DESIGN FEATURES OF A 5 TONNE / DAY MULTI – STAGE, INTERMITTENT DRAINAGE, CONTINUOUS FULL IMMERSION, VEGETABLE OIL SOLVENT EXTRACTION PLANT- MECHANICAL DESIGN

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Abstract

In this work, the mechanical design calculations of the vegetable oil extraction plant presented in part I were show cased. Process description and flow sheet of the plant have been given in the design features in part I, and the mechanical design calculations are here based upon the figures obtained at various stages downstream in the process design. In fact, design stress due to load on hopper, agitated vessel, launder, sumps and down-comers, as well as extractor accessories of pipes, pumps, conveyor belts and screw, and miscella drainage, were also presented. Design was based on KPO as in Part I for the obvious reason that it is a simple oil which takes into consideration the properties of soyabean and palm oil, with an over design tolerance of plus/minus 10%. It was established from the mechanical design calculations that the volume of the extractor is 2.17m^3 . Cost estimation of the designed extractor was carried out to also establish the cost of one unit to about three and a half million Naira (N3.5M), ($20,588.64). The design may be scaled up to any capacity for big industrial out-fit, and when fully developed and constructed, will serve the rural dwellers of the globe.

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1. INTRODUCTION

Vegetable oils and fats were defined in 4,000-year oil "Kitchen" unearthed in Indiana [1], as triglycerides of fatty acid extracted from plants. They are primarily extracted from seeds and nuts, even though they may be extracted from other parts of the plant.

Human beings have known how to extract these oils from various sources and make them good for their own use. The natives in the tropical regions of the world have long extracted these oils after drying the seeds and nuts under the sun [1]. Mahatta observed that Olive Oil was extracted as far back as 3000BC in ancient Egypt[2]. Vegetable oils and fats are used as ingredients in the many manufactured goods, including soap, candle, perfumes, cosmetics, margarine, venaspati, shortening, hydraulics fluids, biodiesel and lubricants, [3].

Many authors have, at different times, written and published articles on the design of oil extractors, and oil extraction from seeds and nuts using various methods and characterization of the extracted oils,[4], [5] and [6] They have noted that mechanical expression, termed crushing, or pressing method, offers advantage in terms of purity of the final product over the solvent extraction method. The latter, which is a separation process based on apparent equilibrium steps, offers the advantage of perfect penetrating action in the cell of the prepared oil seeds and nut to improve yield, [7], and is less expensive, [8] and [9].

Vidke and Souslski, [10], and Swetman and Head, [11], carried out mechanical expression of oil using different presses; lever and box, hydraulic, Ram, Bridge and Continuous Screw press.

Gurnham, and Masson, [12], have studied the equilibrium condition of expression after a constant pressure has been applied and maintained until no further flow of oil occurred. have studied the equilibrium condition of expression after a constant pressure has been maintained until no further flow of oil occurred. They noted that an increase in pressure on a system of expressible material considered as a fractional increase over the previous pressure causes a proportional increase in the bulk of the solid portion of the system. Hence;

$$\frac{dP}{P} = Kd\rho_S = k'd\left(\frac{1}{V}\right) \quad 1$$

Or $$\frac{dP}{d(1/V)} = k'P \quad 2$$

On integration , equation 2 gives

$$LogP = K + \frac{k'}{V} \qquad 3$$

where K, k and k´ are constants, depending on the nature of material, and on the expression conditions, ρ_s is the bulk density of the solid portion of the system, P and V , the pressure and specific volume of the system respectively based on the solid content.

[13] carried out experiment on a homogeneous oil impregnated material consisting of thin platelet of uniform thickness with two phases as the total surface area based on single diffusion and observed that the theoretical rate of extraction is given by;

$$E + \frac{8}{\pi^2} \sum_{n=0}^{n=\infty} \frac{1}{(2n+1)^2} e^{-(2n+1)^2 \pi/2 \frac{D\theta}{4R^2}} \qquad 4$$

Where E is the fractional total oil unextracted at the end of time, e; R is one-half of the plate thickness (ft); and D the diffusion coefficient in (ft^2/hr). For n = o, eqn. 4 will reduce to;

$$E = \left(\frac{8}{n^2} e^{-\pi/2} \right) \left(\frac{D\theta}{4R^2} \right) \qquad 5$$

Or

$$\log_{10} E = -0.091 - 1.07 \frac{D\theta}{R^2} \qquad 6$$

The number of theoretical stages needed to ensure effective extraction was given by Coulson and Richardson [14] as;

$$a^m = \left(\frac{S_o}{S_m} \right) \left(1 - \frac{S_1}{W_1} \right) \qquad 7$$

Treybal [11], also gave an expression to be used to estimate efficiency as;

$$E_o = \frac{1}{1 + 3.7(10^4) \frac{KM}{hT\rho}} \qquad 8$$

In the present work, attempts have been made to give the detailed mechanical design calculations of a 5 tonne per day vegetable oil solvent extraction plant with the necessary accessories, with a view that when fully developed/constructed will provide the rural communities of the globe with a feasible and cost effective way of processing their oil seeds and nuts.

2. PROCESS DESIGN

2.1 Process Description

Flaked oil seed (S1) is transferred to the feed hopper (E1) by means of a belt conveyor. Solvent (S2), is also pumped into the same hopper tank. The two components are well mixed to ensure homogeneity and easy contact of solvent with the flake to leach out the oil. Extraction takes place by the diffusion of the oil into the solvent. The meal (S3), is then transferred to the Launder (E6), for leaching with recycle miscella (S4). The leached meal is then transferred to the next hopper for further extraction of the oil content by means of screw conveyor (E2).

