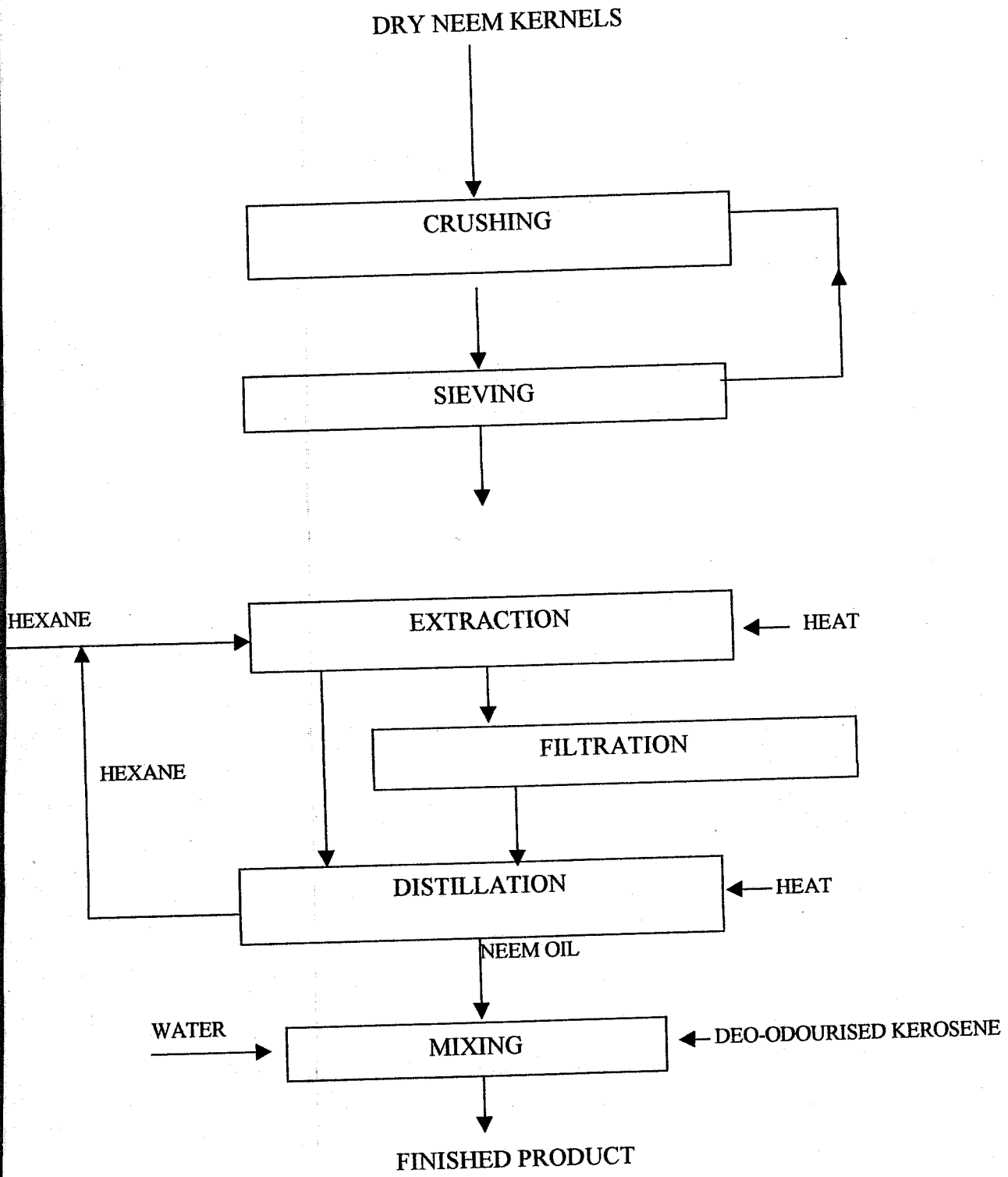
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BLOCK DIAGRAM SHOWING PRODUCTION SEQUENCE OF BIO-INSECTICIDES FROM NEEM KERNELS



THE TEMPERATURE: The solubility of the material, which is being extracted increases with temperature to give a higher rate of extraction. Further, the diffusion co-efficient will be expected to increase with rise in temperature, and this will also improve the rate.

THE AGITATION OF THE FLUID: The agitation of the solvent increases the eddy diffusion and therefore increases the transfer of material from the surface of the particles to the bulk of the solution. Further agitation prevents sedimentation.

DEDICATION

To Mum and Dad.

They know why.

ACKNOWLEDGEMENT

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For sacrifices made that I may be what I am today, I say a loud thank you to my parents, Mr. And Mrs. Richard O.M. Uwagwu.

ABSTRACT

A design of a batch agitated vessel to produce 6000 tons per annum of formulated bio-insecticides from neem kernels has been carried out. A detailed design of the vessel came out with specifications, costing, and a proposed control system. Calculations from material and energy balances, based on a proposed process flow diagram, indicated that the 4.572m² vessel will need 2598.75Kg (per batch) of crushed neem kernels against 4287.9375Kg (per batch) of extracting solvent (n-hexane), 43.55Kg (per batch) of steam, and a power requirement of 4.4109Kw to function optimally.

CHAPTER ONE

1.0 INTRODUCTION

The need to look for alternative methods of pest control on the face of serious environmental problems created by the use of synthetic pesticides and the realization of their gradually depleting and non-renewable sources have prompted the screening of indigenous African plant extracts for pest control. Only very few of these plants, however, have been studied and consequently developed into useful bio-insecticides. Pyrethrum flowers (from Kenya), tobacco (nicotine), ryanodine, rotenone, and sabadilla, are among the few extracts whose potentials have been utilized in insect- pest control. Extracts from parts of the neem, *azadirachta indica* – a fuel plantation tree commonly found in Nigeria – is another potential bio-insecticide whose potentials have both been tapped commercially. This work, therefore, is an attempt to design a batch plant to develop this product on a larger scale, satisfactory preliminary laboratory work having been carried out earlier.

1.1 PROBLEM STATEMENT

It is required to design a plant capable of producing 6000 tons per annum of bio-insecticides from neem kernels in one year.

1.2 SCOPE OF WORK

The scope of this work is limited to the following areas:

- (1) A comprehensive flow diagram;
- (2) Material and energy (heat) balances across the entire plant and across each unit;
- (3) A detailed design of the extracting unit of the plant;
- (4) A concise cost analysis of the designed unit;
- (5) Safety evaluations of the entire plant and a control of the designed unit;
- (6) A model proposal of the plant/site layout.

