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EQUIPMENT DESIGN FOR PREKESE FUNCTIONAL FRUIT DRINK PROCESSING

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ABSTRACT

The need to design process equipment to produce Tetrapleura tetraptera (prekese) functional fruit drink is necessary in order to meet the needs expressed by customers. These equipment were carefully selected and designed to suit the task each is expected to perform at their various stage functions. The major areas of a process plant needed to produce prekese functional fruit drink have been identified along the production line as fruit preparation, milling, extraction, filtration, evaporation and mixing. The extraction and evaporation unit operations are crucial for obtaining the prekese extract with retained active ingredients needed in the functional fruit drink. This study successfully designed the various equipment needed for the production of prekese functional fruit drink. The equipment design was based on laboratory scale results of producing Prekese functional fruit drink which was operated in a batch mode. The equipment comprised a washer, a cutter, a miller, an extractor, a filter, an evaporator, and a mixer. The equipment were sized and engineering drawings were prepared. Electricity has been identified as the major source of energy to the various unit operations except the evaporator and extractor which are also powered by heat energy. With prekese feed flow rate of 1000 kg/h, the total electrical power requirement was determined to be 88.06 kW and steam power requirement was 55.19 kW. The capacity of the washer, miller, extractor, filter, evaporator and mixer were respectively 56.5 m^3, 1020 kg/h, 7.1 m^3/h, 5.97 m^3/h, 14.13 m^3/h and 10 m^3/h.

Contribution/ Originality: This study documents the design of various equipment needed for the production of *Tetrapleura tetraptera* functional fruit drink. The designed equipment make it possible to process the prekese fruits in order to maintain its antioxidant properties and other health-benefit properties which makes it suitable as a functional fruit drink.

1. INTRODUCTION

Manufacturing equipment usually are large vessels or sections called units or lines that are interconnected by piping or other material or moving equipment which can carry streams of material. Such material streams can include fluids (gas or liquid carried in piping) or sometimes solids or mixtures such as slurries. A chemical plant is an industrial process plant that comprises of various unit operations or equipment that manufactures (or otherwise processes) chemicals, usually on a large scale Ellison-Taylor [1]. Lutz [2] has posited that inherent safety alternatives have become a requirement in companies that understand that, inherently safer equipment have lower lifetime costs and therefore are more profitable.

Industrial equipment for solid–liquid extraction is designed for batch wise, semi continuous or continuous processing [3]. The method of contacting solids with solvent is either by percolation of solvent through a bed of solids or by immersion of the solid in the solvent followed by agitation of the mixture. When immersion is used, counter current, multistage operation is common. With percolation, either a stage wise or a differential contacting device is appropriate. An extractor must be efficient to minimize the need for solvent because of the high cost of solvent recovery [4]. The extraction process may have energy saving possibilities, when solvent recovery is easy as the process can be operated in moderate temperatures and the solvent reused [5]. Some important aspects of extractor selection are costs, availability, chemical stability and nontoxicity of the solvent [6].

In filtration, suspended solid particles in a liquid or gas are removed by passing the mixture through a porous medium that retains particles and passes the clear filtrate [7]. Filtration is performed on screens by gravity or on filters by vacuum, pressure or centrifugation [8]. In cake filtration, the filter medium can be a cloth of natural or artificial fibres or metal [9]. After filtering, the washing of the cake takes place by displacement of the filtrate and by diffusion [7]. Batch filters can be coupled to continuous plant by using several units in parallel, or by providing buffer storage capacity for the feed and product [10]. A guide to filter selection by slurry characteristics is given by Towler and Sinnott [10]. To release the solid particles captured within the bed, the flow is periodically reversed [9].

Evaporators are normally used to produce a concentrated liquid, but a dry solid product can be obtained with some specialized designs [10]. The type of evaporator also affects the overall heat transfer coefficient, being higher with forced circulation than with natural circulation [11]. In long-tube evaporators the liquid flows as a thin film on the walls of long, vertical heated tubes. Both falling film and rising film types are used and are suitable for high capacities and low viscosity solutions [10]. Single-effect evaporators are only used when the capacity needed is small. Multi-effect systems recover and reuse the latent heat of the vaporized material which is lost in a single effect evaporation. In multi-effect evaporator, each effect in itself acts as a single effect evaporator [7]. Multi-effect evaporators may be forward-feed operated, backward-feed operated or parallel-feed operated [9].