Miscella is transferred through percolation filter (E3), to each of eight (8), miscella sumps. With the miscella transfer pump (E5), the miscella is transferred to the next Launder through valve, (E7), to leach out more oil from the meal. The miscella from the last sump (E8), is pumped to the distillation unit, (E11), for separation, and the distilled solvent (S7), is recycled to the first hopper. The still bottom (S6), is discharged into a decanter (E12), where water (S13), is separated and sent to the sundry water (S14). Steam (S11) is used for distillation and the condensate (S12), goes to the sundry water also. The heat exchanger (E14), is used to heat up the bottom product so as to facilitate separation of water/oil mixture (S9) in the decanter. The cake (S10), with less than 4% oil content is discharged to the desolventizer, and the oil extract (S8), is sent to storage. The miscella recycle pump (E9), is now used to recycle the miscella to the first launder, through the control valve, (E10).

3. MECHANICAL DESIGN CALCULATIONS

3.1 Introduction

The object of mechanical design is to develop an equipment which will withstand stress and strain when put into operation. The design is based on stainless steel material of construction, since a given construction must be in consonance with the material being handled. This is so in order to avoid, or at least, reduce corrosion tendency of the material of construction, or the contamination that may arise as a result of using wrong material of construction for a given process material, especially in food industries.

3.2 Design Procedure

The procedure assumes that the flow rates, as well as the process steam temperature are known. In addition, the following geometrical data of an extractor are specified: extractor height and diameter, number of stages, hopper and launder dimensions. The physical properties are either specified or are estimated using some correlations and empirical expressions as shown in the report. The steps followed in the design include;

i) Calculate the flow rates of flakes and solvent, as well as the miscella
ii) Use the values obtained in i) above to calculate the number of theoretical stages

iii) Determine the efficiency of the process
iv) Use ii) and iii) to determine the number of actual stages desired for the extraction
v) Determine the heat capacities of the steams to be used in energy balance calculations
vi) Perform the process design (material and Energy balance) calculations.
vii) Use the information in (vi) to perform the mechanical design

3.3 Design Data

Table 1 Summary of Palm kernel variables used for plant design

Variables (day)	Values
Number of sections	8
Feed required	7635.6
Hexane required	12927.6
Miscella recovered	12171.6
Raffinate withdrawn	8391.6

Hopper Design Calculations

The hopper is a holding vat for the solid charge. Solids are charged from it mechanically propelled into the extractor. The basis for hopper design calculation is presented hereunder.

Assumptions: 3 Shift operations per day, and 3 runs per shift.

Radius of hopper cylindrical part = 0.5m
Height of hopper cone base = 0.09m
Height of hopper down comer = 0.6m
Radius of down comer = 0.12m
Radius of down comer part = 0.5m

Quantity of solids required per shift= $\frac{7635.6}{3}$ = 2545.2 Kg/shift

For 3 runs it becomes = $\frac{2545.2}{3}$ = 848.4Kg/run

For hexane, we have $\frac{12927.6}{3}$ = 4309.2Kg/shift

For 3 runs it becomes = $\frac{4309.2}{3}$ = 1436.4Kg/run

Volume of PK Grit

Density of PK grit = 0.5682Kg/lit.

Volume of grit $= \frac{848.4/\text{run}}{0.5682\text{Kg}/\text{Lit.}} = 1.493\text{m}^3 \approx 1.5\text{m}^3$

Vol. of grit in cone part $= \frac{\pi r^2 h}{3} = \frac{\pi(0.5)^2 0.09}{3} = 0.0236\text{m}^3$

If an allowance of 5% is given in the design, then we have,
0.0236 x 0.05 = 0.00118m^3

Total volume of cone part = 0.0236 + 0.00118 = 0.02478m^3
The volume of cylindrical part will be, = 1.5 - 0236 = 1.47m^3
and for allowance of 5% in the design, we have
1.47 x 0.05 = 0.07382m^3

Therefore, total volume of hopper cylinder
= 1.4764 + 0.0738 = 1.550m^3

But $1.550\text{m}^3 = \pi r^2 h$
Therefore h = 1.973m^3
Total height of hopper = 1.973 + 0.09 = 2.063m

Total volume of hopper (cylinder and cone)
= 1.550 + 0.02478 = 1.575m^3

Volume of cylindrical down comer = 3.142 x $(0.12)^2$ x 0.6 = 0.0272m^3

Then grand total of hopper volume = 0.0272+ 1.575 = 1.6m^3
Surface area of hopper = $2\pi rh$

Surface area of cylindrical part = 2 x 3.142 x (0.5) x 1.973 = 6.20m^2

Surface area of cone = 3.142 x (0.5) x h
Where h is the slanting height

Now slanting height can be calculated from the volume

Volume of cone = 0.02478m^3

$$= \frac{\pi r^2 h}{3} = 0.02478\text{m}^3$$

$$h = \frac{3(0.02478)}{\pi(0.5)^2} = 0.0946\text{m}$$

Therefore, surface area of cone = 3.142 x 0.5 x 0.0946 = 0.15m^2

Surface area of down comer = 2 x 3.142 x 0.6 = 0.453m^2

Total surface area of hopper = 6.2 + 0.15 + 0.453 = 6.802m^2

Wall Thickness of Hopper

From [14], the minimum wall thickness of the cylindrical shell of the hopper is given by;

$$t = \frac{P_i D_i}{2fj - P_i} + C = 4.34\text{mm, say } 5\text{mm} \qquad 10$$

Where, t -Shell thickness, mm; P_i - Internal Pressure N/mm^2 = 0.2 bar (the operating pressure)

D_i - Internal Diameter of vessel, = 1000mm
f - Design stress factor
C - Corrosion allowance, = 3mm (assumed)
j – A factor that takes care of welded or threaded portion

The design pressure is normally higher than operating pressure by10%.