1.3 TECHNOLOGY OF PRODUCTION

The process of production/formulation of bio-insecticides from neem kernels makes use of decorticated neem seeds and n – hexane as the basic raw materials. The seeds come in dry into the crusher, where their sizes are reduced and then

passed through a series (450um and 550 um) of sieves. Particle fractions that do not fall within this size range are either recycled or turned out as part of the waste. Extraction of neem oil out of the crushed seeds is done in an agitated vessel with n - hexane and with steam as the heating medium. Under the effect of gravity, the extract phase (oil-solvent solution) leaves to the flash distillation column for separation, while the raffinate phase is removed from the upper part of the extractor and passed through a filter press to remove any trapped oil or solvent.

In the distillation column, two notable operations are achieved: Solvent recovery and extract concentration. The removed solvent (about 90% of what went in) is then recycled back to the hexane tank, for re-use. The formulation of the final product takes place in the batch mixer. Here, the concentrated neem oil from the distillation column is blended with water (40C w/w) and deodorized kerosene (30% w/w)

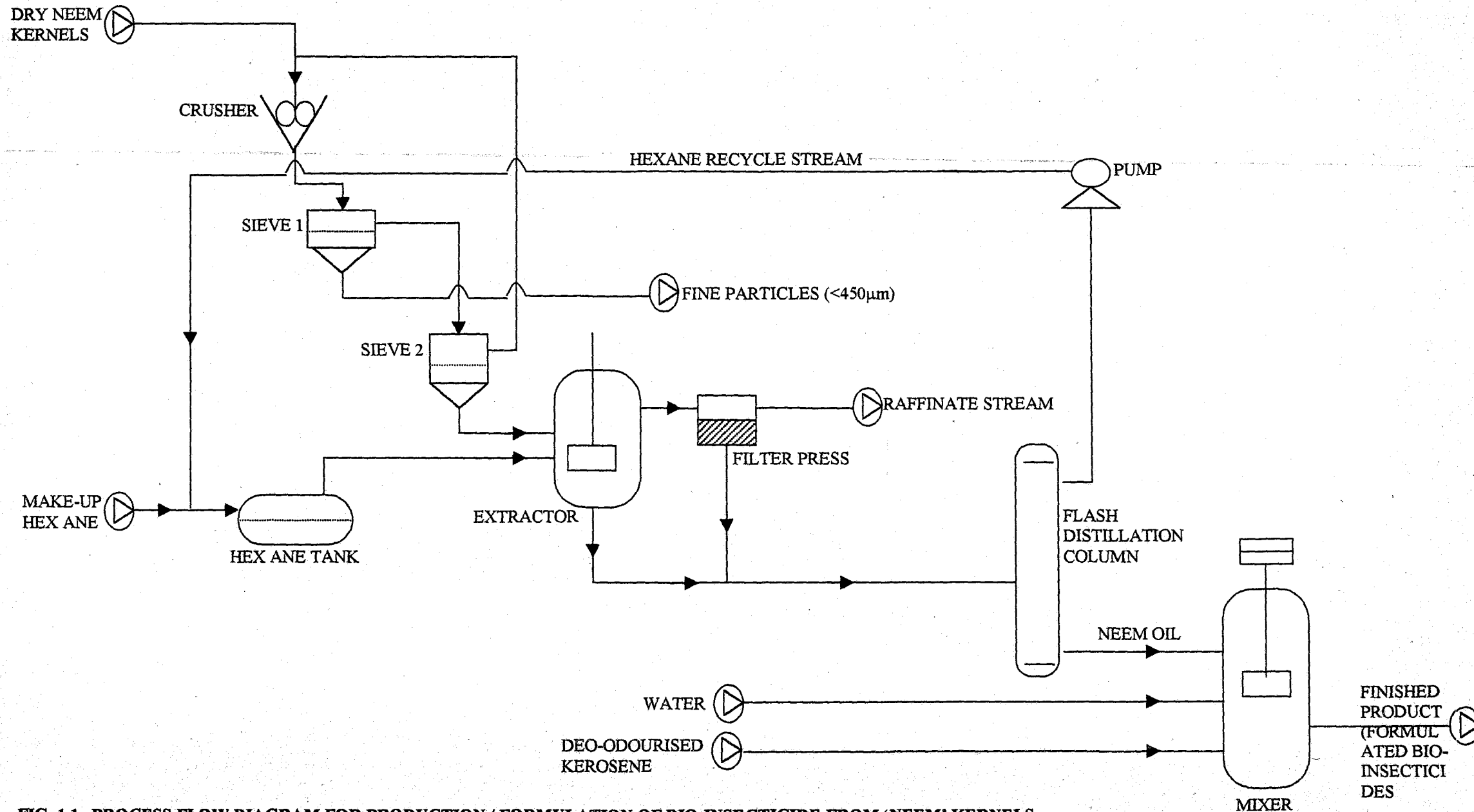


FIG. 1.1. PROCESS FLOW DIAGRAM FOR PRODUCTION / FORMULATION OF BIO-INSECTICIDE FROM 'NEEM' KERNELS

CHAPTER TWO

2.0

LITERATURE REVIEW

2.1 PROPELLER AND TURBINE AGITATORS

Propeller and turbine agitators are similar to mechanical mixers and blenders found in laboratories and kitchens. These devices are, by far, the predominant type of agitator employed in chemical process plants. They consist basically of a motorized rotating impeller immersed in a liquid pool or paste medium. The variety of impeller vessel configuration is large and propeller and turbine agitators are significant [McCabe and Smith (1976)].

Propellers are employed extensively in small-scale, flexible applications. Characterized by high rotational speeds, propellers, when used in liquid-only mediums, seldom exceed 1.5 meters in diameter. For large storage tanks, one or more propeller units are inserted through the side. They range in power from those laboratory sizes to 50KW.

Most common turbine impellers fall in either the radial flow or axial flow category. Because of uniformity and control of circulation, axial flow turbines have been found to be superb for suspension of solids, dispersion of immiscible liquids, heat transfer enhancement, and promotion of chemical reactions. Radial impellers, on the other hand, are superior for gas dispersion.