The general objective of equipment design is to manufacture the various unit operations needed along the production line of a product to perform their respective stage functions in the production process [12] at a minimum cost, being environmentally benign and user friendly. With the use of rules of thumb and the various design equations as guide, in this study, the various equipment used in the production of the prekese functional food drinks were selected and designed. The major process equipment needed for the production of prekese functional fruit drink have been identified along the production line as washing unit (fruit preparation), milling unit, extraction unit, filtration unit, evaporation and mixing unit. These equipment were carefully selected and designed to suit the task each is expected to perform at their various stage functions.

2. MATERIAL AND METHODS

The equipment design was based on laboratory scale results of producing Prekese functional fruit drink which was operated in a batch mode. The equipment comprised a washer, a cutter, a miller, an extractor, a filter, an evaporator, and a mixer. Material balances and energy requirements were calculated around each unit. The equipment were sized and engineering drawings were prepared.

In the production of the prekese functional food drink, the raw material (prekese fruit) is washed to get rid of dirt. The pulp of the fruit is shredded and sent to the hammer mill for milling. The milled pulp is then mixed with water and a slurry obtained by boiling in an extractor. The slurry is filtered to obtain an extract, which is sent to an evaporator for concentrating into a syrup. The syrup is then diluted in a stirred tank and sugar added to taste. The extraction and evaporation unit operations are crucial for obtaining the prekese extract with retained active ingredients, antioxidants, needed in the functional fruit drink. The block diagram of the processing of prekese functional fruit drink is shown in Figure 1.

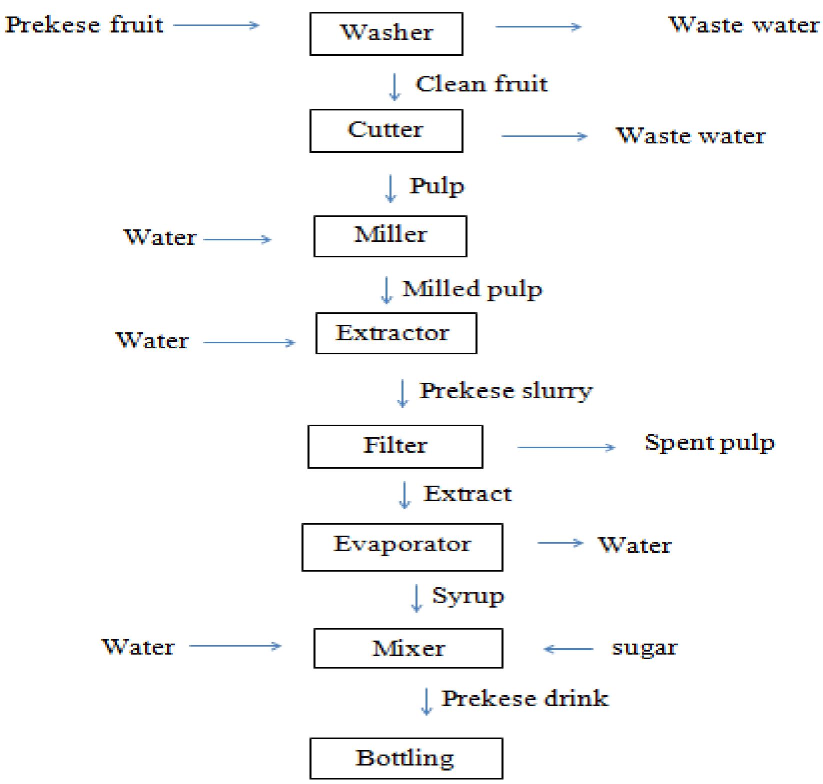


Figure-1. Process block diagram for the processing of prekese fruit drink

3. THEORY AND CALCULATIONS

3.1. Mass Balance Calculations around the Various Units

Figure 2 depicts the mass balance calculations around the milling unit, whilst a summary of mass balances around all the unit equipment is presented in the results (Table 1).