Design pressure of the hopper
= 0.20 + 0.1(0.2)bar, = 0.022N/mm^2

Operating temperature is taken as that of steam = 65^{o}C
[14] also gave, the design stress factor for stainless steel at temperature of between 0 and 50^{o}C as 165.

Using these values in the design equation, we have

$$t = \frac{0.022 \times 1000}{2 \times 165 \times 0.05 - 0.022} + 3 = 1.34 + 3 = 4.34\text{mm} \approx 5\text{mm}$$

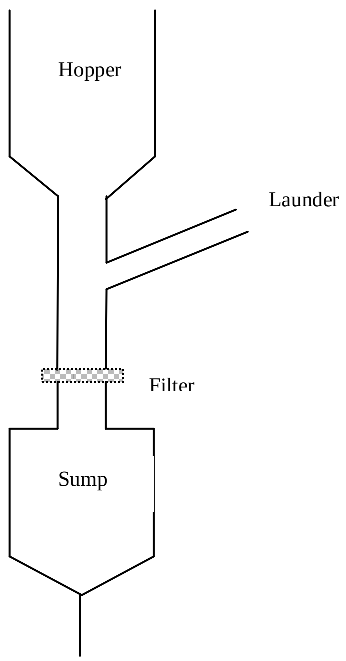

Fig 1 Diagram of Hopper, Launder, and Sump arrangement

Stress on the Hopper Cylinder

A cylinder is swept out by the rotation of a line parallel to the axis of revolution.

Equations of revolution are given by [14] as;

$$\frac{\sigma_2}{r_1} + \frac{\sigma_2}{r_2} = \frac{P}{t} \qquad 11$$

$$\sigma_1 = \frac{Pr_2}{2t} \qquad 12$$

Where, P - Pressure
t - Shell thickness
σ_1 - The meridional (longitudinal) stress, the stress acting along a meridian
σ_2 - The circumferential or tangential stress, the stress acting along parallel circles
r_1 - The meridional radius of curvature
r_2 - The circumferential radius of curvature

For a cylinder, $r_1 = \infty$, and $r_2 = D/2$

Where D is the diameter of cylinder

Substituting data in equations 11 and 12, we have,

$$\sigma_1 = \frac{PD}{4t} = 1.1\text{N/mm}^2 \qquad 13$$

$$\sigma_2 = \frac{PD}{2t} = 2.5\text{N/mm}^2 \qquad 14$$

Stress due to Load on Hopper Cylinder

Stress due to weight of vessel, its contents, and any other attachments, which will be tensile (positive) for points below the plane of the vessel support and compression (negative) for points above the support, is given by [14] as;

$$\sigma_w = \frac{W_v}{\pi(D_i + t)t} = 0.000225\ \text{N/mm}^2 \qquad 15$$

Where W_v - Total load which is supported by the vessel's wall at the plane
t - Shell thickness
D_i - Shell diameter
H_v - Height of cylinder = 2m
t = 5mm = 0.005m
Now W_v is obtained from the relation
$W_v = 240C_vD_m(H_v + 0.8D_m)t$
Where D_m - Mean diameter, given by;
$D_m = D_i + t \times 10^{-3}(m) = 1 + 5 \times 10^{-3} = 1.005m$
C_v is a factor that accounts for any other attachment e.g, nozzle, manhole, internal support etc.

Therefore, W_v = (240 x1.005)[1.973 + 0.8 x 1.005]0.005
= 3.55N
σ_w = 0.000225N/mm^2

Estimation of Hopper Cone Thickness

From Coulson and Richardson, thickness of cone of internal pressure vessel is given by;

$$t = \frac{P_i D_c}{2fj - P_i} x \frac{1}{\text{Cos}\alpha} = 5\text{mm} \qquad 16$$

Where, D_c = Diameter of cone
α = ½ cone apex angle
C_c = Design factor - a function of half apex angle α
The cone apex angle = 30^o
Take welding factor to be 0.1
P_i = $0.150 N/mm^2$
D_c = 1000mm
f = $165N/mm^2$
j = 0.05

Stress on the Hopper Cone

From Coulson and Richardson, (1993), page 728

$$\sigma 1 = \frac{Pr}{2t\text{Cos}\alpha} = 8.66 \text{ N/mm}^2$$

$$\sigma 2 = \frac{Pr}{t\text{Cos}\alpha} = 17.32 \text{ N/mm}^2$$

For r = 0.5m = 500mm, α = 30^o and P = $0.15 N/mm^2$

Stress due to Load on Hopper Cone

From equation 15, $\sigma_W = \frac{W_V}{\pi(D_i + t)t}$ = 7.2 x $10^-5 N/mm^2$
D_m = 1.005
Where, Pressure on cone, P = 1.5 bar ($0.15N/mm^2$)
D_c for cone base is equal to the radius of hopper cylinder = 0.5 x 2 = 1m
t = 0.5m

Height of cone, H_v = 0.09m
Then D_m = 1 + 0.005m = 1.005m
W_v = 240 x 1.06 x 1.005(0.09 + 0.8 x 1.005) 0.005 = 1.143N

5. AGITATED VESSELS AS LEACHING EQUIPMENT

5.1 Introduction

According to [15], finely divided solids which can be readily suspended in liquids by agitation may be continuously leached in any of the many types of agitated vessels. This must be arranged for continuous flow of liquid and solid into and out of the vessel and must be carefully designed so that no accumulation of solids occurs. Thorough mixing is usually achieved by means of the agitator. These devices are single stage in their operation, the liquid and solids tending to come to equilibrium within the vessel.

The average holding time in an agitated vessel may be calculated by dividing the vessel content n\by the rate of flow into the vessel. This can be done separately for solids and liquids. The holding time for each may be different if the ratio of the amount of one to the other is different. The average holding time of the solids must be sufficient to provide the leaching action required.