Practical turbine impellers are limited to about 5 meters in diameter. Where larger capacities are required, multiple vessels, or multiple agitators are recommended [Ulrich, (1984)]. Although an infinite confirmation of scale parameters is possible, most turbine-agitated vessels are designed with a ratio of tank diameter to impeller diameter ranging from about 2 to 5, with or without baffles. The impeller is normally located above one-third to one-fourth of a tank diameter above the bottom. As a rule, in both propeller and turbine-agitated vessels, the liquid height ranges from 0.75 to 1.5 times vessel diameter. If it must be substantially greater, two or more impellers are mounted on the same shaft.

POWER CONSUMPTION

Like most process equipment, final selection of an agitator should not be made without consulting a specialist. However, most commercial applications fit within

a rather narrow band of specifications. Power consumption, for example, falls within the range of 0.03 to 0.2KW/m³ for mild, 0.2 to 0.5KW/m³ for vigorous, and 0.5 to 2KW/m³ for intense agitation [Ulrich (1984)]. This is overall power consumption, assuming 90% efficiency within the driver speed reducing system. Power consumption is related to agitation intensely in a stirred vessel much as it is related to flow rate in a pipe.

Miscible Liquids and Solutions

For this operation, moderate agitation is recommended, with either a propeller or a turbine impeller requiring a specific power consumption of 0.2 to 0.5KW/m³. The mixing time for a batch vessel [McCabe and Smith (1976)] can be calculated by:

$$\theta = 12000 (\mu v/p)^{1/2} (V/1.0m^3)^{1/5}$$

where μ is viscosity (Pa-s), P is in watts, and V is in cubic meters.

Dispersion of Immiscible Liquids

For extraction, where liquids will be separated again by sedimentation, droplets should be between 0.1 and 1mm in diameter. Such can be dispersed in volume fractions up to 0.6 or 0.7, with turbine axial impellers.

Solid Agitators

For agitating (or milking) pastes, dough, and dough polymers that have viscosities greater than 200 Pa-s, simple agitation is often not enough. Simultaneous squeezing, dividing, and folding is necessary with increasing power consumption as the paste becomes more viscous. McCabe and Smith categorized the action in the order of least to greatest difficulty as kneading, dispersion, and mastication. 100 – 500Pa-s, 500 – 4000 Pa-s, and 4000 – 10000 Pa-s are respectively the approximate viscosity ranges for these subdivisions.

2.2 MATERIALS OF CONSTRUCTION

Properties of Materials

STRENGTH: For conventional steel construction, temperatures above 600C are impractical because they result in poor strength and poor oxidation resistance. Temperatures up to 800C are possible with high alloy stainless steels, but strength at this temperature is ten times less than that at room temperature. The maximum pressure of a vessel is directly proportional to metal thickness. For a cylindrical shell subject to internal pressure, the force balance, appropriately corrected by safety factors and joint efficiencies is:

$$t = PR / (0.9s - 0.6P)$$

$$P = 0.9st / (R + 0.6t)$$

For a spherical shell, the equations are:

$$t = PR / (1.8s - 0.2P)$$

$$P = 1.8st / (R + 0.2t)$$

Where t is shell thickness, P is the pressure, R is the inside vessel radius, and s is the allowable tensile stress.

An additional allowance, typically 3mm, is added to the thickness to compensate for corrosion of the vessel walls. At temperatures above 800C, refractory metals like graphite, or ceramics are necessary. Most refractory metals and graphite burn readily in air, and, if used, must be protected from the atmosphere or any other oxygen-containing gases. Numerous inexpensive ceramics are strong for up to 1800C, but they are fragile and brittle.

Based on strength, cost, and temperature resistance, carbon steel is outstanding. This is the reason for its overwhelming popularity in the chemical process industries.

2.3 FACTORS INFLUENCING THE RATE OF EXTRACTION

PARTICLE SIZE: The particle size influences the extraction rate in the following ways:

The smaller the size, the greater the interfacial area between the solid and liquid, and therefore the higher the rate of transfer of the material. Further, the smaller the distance the solute must diffuse within the solid. On the other hand, the surface may not be so effectively used with a very fine material if circulation of the liquid is impeded, and separation of the particles from the liquid and drainage of the solid residue are made more difficult.

THE SOLVENT: The liquid chosen should be a good selective solvent, and its viscosity should be sufficiently low for it to circulate freely. Generally, a relatively pure solvent will be used initially, but as the extraction proceeds, the concentration of solute will increase, and the rate of the extraction will progressively decrease, first because the concentration gradient will be reduced, and secondly, because the solution will generally become more viscous.

CHAPTER THREE

3.0 MATERIAL AND ENERGY (HEAT) BALANCES

3.1 DESIGN BASIS

A design basis of 6000 tonnes of finished products per annum has been chosen. But this is too bogus a figure. To get a workable figure, there therefore arises a need to convert from tonnes per annum to kg per batch.

Conversion:

$$6000 \frac{\text{tonnes}}{\text{year}} = 6000 \frac{\text{tonnes}}{\text{year}} \times \frac{1000\text{kg}}{1 \text{ ton}} \times \frac{1\text{year}}{300\text{days}} \times \frac{1\text{day}}{24\text{hours}} \times \frac{5\text{hours}}{1\text{batch}}$$

$$\text{Basis: } 6000 \text{ tonnes/annum} = 4166.67 \text{ kg/batch}$$

It is, however, assumed that 300 days are available for work per annum and that it takes 5 hours to turn out a batch of finished products.

Assumptions

The following assumptions are made from the precept that, at the laboratory pilot level, 10g of seeds yielded 4.81g of neem oil.

$$\text{Ratio of oil to feed (for a batch)} = 4.81:10 = 1:2.079$$

$$\text{Ratio of feed to solvent} = 1: 1.6$$

The finished product is made up of just 30% neem oil:

$$\therefore 30\% \text{ of basis} = 0.3 \times 4166.67 = 1250.001\text{kg/batch.}$$

$$\text{The amount of feed per batch that goes into the extractor is } 1250.001(2.079) = 2598.75\text{kg/batch.}$$

3.2 MATERIAL AND ENERGY (HEAT) BALANCES

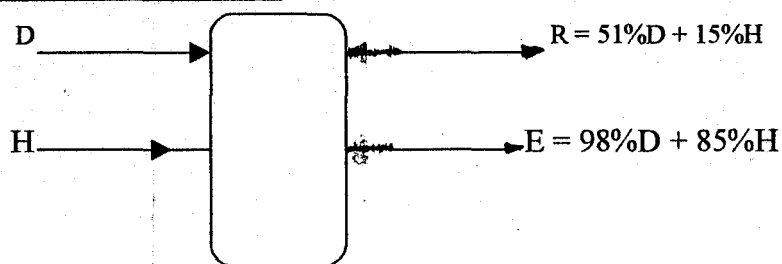
3.3.1. MATERIAL BALANCES

These are going to be based on the conservation law of:

$$\text{Materials in} = \text{Materials out} + \text{Accumulation} + \text{Losses.}$$

It is however assumed that cases of losses and accumulations, for most of the units, are rare and where present, are of negligible effects.