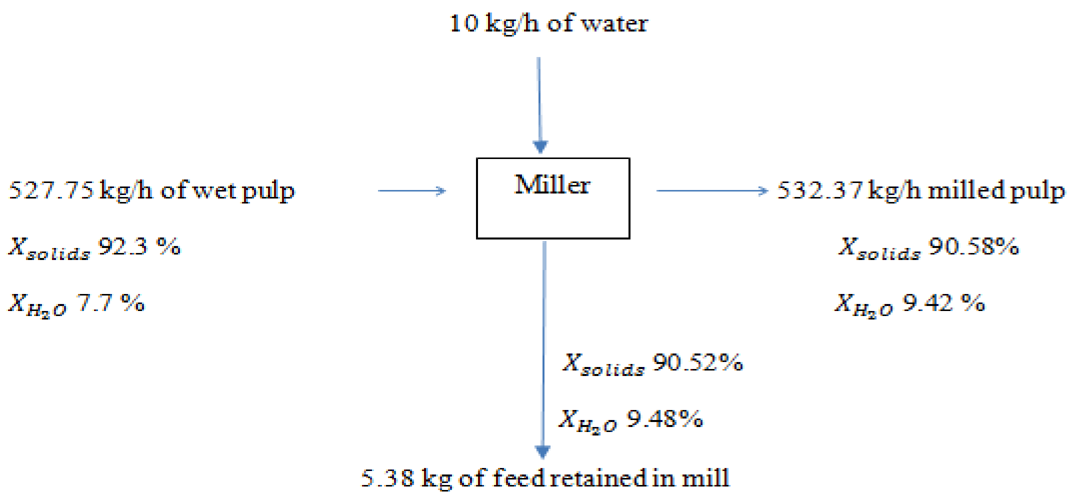


Figure-2. Mass balance around milling unit

Calculation around the miller

Assumption: 1% loss of water and pulp

Pulp component balance

Amount of solids= 0.923(527.75) = 487.11 kg

Amount of solids retained in mill = 0.01(487.11) = 4.87 kg

Water component balance

Amount of water in pulp= 0.077(527.75) = 40.64 kg

Amount of water in feed= 40.64 kg + 10 kg = 50.64 kg/h

Amount of water retained in mill = 0.01(50.64 kg) = 0.51kg

Amount of feed retained in mill= amount of solids retained + amount of water retained

= 4.87 kg + 0.51 kg

= 5.38 kg

Compositions of components in retained feed in mill

X_{solids} and X_{water} represent mass fractions of solids and water respectively

$$X_{solids} = \frac{4.87}{5.38} = 0.9052 = 90.52\%$$

$$X_{water} = \frac{0.51}{5.38} = 0.0948 = 9.48\%$$

Composition of milled feed

solids component balance:

$$527.75(0.923) = 5.38(0.9052) + 532.37(X_{solids})$$

$$487.11 = 4.87 + 532.37X_{solids}$$

$$532.37X_{solids} = 482.24$$

$$X_{solids} = \frac{482.24}{532.37} = 0.9058$$

Hence X_{water}= 1-0.9058= 0.0942

3.2. Energy Requirements by the Various Units

3.2.1. Washer

A turbine agitator is proposed to be employed in the washer to create a turbulent region to aid in the removal of dirt. The specification includes an Impeller speed (N) of 180rpm (3rps) and Agitator diameter (D) of 1m with density of water being 1000 kgm^{-3}. The power number (Np) for a pitch blade turbine impeller is 1.27 (www.fusionfluid.com/fusionfluid equipment LLC/html/impellers_pb turbine.html).

Power, P is calculated using definition of power number:

Power (P) = $Np \times \rho \times N^3 \times D^5$

Where P is the turbine power, N_p is the Power Number, ρ is the density of water, kg/m^3, N is the agitator speed measured in rps, and D is the impeller diameter.

Thus, P = 1.27×1000 kgm^{-3} × (3rps)^{3} × $(1m)^5$ = 34290 W = 34.29 kW

Hence agitator power required to effect some turbulence needed for the washing of the prekese fruit is 34.29 kW.