Individual solid particles, of course, may short – circuit the vessel; that is, pass through in time much shorter than the calculated average, and this will lead to low state efficiency. Short – circuit can be eliminated by passing the solid – liquid system through a series of smaller agitated vessels one after the other, the sum of whose average holding time is the necessary leach time. The above suggestion as well as the experimental result, is the basis for the choice of the design configuration of a battery of small units of extractors in a single equipment interconnected by the down comers.

5.2 Launder Design

The launder is the system where a solvent and solid to be leached of its solute content are contacted. It may be a component in a batch or continuous extractor. Its shape is dependent on convenience and experience. It may be a hollow vertical, horizontal or inclined cylinder bearing a screw conveyor within. The conveyor is used to transport the material to be extracted on a continuous basis.

Solvent used for extraction is pumped or sprayed into the launder to contact the solid matter in a counter – current manner or cross – current arrangement or any other contacting pattern.

In this work, the launder is made up of a number of units equal to the number of theoretically determined number of sections required for a complete extraction.

Actual number of sections required = 8
Time of extraction = 18 minutes
Mass flow rate = 0.101Kg/s

$$\text{Holding time} = \frac{\text{Extractor content}}{\text{Mass flow rate}} =$$

$$\frac{848.4\text{Kg/ru n}}{0.101\text{Kg/s}} = 8400\text{sec/ru n} = 2.33\text{hours}$$

5.3 Solvent Flow Rate

Weight of hexane required = 12927.6Kg

$$\text{Weight per shift} = \frac{12927.6}{3} = \frac{4309.2\text{Kg}}{\text{shift}}$$

$$\text{Quantity per run} = \frac{4309.2}{3} = \frac{1436.4\text{Kg}}{\text{run}}$$

$$\text{Volume flow rate} \quad \frac{m}{\rho} = \frac{1436.4}{0.659} = 2170\text{lit} = 2.17\text{m}^3$$

Mass flow rate of hexane = 0.171Kg/s

Holding time = $\frac{1436.4Kg}{0.171Kg/s)} = 8400\ sec$ = 2.33hours

Note that the holding time is the same with liquid as for solid.

Velocity of Feed

The velocity of feeds in the extractor is equivalent to that of conveyor which transport them Assume that it is fixed at 0.002m/sec.

Extractor Size (Total Distance Travel)

The total distance to be traveled by a solid material charge is given by, D, and D = Velocity of feed x Holding time
With velocity as 0.002m/s

Then total distance traveled by a solid charge as propelled by a screw conveyor will be,

8400s x 0.002m/s = 16.8m

Since the extractor is made up of small interconnected units, the size of each unit in the battery is given by

$$\text{Unit length} = \frac{\text{Total length of extractor travel}}{\text{Number of theoretical sections}} = \frac{16.8m}{7} = 2.4m$$

Table 2 Summary of Extractor design calculations

Components	Values
Hopper volume	$1.16m^3$
Extractor length	2.40m
Holding time liquid	8400sec
Holding time solids	8400sec

Note that the smaller the unit length the higher the number of intermittent discharges and consequent break up of new channels for solvent penetration.

Velocity of Flow for Hexane/Miscella

The velocity of hexane through each extractor unit,(which fixes the velocity of the various stage pumps) is given by:

$$\text{Velocity (u)} = \frac{\text{Distance (unit length)}}{\text{Holding time/unit}} = \frac{2.4 \times 7}{8400} = 0.002m/s$$

Thus, the stage pump velocity = 0.002m/s

Extractor Cross – Sectional area

The cross – sectional area of the extractor may be calculated on the basis of solid or liquid volume flowing into the extractor. For solid as basis, we have

$$\text{Area (A)} = \frac{\text{Volume flow rate, Q}}{\text{Velocity (u)}}$$

But volume flow rate, Q = $\frac{\text{Mass flow rate}}{\text{Density/time}}$

$$Q = \frac{\text{Mass flow rate x Time}}{\text{Density}}$$

Therefore, $\frac{Q}{t} = \frac{\text{Mass flow rate}}{\text{Density}} = \frac{1.71m^3}{8400} = 0.0002m^3/sec$

Cross – sectional area, A = $\frac{Q}{u} = \frac{0.0002m^3/s}{0.002m/s} = 0.1m/s$

Radius of extractor can then be calculated from the area.
Now area πr^2

Then $\pi r^2 = 0.1m^2$

$r = \sqrt{\frac{o.1}{3.142}} = 0.18m$

Surface Area of Extractor Unit

This is given by the total area minus allowance for service point

Surface area of Cylinder $2\pi rh$
Area $= 2\pi rh = 2 \times 3.142 \times (0.18) \times 2.4 = 2.71m^2$

Allowances, 1) Area of hopper attachment
2) Area of Orifice for solvent pipe
3) Area of down comer attachment
Assume that the orifice radius is 0.1m
Then for $\pi r_1^2 = 3.142 \times (0.12)^2 = 0.0452m^2$
$\pi r_2^2 = 3.142 \times (0.10)^2 = 0.0314m^2$
$\pi r_3^2 = 3.142 \times (0.12)^2 = 0.0452m^2$
Total allowance, $= 2(0.0452m^2) + 0.0314m^2 = 0.1218m^2$
Therefore surface area of extractor unit $= 2.5882m^2$

Mechanical Design of Launder

The mass flow rate of material in launder = 0.101Kg/s
The volume of grit in the launder = $2.17m^3$
But volume of launder is given by = $2.17m^3$
Unit length of a launder = 2.4m $= 2.4\pi r^2 = 2.17$

$r^2 = \frac{2.17}{\pi 2.4}$; $r = \sqrt{\frac{2.17}{\pi 2.4}} = 0.54m$

We shall multiply this value by a factor of 0.5 to reduce the size to half
Therefore, r = 0.54 x 0.5 = 0.27
$D_i = 0.27 \times 2 = 0.54m$