Balance around the extractor



$$\text{Material in} = \text{Material out}$$

$$D + U = R + E \quad \text{----- (3.1)}$$

$$D = \text{crushed decorticated seeds} = 2.079(1250.001) = 2598.75 \text{ kg}$$

$$H = \text{solvent stream} = 1.65 D = 1.65(2598.75) = 4287.9375 \text{ kg}$$

It is assumed that R (the raffinate stream) is made up of 51.9%D and 15%H, while E (the extract phase) is made up of 48.1%D and 85%H, so that

$$R = 0.519D + 0.15H = 0.519(2598.75) + 0.15(4287.94)$$

$$R = 1991.94 \text{ kg}$$

$$E = 0.481D + 0.85H = 0.481(2598.75) + 0.85(4287.94) = 4894.748 \text{ kg}$$

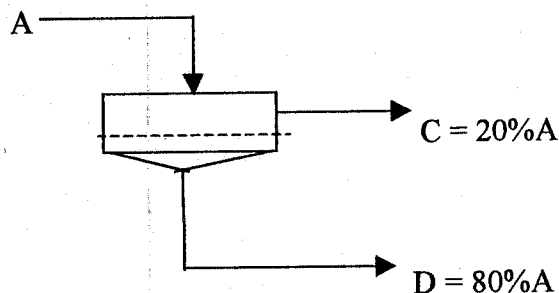
Going back to equation (3.1): $D+H = R + E$,

$$2598.75 + 4287.93 = 1991.94 + 4894.748$$

$$\underline{6886.68 \text{ kg} = 6886.688 \text{ kg}}$$

Balance across the sieves

sieve 1:



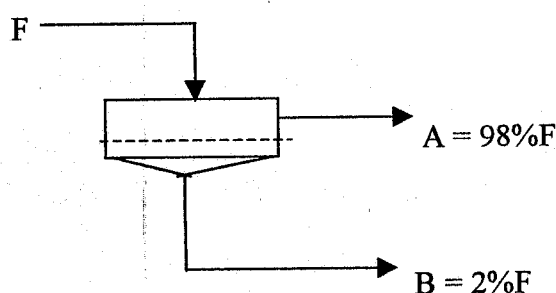
$$A = C + D \quad \text{-----} \quad (3.2)$$

Here, it is assumed that 20% of A comes out as overflow while the remaining 80% comes out as underflow and that there are neither losses nor accumulations of materials on the sieve plate.

$$D = 0.8 A, \text{ so that } A = \frac{D}{0.8} = \frac{2598.75}{0.8} = 3248.4375 \text{ kg}$$

$$C = 0.2A, = 0.2 (3248.4375) = 649.6875 \text{ Kg}$$

Sieve 2:



$$F = A + B \quad \text{-----} \quad 3.3$$

Assumptions: $A = 0.98F$ and $B = 0.02F$

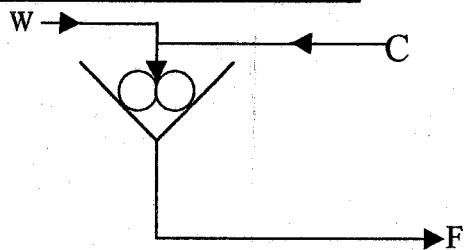
$$\text{Therefore, } F = \frac{A}{0.98} = \frac{3248.4375}{0.98} = 3314.73 \text{ kg}$$

$$\text{and, } B = 0.02(3314.73) = 66.295 \text{ kg}$$

Balance: $3314.73 = 3248.4375 + 66.295$

$3314.73 = 3314.73\text{kg}$

Balance around the crusher



$W + C = F$ ----- 3.4

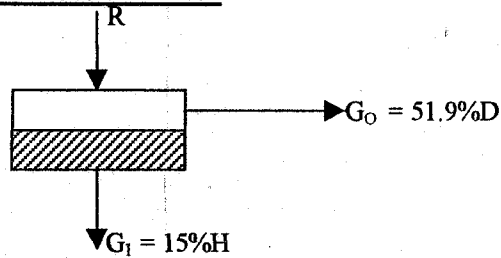
From the equation (3.2), $C = 649.6875\text{ kg}$

From equation (3.3), $F = 3314.73\text{kg}$;

So that $W = F - C = 3314.73 - 649.6875$

$W = 2665.045\text{kg}$

Balance across the filter



$R = G_o + G_1$ ----- (3.5)

$G_o = 51\%D = 0.519 (2598.75)$

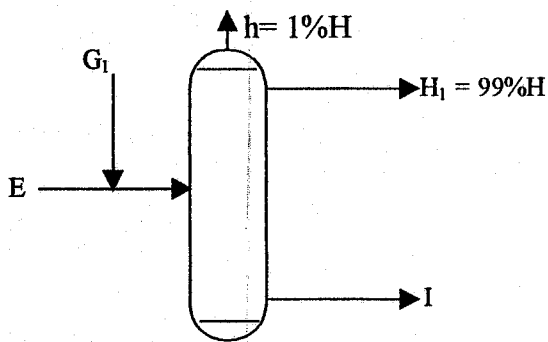
$G_1 = 15\%H = 0.15 (4287.9375) = 643.1906\text{ kg}$

From equation 3.1, it has been calculated that $R = 1991.94\text{kg}$

Balance: $1991.94 = 1348.75 + 643.1906$

$1991.94\text{kg} = 1991.94\text{kg}$

Balance across the flash distillation column



$E + G_1 = H_1 + I + h$ ----- 3.6

Here, it has been assumed that 99% of the solvent that comes with the extract phase is recovered and that part of the remaining 1% goes out with the oil concentrate and the

remaining (of negligible percentage) goes out as losses in the course of the distillation operation.