3.2.2. Miller

A hammer mill is used to shred or crush aggregate material into smaller pieces by repeated blows of little hammers. The basic principle is straight forward: it contains a horizontal or vertical rotating shaft on which hammers are mounted. The hammers are free to swing on the ends of the cross, or fixed to the central rotor. The rotor is spun at a high speed inside the drum while material is fed into the feed hopper. The material is impacted by the hammer and is thereby shredded and expelled through screens in the drum of a selected size. The hammer mill uses air flow to separate small particles from larger ones. Calculating the horsepower of the motor;

$$Hp = \frac{V \times I \times E_{ff}}{746}$$

Where Hp is horsepower, V is voltage, I is Current (amps), E_{ff} is Efficiency

V = 230

I = 10 amps

E_{ff} = 85%

$$Hp = \frac{(230)(10)(0.85)}{746} = 2.62 \text{ Horsepower} = 1.83 \text{ kW}$$

The speed of the shaft motor is calculated as:

$$S = \frac{120 \times F}{P}$$

Where S is speed of motor shaft (in revolution per minute), F is supply frequency (in cycles/sec) and P is number of motor winding poles.

F = 50 Hz; P = 4 winding poles thus, $S = \frac{120 \times 50}{4}$ = 1500 rpm

The braking Torque is calculated as:

$$T = \frac{5252 \times Hp}{S}$$

Where Hp is motor horsepower, and T is full-load torque

Hp = 2.62 horsepower

$$T = \frac{5252 \times 2.62}{1500} = 9.17 \text{ Nm}$$

The Energy required for size reduction is calculated as:

$$\frac{E}{\dot{m}} = C_B\left(\frac{1}{P_1} - \frac{1}{\sqrt{F_1}}\right)$$

Where E is energy required per kg of feed, W_i is work index of feed material, ṁ is mass flow of feed material, P_1 is product size, F_1 is feed size.

$W_i = 11.2$; $\dot{m} = 1020$ kg/h; $P_1 = 0.05$ mm and $F_1 = 1.5$ mm

$C_B = 0.3162\ W_i = 0.3162(11.2) = 3.541$

$$E = \dot{m}\, C_B\left(\frac{1}{\sqrt{P_1}} - \frac{1}{\sqrt{F_1}}\right) = (1020)\,(3.541)\left(\frac{1}{\sqrt{0.05}} - \frac{1}{\sqrt{1.5}}\right) = [3611.82)\,(3.648)] = 13.18\,\frac{KJ}{Kg}$$

Thus, power required $= 13.18\,\frac{KJ}{Kg}$ x 1020 kg/h = 3.73 kW

The volume of the Square Hopper is determined from the equation:

$$V = \frac{1}{3} \times H \times (L_1^2 + L_2^2 + L_1L_2)$$

Where V is volume of the hopper, H is height of the hopper, L_1 is length of upper section L_2 is length of lower section.

$H = 2.4$m; $L_1 = 1.8$ m; $L_2 = 1.3$ m

$$V = \frac{1}{3} \times 2.4 \times [(1.8)^2 + (1.3)^2 + (1.8 \times 1.3)] = \frac{1}{3} \times 2.4 \times (3.24 + 1.69 + 2.34) = 5.816\text{m}^3$$

3.2.3. Extractor

In the extractor, the feed consists of the solute to be extracted and solvent. The principle for the solid-liquid extraction is that the soluble compounds of a solid matter, are extracted by a solvent. The solute diffuses from inside the solid into the surrounding solvent. Either the extracted solid fraction or the insoluble solids, or both, may be valuable products. Leaching is widely used in the metallurgical, natural product, and food industries [4]. In this study, the solvent of choice was saturated steam.

Saturated steam (from Steam Table) has a temperature of 150 °C, specific heat capacity of 1.9857 $kJkg^{-1}K^{-1}$, and a pressure of 1bar. In this study, mass of prekese to extractor is 531.9687 kg/h, at an inlet temperature of 37°C and outlet temperature of 100°C. It is assumed that the specific heat capacity of prekese slurry is the same as that of orange juice which is 3.8 $kJkg^{-1}K^{-1}$.