Observation is that the pressure in cylindrical vessels is a function of size (Diameter). The pressure on down comer of D_i = 240mm is 0.3n/mm^2. Therefore, the pressure on the launder of diameter 540mm should be less than that for down comer. However, the material will be dragged by a screw conveyor up the inclined launder, and hence, the pressure for such drag should be taken into consideration. Therefore we shall multiply the pressure on the launder by a factor of 0.7 ,(assumed). Hence

$$\text{PressureP} = 0.7\frac{\text{Di Launder}}{\text{Di Comer}} \text{ x } 0.3\frac{N}{mm^2} = 0.473N/mm^2$$

Therefore, Launder's working pressure shall be 0.473N/mm^2

Shell Thickness of Launder

The wall thickness is given in [14] as;

$$t = \frac{P_i D_i}{2fj - P_i} + C = 4.6mm \approx 5mm$$

Where the welding factor is taken to be 0.5

Stress on Launder

$$\sigma_1 = \frac{PD}{4t} = 12.771N/mm^2$$

$$\sigma_2 = \frac{PD}{2t} = 25.54N/mm^2$$

Stress due to Weight and Load on Launder [14]

$$\sigma_w = \frac{W_v}{\pi(D_i + t)t}$$

$W_v = 240C_vD_m(H_v + 0.8D_m)t$
$= 240 \text{ x } 1.06 \text{ x } 1.005(2.4 + 0.8 \text{ x } 1.005)0.005$
$= 4.096N$

$$\sigma_w = \frac{4.096}{\pi(540+5)5} = 4.78 \text{ x } 10^{-4}N/mm^2$$

Sump Design

Surface Area: The miscella withdrawn from the extractor is given in table 14, as 12171.6Kg/day. For each run, it is;

$$\frac{12171.6}{3 \text{ x } 3} = 1352.4Kg/run$$

Density of miscella = 0.8363Kg/lit

Therefore volume per run $= \frac{1352.4Kg}{0.8363Kg/l\,it} = 1617.12Li\,t$

The sump is not just a storage tank but a holding vat from which material is continuously withdrawn for transfer to the distillation unit therefore it must contain enough liquid head to ensure a continuous flow.

Now the holding time = 8400sec

Volume flowing into sump per sec $= \frac{1.62m^3}{8400\,sec} = 0.0002m^3/sec$

Assume that the liquid head is 25% of inflow miscella, which means that 75% is continuously being withdrawn, then using the volume flow in per second as basis for design on a radius of 0.15m

Volume of miscella = $\pi r^2 h$ = 0.0002m^3

Height of liquid (h) $= \frac{0.0002}{\pi r^2} = \frac{0.0002}{3.142x(0.1\,5)^2}$
= 0.003m

If we also assume that the vapour space above the liquid is half of liquid level, that is
Vapour space = 0.025m
Then total height h_2 = 0.05 + 0.025 = 0.075m
If the cone base of the sump is 0.05m high,

Then its volume will be

$$\frac{1}{3}\pi r^2 h_C = \frac{1}{3} 3.142 \text{ x } 0.05 \text{ x } (0.15)^2 = 0.00118m^3$$

Circumference of cone $2\pi r$ = 0.942m
Surface area of cone is πrh, where h is slanting height,
3.142 x 0.15 x 0.05m^2 = 0.002357m^2

Surface area of cylinder $2\pi rh$ = 0.0707m^2
Area of cylinder top, πr^2 = 3.142 x $(0.15)^2$ = 0.0707m^2

Total surface area of each sump = 0.0707 + 0.0707 + 0.002357
= 0.1438m^2

But total number of sump is 8
Therefore total surface area of 8 sumps = 8 x 0.1438 = 1.1504m^2

Wall Thickness of Sump

$$t = \frac{P_i D_i}{2fj - P_i} + C = 5.36mm$$

Where P_i = 0.473N/mm^2
D_i = 2r = 0.3m = 300mm
j = 0.1
f = 1.06
C = 1

Estimation of Stress on Sump Cylindrical Section

$$\sigma_1 = \frac{0.473N}{mm^2} x \frac{300}{4 \text{ x } 5} = 7.095N/mm^2$$

$$\sigma_2 = \frac{0.473N}{mm^2} x \frac{300}{2 \text{ x } 5} = 14.2N/mm^2$$

Stress due to Load and Weight on the Sump

$$\sigma_w = \frac{W_v}{\pi(D_i + t)t} = 2.6 \text{ x } 10^{-5}N/mm^2$$

W_v = $240C_vD_m(H_v + 0.8D_m)t$ = 0.124N
Where D_m = $(300 + 5)\ 10^{-3}(m)$ = 0.305m

Down Comer Design

Surface Area

The down comer is a hollow cylinder threaded at both ends for fixing unto the extractor
Radius of down comer = 0.12m
Height of down comer = 0.6m
Surface area of down comer = $0.452m^2$
Number of down comers = 8
a) Total surface area of down comer = 8(0.453) = $3.624m^2$

Wall thickness of Down Comer

$$t = \frac{P_i D_i}{2fj - P_i} + C = 4.44mm, \text{ say, } 5mm$$

Where the working pressure is 3 bar = $0.3N/mm^2$,
D_i = 0.24m = 240mm
C = 1mm

Stress on Down Comer

$$\sigma_1 = \frac{0.3N}{mm^2} x \frac{240}{4 \text{ x } 5} = 3.6N/mm^2$$

$$\sigma_2 = \frac{0.3N}{mm^2} x \frac{240}{2 \text{ x } 5} = 7.2N/mm^2$$

Stress due to Load and Weight on Down Comer

$$\sigma_W = \frac{W_V}{\pi(D_i + t)t}$$

W_v = $240C_vD_m(H_v + 0.8D_m)t$
D_m = $(240 + 7.2)\ 10^{-3}(m)$
= 0.247m
W_v = 240 x 1.06 x 0.247(0.6 + 0.8 x 0.247))0.00744
= 0.373N