From equation 3.1, $E = 4894.748 \text{ kg}$

From equation 3.5, $G_1 = 643.1906 \text{ kg}$

But $H_1 = 0.99H = 0.99(4287.7375) = 4245.06 \text{ kg}$

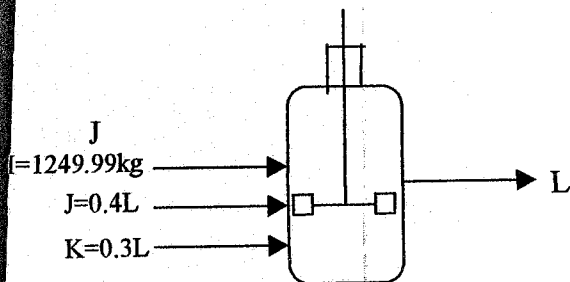
and $h = 0.01(4287.9375) = 42.879 \text{ kg}$

substituting these into equation 3.6 gives:

$$4894.784 + 643.1906 = 4245.06 + 42.8794 + I$$

$$\therefore I = 1249.99 \text{ kg}$$

Balance across the mixer



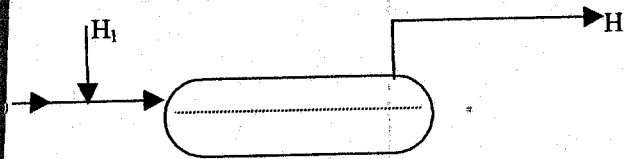
Materials in = Material out

$$I + J + K = L$$

$$1249.99 + 0.4L + 0.3L = L$$

$$L = 4166.63 \text{ kg}$$

Balance around the hexane tank



Material in = material out

$$H_o + H_1 = H \text{ ----- 3.8}$$

$$H_o + 4245.06 = 4287.7375$$

$$\therefore H_o = 42.6775 \text{ kg}$$

3.3 ENERGY (HEAT) BALANCES

The energy (heat) balance for any apparatus can be described by the equation relating inputs and outputs of energy (heat) of the process (apparatus). The energy balance is based on the law of conservation of energy according to which, in a closed system, the

sum of the energies of all types is constant. Typically, the chemico-technological processes are described by the heat balance equation:

$$\Sigma Q \text{ input} = \Sigma Q \text{ output}$$

OR

$$\Sigma Q \text{ input} - \Sigma Q \text{ output} = 0$$

} ----- 3.9

3.4.1 Energy balance around the extractor

Heat supplied by steam = Heat gained by the mixture

$$Q_s = Q_m$$

$$Q_s = UA\Delta T \text{ and,}$$

$$Q_m = mC_p \frac{d\theta}{dt}$$

where U = heat transfer coefficient at $70^\circ\text{C} = 0.1648 \text{ Kw/m}^2\text{ }^\circ\text{C}$

$A = 3.59 \text{ m}^2$ (see chapter four, area of extractor)

ΔT = temperature change = $100 - 70 = 30^\circ\text{C}$

$$Q_s = 0.1648 \times 3.59 \times 30 = \underline{17.75 \text{ kJ}}$$

$$Q_m = Q_s = mC_p \frac{d\theta}{dt}$$

$$\therefore m = \text{mass of mixture} = 2598.75 + 4287.9375 = 6886.69 \text{ kg}$$

C_p = specific heat capacity = $0.96 \text{ kJ/Kg }^\circ\text{C}$

$$d\theta = 70 - 30 = 40^\circ\text{C}$$

$$\therefore 17.75 = 6886.69 \times 0.96 \times \frac{40}{dt}$$

$$dt = 14877.333 \text{ seconds.}$$

$$\therefore Q_m = \frac{6886.69 \times 0.96 \times 30}{14877.333}$$

$$Q_m = 13.31 \text{ KJ}$$

$$\therefore Q_m = Q_s + \text{heat loss}$$

$$\therefore \text{heat loss} = Q_m - Q_s = 17.75 - 13.31$$

$$\underline{\text{heat loss} = 4.47 \text{ KJ}}$$

CHAPTER FOUR

4.0

DETAILED EQUIPMENT DESIGN

4.1 EQUIPMENT SIZING

For an extractor, emphases on design specifications lie on the height and diameter of the equipment. The primary source of information is knowledge of the volume of the mixture in the extractor.

Generally, density (Kg/m^3) = mass (Kg) / volume (m^3)

So that volume = mass / density

For a mixture, $\rho_{\text{mix}} = w_1\rho_1 + w_2\rho_2 / (w_1 + w_2)$

Where:

W_1 = weight of solid fed into the extractor = 2598.75Kg

W_2 = weight of solvent into the extractor = 4287.93Kg

ρ_1 = density of feed = 1600Kg/m³

ρ_2 = density of solvent = 651Kg/m³

$\rho_{\text{mix}} = (2598.75)(1600) + (4287.9375)(651) / (2598.75 + 4287.9375)$

$\rho_{\text{mix}} = 1009.45\text{Kg/m}^3$

Volume of mixture, $V_{\text{mix}} = (w_1 + w_2) / \rho_{\text{mix}}$

$= 2598.75 + 4287.9375 / 1009.45$

$V_{\text{mix}} = 6.82\text{m}^3$

Taking a 20% safety factor into consideration, operating volume;

$= V_{\text{mix}} \times (100 + 20) / 100 = 6.82 \times 1.2 = 8.814$

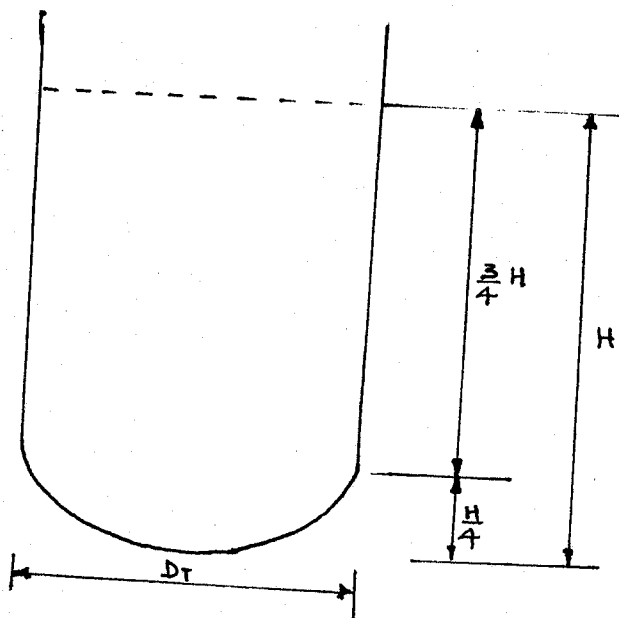
Therefore, operating volume, $V = 8.814\text{m}^3$