Rate of heat lost by steam (Q_{steam}) = rate of heat gained by slurry (Q_{slurry})

$$Q_{steam} = Q_{slurry}$$

Rate of heat lost by steam (Q_{steam}) $= (mc_p\ \Delta\ T)_{slurry}$

$$Q_{steam} = 531.9687\ \text{kg/h} \times 3.8\ \text{kJkg}^{-1}\text{K}^{-1} \times (100\text{-}37)\ \text{K} = 127{,}353.31\ \text{kJh}^{-1} = 35.376\ \text{kW}$$

Hence the rate of heat transfer to the extractor is obtained from calculation as 35.376 kW

3.2.4. Filter

The rotary vacuum drum filter is used to filter the slurry. To obtain a formula for sizing a rotary-drum filter, the mechanism of liquid flow through a porous medium is considered. As the filter drum rotates through the slurry tank, a porous solid deposits on the surface of the drum, increasing the resistance to liquid flow. The surface of the filter cake is at atmospheric pressure. If it is assumed that the pressure downstream of the filter medium is constant (created by a vacuum pump), then the pressure drop across the filter cake and medium is constant. As the filter cake thickens, the liquid flow rate decreases because of the increasing resistance to flow. The starting point for deriving a formula to calculate the filtration area is the Kozeny-Carmen equation for flow through porous media [13]. The flow, which is laminar, follows a path through the cake. The Kozeny-Carmen equation, for a differential cake thickness, is

$$-(dP/dx) = [4.17s^2\mu v_s(1-\varepsilon)^2] / \varepsilon^2 \qquad \text{(i)}$$

where P is the pressure at any point in the cake, x is cake thickness, ε is the specific surface (surface area per unit volume of particle), μ is the liquid viscosity, v_s, is the superficial liquid velocity, and s, is the porosity of the cake [13]. The differential mass of dry cake, dm, is given by

$$dm = (1-\varepsilon)\,\rho_s\,A_F\,dx \qquad \text{(ii)}$$

where dm is the differential amount of dry cake in a layer of thickness *dx* and the volume fraction of solids in the wet cake is (1 - ε).

From equations i and ii,

$$-dP/dm = ks^2\mu v_s(1-\varepsilon) / \rho_s\,\varepsilon^2\,A_F \qquad \text{(iii)}$$

Specific resistance, α is defined as

$$\alpha = ks^2(1-\varepsilon) / \rho_s\,\varepsilon^2 \qquad \text{(iv)}$$

The rotary-drum filter is to filter 20 m^3/h of a prekese extract at 20 °C. The pressure drop across the cake is 9.541 psi. The slurry contains 0.15 mass fraction of prekese fruit, and the filter cake contains 0.40 mass fraction of water. Water density is 998.3 kg/m^3 and its viscosity (20 °C) is 0.001 Pa-s (1 cp). Prekese density is 2709 kg/m^3, thus, average density of the slurry,

$\rho = 0.85\,(998.3) + 0.15\,(2709) = 1255\ kg/m^3$

Mass Balance Equations:

$$y_{1,1}\,\rho_1\,V_1 = y_{c,1}\,m_c + \rho_2\,V_2 \qquad \text{(1)}$$

$$y_{1,2}\,\rho_1\,V_1 = y_{c,2}\,m_c \qquad \text{(2)}$$

$$y_{1,1} + y_{1,2} = 1 \qquad \text{(3)}$$

$$y_{c,1} + y_{c,2} = 1 \qquad \text{(4)}$$

For the first subscript, 1 represents entering stream and 2 represents the leaving stream. For the second subscript, 1 represents liquid, and 2 represents solid, and c represents wet cake.

Rate Equation:

$$A_F^2 = [(1-n)\alpha\mu(c_{1,2})(V_F^2)] / [2t_F(P_o - P_V)] \qquad \text{(5)}$$

$$A_F = fA_T \qquad \text{(6)}$$

Where α is the specific resistance, μ is the liquid viscosity and $P_o - P_v$ is pressure drop.

System Properties:

$$\rho_1 = y_{1,1}\,\rho_{1,1} + y_{1,2}\,\rho_{1,2} \qquad \text{(7)}$$

$$c_{1.2} = y_{1,2}\,\rho_1 \qquad \text{(8)}$$

$$\alpha = \alpha_o(P_o - P_v)^n \qquad \text{(9)}$$

n, usually varies from 0.2 to 0.8. If n = 0, the cake is incompressible.