Therefore, σ_w of down comer = $\sigma_W = \frac{0.373}{\pi(240 + 7.44)7.44}$
= $6.45N/mm^2$

6. EXTRACTOR ASSESSORIES

Down comer for miscella draining: The second down comer is a pipe for drawing miscella .It is threaded at both ends also for fixing to extractor and sump respectively.
Length of pipe = 0.6m
Total length = 0.6 x 8 = 4.8m
Diameter based on gauge = 0.0334m
Inside diameter of pipe = 0.0266m

Steam pipe: The steam pipes are connected to each extractor from the main steam supply pipe from the boiler.
Length of pipe = 0.3m
Total length = 0.3 x 8 = 2.4m
Diameter = 0.0334m
Inside diameter of pipe = 0.0266m
Total length of steam pipe required = 0.3 x 8 = 2.4m
Saturated steam drain pipe 0.6 x 8 = 4.8m

c) Miscella transfer pipes: the transfer pipes are those through which extractor liquid is transferred from one section to another through stage pumps.
Length of each pipe = 2m
Total length required = 2 x 8 = 16m

Screw conveyor Design

This is a piece of equipment for the transport of solid being leached from section to section until it is discharged. The screw conveyor consists of a motorized shaft bearing perforated helical flights.
Length of each shaft = 2.74m
Pitch of flight = 0.02m
Hole size of perforation = 0.02mm
Surface area of flight is given by, $2\pi r$
Assume the radius to be 0.5m
Then cross – sectional area becomes;
$\pi r^2 = \pi(0.5)^2 = 0.79m^2$

Surface area of screw conveyor , $2\pi rh$ = $2.5882m^2$

Therefore $r = \frac{2.5882}{2 \text{ x } \pi \text{ x } 2.74} = 0.15m$

Area of cross section of screw conveyor is $\pi r^2 = 0.71m^2$
Feed rate to the screw conveyor = 0.101Kg/s

$$= \frac{0.101Kg}{s} \left| \frac{3600s}{hr} \right| \frac{1ton}{907.2Kg} = 0.4008Tons/hr$$

The maximum travel obtained by design = 2.74m

From Perry and Chilton, [16], table 7.6, for a minimum flow rate of 5 tons per hour, of feed material at 15ft (4.6m) travel, the required horsepower is 0.43hp. Since these values are above the calculated values, we have chosen that as the standard in the choice of the hp of electric motor to drive the flight. Therefore a 0.5hp electric motor is chosen to drive the flight.

Pump power

Coulson and Richardson, [14], gave an expression for the power of the sump pump as

$$\text{Power} = \frac{\Delta P Q_p}{\eta_p} \qquad 18$$

Where ΔP - Pressure differential across the pumpN/m^2
Q_p - Flow rate m^3/s
η_p - Pump efficiency, percent
Now Total volume of miscella=1.62+0.00118 = $1.62118m^3$
Total time = 8400 second

$$\text{Flow rate} \quad Q_p = \frac{1.62118m^3}{8400sec}\left|\frac{3600sec}{hr}\right. = 0.72m^3/sec$$

Inlet pressure P_1 = $0.473N/mm^2$

Outlet pressure P_2 = $0.6\ N/mm^2$ (Assumed).

From Fig 10.62, of [14], efficiency, η_p is obtained as 64%
$\Delta P = P_2 - P_1$
$= 0.6 - 0.473 = 0.127N/mm^2 = 127000N/m^2$

$$\text{Hence the power} = \frac{127000N}{m^2}\left|\frac{0.0002m^3}{Sec}\right|\frac{100}{60} = 42.33W.$$

Therefore 42.33 Watt pump is needed for the transfer of miscela.

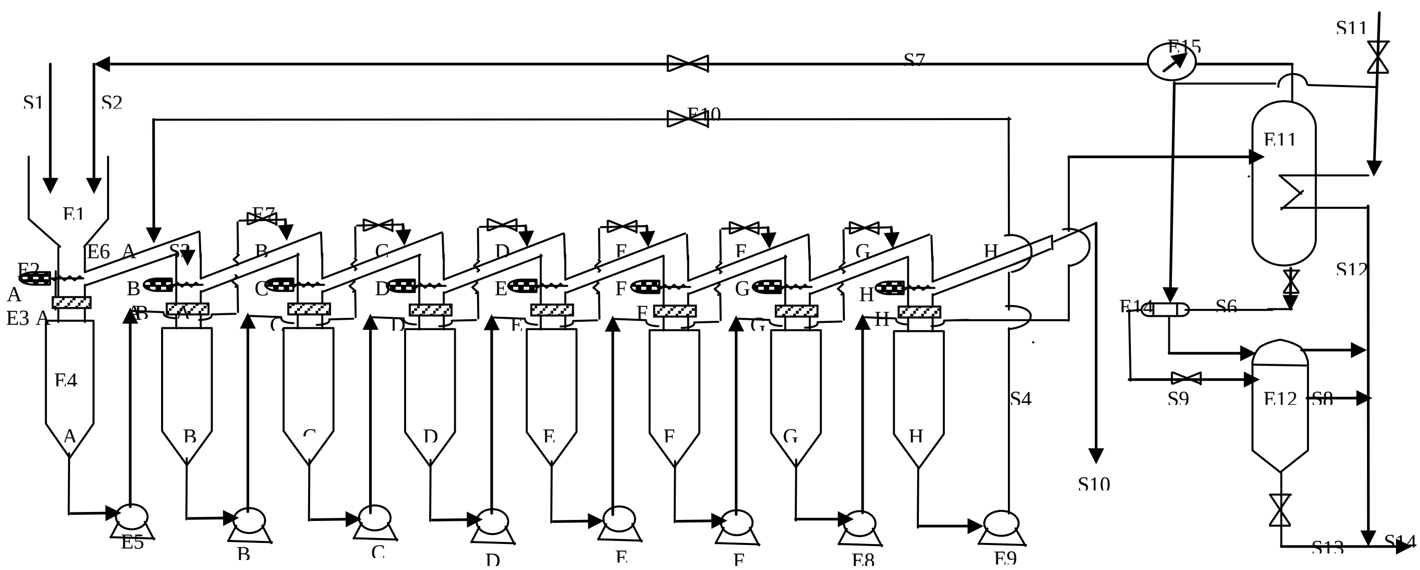

Fig. 1 Flow diagram of a multi – stage intermittent drainage, continuous full immersion, vegetable oil solvent extraction plant.