To calculate the diameter of the extractor,

Total volume = volume of cylindrical part + volume of hemi-ellipsoidal

part

The shape of the extractor is as shown below:



D_T = Diameter, m

H = Height of material in the extractor, m

Volume of cylindrical part = $\pi (D_T/2)^2 (3H/4)$

Volume of the hemi-ellipsoidal part = $\pi (D_T/2)^2 (1H/6)$

$V_T = \pi D_T^2 H/16 + \pi D_T^2 H/24$

In this case, $H = D_T$, so that

$V_T = \pi D_T^3 / 16 + \pi D_T^3 / 24 = 5\pi D_T^3 / 6$

$V_T = 5\pi D_T^3 / 6 = 6.82$

$D_T^3 = 6.82 * 6 / 5\pi = 6.82 * 6 / (3.142 * 5) = 2.6047$

$D_T = (2.6047)^{1/3} = 1.3759\text{m}$

$D_T = 1.3759 = 1.38\text{m}$.

AREA OF THE EXTRACTOR, A (m²)

A = Area of cylindrical part of extractor + Area of hemi-ellipsoidal part

Where Area of cylindrical part = $3\pi D_T H/4 + \frac{1}{2}(2\pi) (D_T/2)^2$
 $= 3\pi D_T H/4 + \pi D_T^2/4$

Area of hemi-ellipsoidal part = $2\pi (D_T/4)(D_T/2) \sin^{-1}e = \pi D_T^2 \sin^{-1}e/4$

Where $e = [(D_T/2)^2 - (D_T/4)^2] / (2D_T)$

Area of cylindrical part = $3\pi D_T H/4 + \pi D_T^2/4$, but $U = D_T$ (assumed)

$= 3\pi D_T^2/4 + \pi D_T^2/4 = \pi D_T^2 (3/4 + 1/4)$

$= \pi D_T^2/2 = 3.142 * (1.38)^2/2 = 2.9918124$

Area of cylindrical part = 2.99m^2

Area of ellipsoidal part = $2\pi (D_T/4) (D_T/2) \sin^{-1}e = D_T^2 \sin^{-1}e/4$

$e = [(D_T/2)^2 - (D_T/4)^2] / (2D_T) = [(1.38/2)^2 - (1.38/4)^2] / (2/1.38)$

$e = 0.5175$

So that area of hemi-ellipsoidal part = $3.142 * (1.38)^2/4 * (0.5439)$

Area of hemi-ellipsoidal part = $0.8136\text{m}^2 = 0.82\text{m}^2$

$A = 2.99 + 0.82 = 3.18\text{m}^2$

Area of extractor (on theoretical basis) = 3.18m^2

Considering a 20% safety factor,

Operating area = $1.2 \times$ Area (calculated)

$= 1.2 \times 3.18 = 4.572\text{m}^2$

Operating area of extractor = 4.572m^2

Thickness of the Extraction Vessel

$2W_b/3$ = Thickness

where $W_b = D_T / 10 = 1.38 / 10 = 0.138\text{m}$

$$\text{Thickness} = 2(0.138) / 3 = 0.092\text{m}$$

$$\text{Thickness of vessel} = 0.092\text{m}$$

Height of Extractor, D_T (m)

$$\text{Let height, } D_T = 1.5D_T$$

$$H_T = 1.5(1.38) = 2.07\text{m}$$

$$\text{Height of extractor} = 2.07\text{meters}$$

Height of propeller above vessel base, H_A (m)

$$H_A = D_T / 3 = 1.38 / 3 = 0.46\text{m}$$

4.1 AGITATOR SPECIFICATIONS

Solid particles in the extraction vessel require a degree of agitation, and because of their flexibility, propeller or turbine agitators are employed for this service.

Degree of agitation

Agitator tip speeds, U_T , are commonly used as a measure of the degree of agitation.

$$U_T = \pi D_T N$$

N = rotational speed, rps

For medium agitation, $U = 3.3 - 4.1\text{m/s}$ and assuming

$$U_T = 4.0\text{m/s}, N = U_T / \pi D_T = 4.0 / 3.142 * 1.38$$

$$N = 0.9225 \text{ rps}$$

POWER REQUIREMENTS

$$P_A / G = U C N^2 D_A^3$$

Where;

P_A = power consumption in watts;

U = viscosity of the medium, Pas

D_A = propeller diameter, m

$C = 71.0$ for a standard tank configuration

$U = 50$ Pas for pastes, $G = 15\text{Kg/s}$ (assumed)

$$D_A = D_T / 3 = 1.38 / 3 = 0.46\text{m}$$

$$50 (71.0) (0.9225)^2 (0.46)^3 P_A / 15$$

$$294.06\text{W} = P_A / 15$$

$$P_A = 4410.9 = 4.4109\text{KW}$$

4.2

PIPE DIAMETERS FOR STREAMS WITHIN THE EXTRACTOR

$$dp = 293G^{0.53} P^{-0.37}$$

dp = pipe diameter, mm

G = flow rate of stream, Kg/s

ρ = density of material, KG/m³

Assuming that the combined flow rate of mixture = 15Kg/s;

Then, flow rate of seeds, $G_F = 15 * 2598.75 / 2598.75 + 4287.93$

$$G_F = 5.67\text{Kg/s}$$

Solvent flow rate, $G_s = 15 * 4287.93 / 2598.75 + 4287.93$

$$G_s = 9.3396\text{Kg/s}$$

$$(dp)_{\text{seed}} = 293(5.67)^{0.53} (1600)^{-0.37}$$

$$(dp)_{\text{seed}} = 47.95\text{mm}$$

$$(dp)_{\text{solvent}} = 293(9.34)^{0.53} (651)^{-0.37}$$

$$(dp)_{\text{solvent}} = 87.12\text{mm}$$

$$(dp)_{\text{raffinate}} = 293G_{\text{raf}}^{0.53} P_{\text{raf}}^{-0.37}$$

where ρ_{raf} = density of raffinate stream = 1100Kg/m³ (assumed)

so that $G_{\text{raf}} = 15 * 1991.94 / 1991.94 = 15\text{Kg/s}$

$$(dP)_{\text{raf}} = 293(15)^{0.53} (1100)^{-0.37}$$

$$(dP)_{\text{raf}} = 92.23\text{mm}$$

(dP)_{ext} = pipe diameter of extract phase

$$(dP)_{\text{ext}} = 293G_{\text{ext}}^{0.53} \rho_{\text{ext}}^{-0.37}$$

$$\rho_{\text{ext}} = 850\text{Kg/m}^3, G_{\text{ext}} = 15\text{Kg/s}$$

$$(dP)_{\text{ext}} = 293(15)^{0.53} (850)^{-0.37}$$

$$(dP)_{\text{ext}} = 101.5\text{mm}$$

4.3

HEAT OF MIXTURE

1 Thermal conductivity of mixture, K_{mix} :

$$K_{\text{mix}} = (W_1K_1 + W_2K_2) / (W_1 + W_2)$$

K_1 = thermal conductivity of solid feed, $\text{Wm}^{-1}\text{C}^{-1}$

K_2 = thermal conductivity of extracting solvent, $\text{Wm}^{-1}\text{C}^{-1}$

$$K_{\text{mix}} = (2598.75 * 0.174) + (4287.9375 * 0.102) / (2598.75 + 4287.9375)$$

$$K_{\text{mix}} = 0.129 \text{ Wm}^{-1}\text{C}^{-1}$$

2 Heat capacity of mixture, C_{pmix} ($\text{KJkg}^{-1}\text{C}^{-1}$)

$$C_{\text{pmix}} = W_1 C_{p1} + W_2 C_{p2} / W_1 + W_2$$

$$C_{p1} = \text{specific heat capacity of solid feed} = 1.675 \text{ KJ/KgC}$$

$$C_{p2} = \text{specific heat capacity of solvent} = 0.527 \text{ KJ/KgC}$$

$$C_{\text{pmix}} = (2598.75 * 1.675) + (4287.9375 * 0.527) / 2598.75 + 4287.93$$

$$C_{\text{pmix}} = 0.96 \text{ KJ/KgC}$$

Since n - hexane enters the extractor at 70C, the heating range for the decorticated seeds will lie between 30C (assumed room temperature of extractor before the commencement of heating) and 70C.

Taking temperatures of 30, 50 and 70C, the viscosities (μ) of n - hexane are, respectively as follows:

$$\mu \text{ at } 30\text{C} = 2.9 \text{ Pa-s}$$

$$\mu \text{ at } 50\text{C} = 2.4 \text{ Pa-s}$$

$$\mu \text{ at } 70\text{C} = 2.1 \text{ Pa-s}$$

$$\text{The Reynold's number } (N_{\text{re}}) = \rho N D_A^2 / \mu$$

$$D_A = \text{diameter of agitator} = 0.46\text{m}$$

$$N = \text{rotational speed of the agitator} = 0.93\text{rps}$$

$$\mu = \text{viscosity of solvent, Pas, subject to temperature.}$$

$$\text{At } 30\text{C}, N_{\text{re}} = 652 * 0.93 * (0.46)^2 / 2.9 = 44.18$$

$$\text{At } 50\text{C}, N_{\text{re}} = 651 * 0.93 * (0.46)^2 / 2.4 = 53.38$$

$$\text{At } 70\text{C}, N_{\text{re}} = 651 * 0.93 * (0.46)^2 / 2.1$$

$$\text{The Prandtt Number } (N_{\text{pr}}) = C_p U / K$$

$$\text{At } 30\text{C}, N_{\text{pr}} = 78.50$$

$$\text{At } 50\text{C}, N_{\text{pr}} = 64.97$$

$$\text{At } 70\text{C}, N_{\text{pr}} = 56.85$$

Now, let's calculate the heat transfer coefficient inside the extractor at different temperature of 30C, 50C, and 70C.

$$h_{\text{mix}} = 0.73 (N_{\text{re}})^{0.659} (N_{\text{pr}})^{0.339} (K/D_T)$$

$$K = K_{\text{mix}} = 0.129 \text{ W/mC}$$

$$D_T = \text{Diameter of extracting vessel} = 1.38\text{m}$$

$$\text{At } 30\text{C}, h_{\text{mix}} = 0.73 (44.18)^{0.659} (78.50)^{0.339} [0.129 / 1.38]$$

$$h_{\text{mix}} (30\text{C}) = 3.636 \text{ KW/m}^2\text{C}$$

$$h_{\text{mix}}(50\text{C}) = 0.73(53.38)0.659 (64.97)0.009 [0.129 / 1.38]$$

$$h_{\text{mix}}(50\text{C}) = 3.86\text{KW/m}^2\text{C}$$

$$h_{\text{mix}}(70\text{C}) = 0.73(61.01)0.659 (56.85)0.339 [0.129 / 1.38]$$

$$h_{\text{mix}}(70\text{C}) = 4.03\text{KW/m}^2\text{C}$$

Calculation of the overall heat transfer coefficient:

$$1/U_T = 1/h_{\text{mix}} + x/K + 1/h_s$$

where:

U_T = overall heat transfer coefficient, $\text{KW/m}^2\text{C}$

K = thermal conductivity of steel = $0.0163\text{KW/m}^2\text{C}$

X = thickness of the vessel wall =

h_s = heat transfer coefficient of steel = $5.6783\text{KW/m}^2\text{C}$

$h_{(\text{mix})T}$ = heat transfer coefficient of mixture at temperature, T .

$$\text{At } 30\text{C}, 1/U_{30} = 1/3.636 + 0.092/0.0163 + 1/5.6783 = 6.095$$

$$U_{30} = 0.1641\text{KW.m}^2\text{C}$$

$$\text{At } 50\text{C}, 1/U_{50} = 1/3.86 + 0.092/0.0163 = 1/5.6783 = 6.079$$

$$U_{50} = 0.1645\text{KW/m}^2\text{C}$$

$$\text{At } 70\text{C}, 1/U_{70} = 1/4.03 = 0.092/0.0162 = 1/5.6783 = 6.068$$

$$U_{70} = 0.1648\text{KW/m}^2\text{C}$$

Amount of steam required to heat the bulk mass from 30C to 70C could be calculated using;

$$M_s L_s = UA\Delta T$$

Where;

M = mass flow rate of steam, A = Area of extractor = 3.18m^2

$U = 0.1648$ = overall heat transfer coefficient of mixture at 70C

ΔT = Temperature change = $(100 - 70) = 30\text{C}$

L_s = specific heat of steam = 2412.03KJ/Kg

$$M_s = UA\Delta T / L_s = 0.1648 \times 3.81 \times 30 / 2412.031 = 7.809 \times 10^{-3}$$

$M_s = 0.007809\text{Kg/s}$; this is the mass flow rate of steam.