LEGEND			
E1 – Feed Hopper	E9 – Miscella recycle pump	S1– Seed flakes to hopper	S8– Oil to storage
E2 – Electric motor	E10 – Miscella recycle valve	S2– Solvent	S9– Oil/water from H/E to decanter
E3 – Percolation filter	E11– Distillation column	S3– Meal (seed cake)	S10– Cake discharge to Desolventizer
E4 – (A–H) Miscella sump	E12– Decanter	S4– Miscella recycle	S11– Steam
E5 –(A–F) Miscella Transfer Pump	E13– Condenser	S5– Miscella to still	S12–Water condenser
E6 – Launder	E14– Heat exchanger	S6– Oil and water mixture	S13– Waste water
E7 – Valve	E15– Solvent condenser	S7– Solvent recycle	S14– Sundary water to treatment
E8 – Distiller feed pump			

Table 3 Specification Sheet for extraction plant

Equipment Name : Extraction Launder **Type Of Equipment : Direct Immersion** **Item Number : E_I**	**Number Required : 8** **Designed By : Egbuna S. O.**
OPERATING DATA	
Extraction Medium	Grits or Flakes of PKO
Extraction Solvent	Normal Hexane
Solvent Flow Rate	$2.17m^3/s$
Number Of Stages	8 Stages
Extractor Duty	0.066kg/s
Function Of Extractor	To extract oil from grit or flake
Operating Temperature	340.15K
Operating Pressure	$0.473N/mm^2$
Enthalpy Of Feed Stream	7.925KJ
Enthalpy Of Solvent Feed	8.55KJ
Enthalpy Of Miscella Stream	13.283KJ
Enthalpy Of Raffinate	9.8893KJ
Steam Requirement	0.0322kg
Quality Of Steam	90%
Heat Load	23.1723KJ
MECHAANICAL DATA	
EXTRACTOR HOPPER	
Extractor Hopper Surface Area	$6.802m^2$
Height Of Hopper	2.063m
Wall Thickness Of Hopper	5mm
Stress On Hopper Cylinder	$3.6 N/mm^2$
Stress Due To Weight And Load On Hopper Cylinder	$0.000225 N/mm^2$
HOPPER CONE	
Hopper Cone Thickness	5mm
Stress On Hopper Cone	$25.98 N/mm^2$
Stress Due To Weight And Load On Hopper cone	$7.2 \times 10^{-5} N/mm^2$
LAUNDER	
Launder Surface Area	$2.588m^2$
Launder Height	2.4m
Launder Shell Thickness	5mm
Stress On Launder	$38.311 N/mm^2$
Stress Due To Weight And Load On Launder	$4.78 \times 10^{-4} N/mm^2$
SUMP	
Volume Of Sump	$1.62m^3$
Surface Area Of Each Sump	$0.1438m^2$
Wall Thickness Of Sump	5.36mm
Stress On Sump	$21.30 N/mm^2$
Stress Due To Weight And Load On Sump	$2.588 \times 10^{-5} N/mm^2$
DOWN COMER	
Surface Area Of Down Comer	$0.453m^2$
Working Pressure Of Down Comer	$0.3 N/mm^2$
Wall Thickness Of Down Comer	5mm
Stress On Down Comer	$10.8 N/mm^2$
Stress Due To Weight And Load On Down Comer	$6.45 N/mm^2$

7. COST ESTIMATION

Costs associated with the material of construction for the extractor unit were obtained from the open market. The following information were needed for the material.

Sheet thickness required	=	5mm	=	0.005m
Length of one sheet	=	2440mm	=	2.44m
Width of sheet	=	1220mm	=	1.22m
Area of a sheet	=	$2976800mm^2$	=	$2.9768m^2$
Cost of one sheet metal	=	₦65,000	=	$382.35

Cost / Area 65000/2.9768 = ₦21,835/m^2 = $128.44

Steel Pipe

From table A 16, for properties of steel pipes adopted from Hardison, [17]:
Outside diameter of pipe = 0.0334m
Inside diameter of = 0.027m
Then;

Thickness = 0.0034m
One length of (5.5m) steel pipe = ₦12000($70.59)
(From open market in Nigeria)

1 m will cost = $\frac{N12000}{5.5m}$ = ₦2,182/m($12.84)

1) For hopper design, cost of material
Area of sheet used x Price per m^2 = 6.802m x ₦21,835 = ₦ 148522($873.65)
2) For Launder, cost of material = 2.5882m x ₦21,835 = ₦56513($332.43)
3) For Sump = 1.15m x ₦21,835 = ₦21110($ 124.18)
4) Down comer = 3.624m x ₦21,835 = ₦79130($32.34)
5) Steam pipe = 2.4m x ₦2,182 = ₦5237($30.81)
6) Condensate pipe = 4.8m x ₦2,182 = ₦10,474($61.61)
7) Down comer draining pipe = 4.8m x ₦2,182 = ₦10,474($61.61)
8) Miscella transfer pump = ₦ 8000($47.06)
9) Screw conveyor shaft = 2.74m x ₦25000 = ₦68500($402.94)
10) Screw conveyor flight = ₦ 20000($117.65)
11) Electric motor for flight = ₦ 200,000(1176.47)