TIME TAKEN TO HEAT THE BULK MASS:

Here, the time it will take to heat the feed and the solvent in the extractor from 30C to 70C will be supplied by heat at 100C:

$$\text{Time } WC_p / UA \log_e (T_s - T_{bi} / T_s - T_{bf})$$

Where T_{bi} and T_{bf} are, respectively, the bulk temperatures at the beginning and at the end of heating = 30C and 70C.

T_s = temperature of steam = 100C

W = weight of feed + weight of solvent = $2598.75 + 4287.9375$

C_p = 6886.6875Kg

$$C_p = 0.96 \text{KJ/KgC}, A = \text{Area of extractor} = 3.18 \text{m}^2$$

$$U = ?$$

$$\text{Time (hours)} = 6886.65 * 0.96 / (0.1648 * 3.81) \log_e (100 - 30 / 100 - 70)$$

$$\text{Time} = 1.549 \text{hours.}$$

$$\text{Mass of steam required } M_s * \text{time (seconds)}$$

$$\text{Mass of steam} = 0.007809 * (1.549 * 3600)$$

$$\text{Mass of steam} = 43.55 \text{Kg}$$

Amount of heat supplied by steam, Q_s :

$$Q_s = UA\Delta T$$

$$Q_s = 0.1648 * 3.18 (100 - 70)$$

$$Q_s = 18.84 \text{KJ}$$

4.4 MATERIALS OF CONSTRUCTION ✓

For the sake of availability, a comparatively cheaper price of purchase, a fairly reliable strength and durability, carbon steel has been chosen as the construction material for this design.

4.4 COSTING ✓

The costing done here follows the format of cost index and scale up factor recommended in Richardson and Coulson's Chemical Engineering, Volume 6.

Cost of Extractor:

$$C_e = CS^n$$

$$C = \$8000, S = \text{Area of extractor vessel} = 4.572 \text{m}^2$$

$$N = \text{cost index} = 0.4, \text{ for an extractor vessel}$$

$$C_e = 8000 (4.572)^{0.4}$$

$$C_e = \text{£}14693.74$$

Cost of Agitator:

$$\text{Power required} = 4.4109 \text{KW} = S$$

$$C = \text{£}3200, n = 0.5$$

$$C_e CS^n = 3200 (4.4109)^{0.5} = 6720.68$$

$$C_e = \text{£}6720.68$$

Cost of Steam:

$$\text{For a batch, } 43.55 \text{Kg} = 0.04355 \text{ tons}$$

$$\text{Standard cost of steam} = \text{£}6 \text{ per ton}$$

$$\begin{aligned} \text{Cost of steam per batch} &= \text{£}6 * 0.04355 \\ &= \text{£}0.261 \end{aligned}$$

Cost of Pipe Fittings:

$$\text{Cost of pipe per mm} = \text{£}27 (0.065)0.55d$$

Where d = pipe diameter

Inlet pipes:

(a) solvent pipe = $\text{£}27(0.065)0.55 (87.12) = \text{£}523.09$

(b) Seed pipe = $\text{£}27(0.065)0.55 (47.95) = \text{£}287.91$

Exit (discharge) pipes:

(a) Raffinate stream = $\text{£}27(0.065)0.55 (92.23) = \text{£}553.78$

(b) Extract stream = $\text{£}27 (0.065)0.55 (101.5) = \text{£}609.44$

COST TABLE:

ITEM	COST (£)
EXTRACTOR	14693.74
AGITATOR	6720.68
STEAM	0.261
SOLVENT INLET PIPE	523.099
EXTRACT DISCHARGE PIPE	609.44
FEED (SEED) INLET PIPE	287.91
RAFFINATE DISCHARGE PIPE	553.78
TOTAL	23388.91

4.8 SAFETY CONSIDERATIONS

A technology involving hazardous materials needs a reasonable approach of assessing its suitability and acceptability to the environment and man [Odigure (1982)]. In order to be able to systematically identify all possible devices of these occurrences, such as approaches should be methodologically okay.

More often than not, a risk appraisal of the entire process at the conceptual stage of design is more desirable. To this end, therefore, a preventive, rather than a curative, safety ethic is recommended for this project.

4.5.3 SITE LAYOUT

The process units and ancillary buildings should be laid out to give the most economical flow of material and personnel around the site. Hazardous processes should be located at a safe distance from other process units or buildings. Process units should be spaced at least 30 meters apart. Control rooms, for ease of movement, will normally be located adjacent to the processing units. With potentially hazardous processes, control rooms may have to be sited at a safer distance.

The siting of the main process units will determine the layout of the plant roads and passage ways, and pipe alleys. Access roads will also be needed for each building, whether of construction for operation, or for maintenance.

4.5.4 SAFETY OF FACTORY PERSONNEL WITH RESPECT TO EQUIPMENT AND LAYOUT.

"Man's natural instinct of self protection has always guided him in his actions; his insatiable urge for self esteem and enviable fight with nature." [Odigure (1998110)]. The designer of an equipment therefore, owes it to the user of his product from foreseeable harm during usage. Safety factors (or over design) of 20% are always integrated in the design. Besides, the control measures have to be automated to sound off warnings where the permissible limits of operation have exceeded.

To prevent an undue heating of the working premises, the boiler rooms should, as much as is reasonable, be isolated.

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Having carried out preliminary material/energy balances of the process units involved in this design, together with a detailed equipment design, it can be concluded that a 4.57m² batch agitated extracting vessel for bio-insecticide production requires 2598.75Kg of crushed neem seeds against 4287.9375Kg of solvent to function optimally. In addition, it will take 43.55Kg (Kg per batch) of steam to heat up the designed vessel in order to meet the designed target of 6000 tons per year.

5.2 RECOMMENDATIONS

The following suggestions are recommended to be explored:

1. A check-up should be carried out to find to what extent heating by heat affect the rate of extraction for the designed vessel.
2. An economic justification of operating the designed plant on a continuous basis, in place of the batch production option adopted here, should be looked into.
3. Profitability of the process could also be improved if ways into viable utilization of the encountered wastes are worked out.

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