Table 4 Bill of Engineering Measurement and Evaluation (BEME), for the Design of an Extractor for Processing 100 Tonnes of Vegetable Oil per day by Solvent Extraction Method

1.0	**CONSTRUCTION OF HOPPER**					
1.1	Sheet metal for construction of Hopper	m^2	54.416	21,835	1,188,173	$6989.20
1.2	Labour for design, construction and installation of Hopper	Man-hour	24 hours	800	19,200	112.94
2.0	**CONSTRUCTION OF HOPPER**					
2.1	Material for construction of Launder	m^2	20.7056	21,835	452,107	2659.45
2.2	Labour for design, construction and installation of Launders	Man-hour	20 hours	800	16000	94.12
3.0	**CONSTRUCTION OF SUMP**					
3.1	Material for construction of sump	m^2	9.2	21,835	200882	1181.66
3.2	Labour for design, construction and installation of sumps	Man-hour	10	800	8000	47.06
4.0	**CONSTRUCTION OF DOWN COMER**					
4.1	Material for construction of Down Comers	m^2	28.992	21,835	633040	3723.76
4.2	Labour for design, construction and installation of Down comers	Man-hour	8	800	6400	37.65
	TRANSFER PUMP					
5.0	Miscella Teransfer pump and installation	Provisional cost	8	-	64,000	376.47
	SCREW CONVEYOR SHAFT					
6.0	Screw Conveyor Shaft and installation	Provisional cost	8	-	68,500	402.94
7.0	**OTHER AUXILLIARIES**					
7.1	Steam Pipe	Meter	6.0	500	3,000	17.65
7.2	Condensate pipe	Meter	8.0	500	4,000	23.53
7.3	Draining pipe	Meter	16.0	500	8,000	47.06
7.4	Pipe installation	Man-hour	10 hours	600	6,000	35.29
7.5	Electrical	Floor area	12months	5000	80,000	470.59
7.6	Civil work	Provisional			200,000	1176.47

7.7	Insullation	Area m^2	$200m^2$	300	60,000	352.94
7.8	Supervisors charge	Man-hour	80 hours	400	32,000	118.24
7.9	Contractor's fee, 6% of TDC				181,038	1064.92
7.10	Contingency fee, 10% of TDC				301,730	1774.64
	GRAND TOTAL				**₦ 3,500,069**	**20,588.64**

1 USD ≈ ₦ 170 in the parallel market

8. CONCLUSION

In this work, a multi stage, intermittent drainage, continuous full immersion vegetable oil, solvent extraction plant for use in vegetable oil extraction has been designed. PKO was used as a case study because it is a simple oil with attributes of those properties of both palm oil and soyabean oil. However the designed extractor is capable of extracting oils from various other oil seeds and nuts. The design is suitable for small scale vegetable oil industries, especially in those sited in the remote and rural areas of the globe. The process and mechanical designs were made on 1.0Kg of material (PKO).However, with suitable scale-up factor, it can be adapted for a large industrial out-fit.

REFERENCES

[1]. 4000year oilKitchen Unearthed in Indiana , Archeo News, January 26,2006, Retieved 30 – 03 – 2014.

[2]. Mahatta, T.L, (1987), Technology of refining Oils and Fats., Small Business Publications, (SSB), Building 4/45, Roop Nagar, Delhi.

[3]. Pahl, G, (2005), Biodiesel growing a new energy economy, White River Junction VT., Chelsea Green Publishing Co.

[4]. Teshajahn, P., and Clifton, E., (1996), Food Analysis, Theory and practice, CBC publishers and Distributors, New Delhi, 575 – 601.

[5]. Iwe, M.O., (2003), The Science and Technology of Soyabean, (Chemistry, Nutrition, Processing and Utilization)., Rejoint Communications Services Ltd. Enugu, Pp1 – 45.

[6]. FAO, (1992), Technology of Production of Edible floarand protein production from Soyabean., Agric Sevices Bulletin, food and Agricultural Organization, Rome, 81: 01 – 63.

[7]. Janet Bachmann, Oil seed Processing for Small Scale Producers., http://www.attra.org/attra - pub/Oil seed.html., Retrieved 11 -10 – 2013.

[8]. "Kalu (Oil presser)", Banglapedia, Retrieved 12 – 11 – 2012.

[9]. Othmer, D.F and Agrawal, J.C. (1955), Extraction of Soyabean Oil, Theory and mechanism, Chemical Engineering progress, 372 – 378.

[10]. Vidke, V.S., and Souslski, F.W., (1988), Mechnism of Oil Expression from Canola. JAOCS, 65 (70), 1169 – 1176.

[11]. Swetman, A.A., and Head, S.W., (1994), Ram Pressing of Niger (noug) seed (Guizotia abyssinica(L) Cass) oil seed Press, No 2.

[12]. Gurnham and Masson, (1975), Industrial Engineering Chemistry, 38, 1309.

[13]. Tray and Bilbe, (1987), Solvent Extraction of Vegetable oils, Chem. Eng. (N.Y), 54, 139.

[14]. Coulson, J.M., and Richardson, J.R., (1993), Chemical Engineering Vol. 6, 1st ed., Butherwort – Heinemann, 724 - 737

[15]. Treybal, R., (1980) Mass Transfer Operations, 3rd ed., McGraw – Hill New York.

[16]. Perry, R.H., C. H Chilton (1973), Chemical Engineering Handbook, 5th ed. McGraw – Hill New York.

`[17]. Hardison B.T (1977), Fluid Mechanics for Technicians, Reston Publishing Company, Reston, Virginia, Pp259-261.