From Equation 3, $y_{1,1} = 0.85$, and from Equation 7 the average density of the slurry,

ρ = 0.85 (998.3) + 0.15 (2709) = 1255 kg/m^3

Equation 4 gives $y_{c,2}$ = 0.60. The formation rate of wet cake, m_c, can now be calculated from Equation 2. Thus, m_c = (0.15/0.6) x 1255 kg/m^3 x 20m^3/h = 6.275 x 10^3 kg/h

From (1) volumetric flow rate of filtrate V_2 = (21340 – 2510) / 998.3 = 18.86 m^3/h

Assume α_o = 1.604x10^{10} and n = 0.2664

The pressure at the interface of the filter cake and filter medium, Pj, is assumed to be equal to the pressure downstream of the filter medium, Pv. Therefore, P_0 - Pv = 0.658 bar or 6.58xl0^4 Pa for filtering a prekese slurry. Therefore, α = 1.604xl0^{10} (0.658)$^{0.2664}$ = 1.435xl0^{10} m/kg

The cycle time for filtering prekese slurry is erstimated to be 5 min. Since the drum is only partially submerged (37.5%), the filtering time, t_f = 0.375 x 5 x 60 = 112.5 s.

The volume of filtrate collected, V_F = V_2 t_f = 0.5894 m^3

From (8) concentration of solids in entering stream $c_{1,2}$ = 0.15(1255) = 188.3 kg/m^3

Finally, the filter area A_F = (1-0.2664)/2(115.5) s x 1.435x10^{10} m/kg x 0.001/6.58x10^4 Pa-s/Pa x 188.3kg/m^3 x 0.5894^2 m^6 = 6.731 m^2

Now, from (6) the drum area, A_T = 6.731/0.375 = 17.95 m^2

With a safety factor of 29.5%, a surface area of approximately 23.22 m^2 is obtained for the filter. From rule of thumb, a sized filter of 23.22 m^2 surface area will require 11.18 kW and 22.37 kW to power the drum drive and agitator drive respectively [13]. This filter with a roll discharge, has a size diameter of 3.05m and a nominal length of 2.44m as also shown by Silla [13].

3.2.5. Evaporator

Agitated thin film evaporators (ATFE) which have short residence times and relatively high heat transfer coefficients, are best used for concentrating foods that are heat sensitive and cannot tolerate high temperatures [14].

The specific heat capacity of prekese extract is assumed to be the same as that of orange juice

$Cp_{orange\ juice} = Cp_{prekese\ extract}$ = 3.8 kJ kg^{-1}K^{-1} and the overall heat transfer coefficient

(U) = 6000 Jm^{-2}s^{-1} ^{o}C^{-1}.

Inlet temperature of extract (t1) = 50 ^{o}C and Outlet temperature of syrup (t2) = 70 ^{o}C.

Steam inlet temperature (T1) = 95 ^{0}C and Steam outlet temperature (T2) = 70 ^{o}C

From design equation of evaporators, rate of heat transfer is given as: Q = UAΔT_m

Rate of heat lost by steam (Q_{steam}) = rate of heat gained by extract ($Q_{extract}$)

$$Q_{steam} = Q_{extract}$$

Rate of heat lost by steam (Q_{steam}) = $(mc_p\ \Delta\ \text{T})_{extract}$

Where m = mass of prekese infusion, C_p = specific heat capacity of prekese extract and

ΔT = change in temperature of prekese extract.

Hence;

Q = 939.14 kg/h ×3.8 kJ/kg K× (70-50) K=71374.64 kJh^{-1} = 71374.64 kJh^{-1} = 19826.29 J/s.

In calculating the log mean time temperature difference (ΔT_m), it is important to note that counter current flow was used to maximize the chance of achieving high heat transfer coefficient. Hence, in counter flow the inlet temperature of the feed to the unit and the exist temperature of steam are found at the same stream, this can be denoted as $\Delta T1$ whiles the exit stream comprise of the steam inlet temperature and the feed outlet temperature, denoted as $\Delta T2$. This could be expressed as:

$\Delta T1$ = steam outlet temperature (T_2) - feed inlet temperature (t_1)

ΔT2 = steam inlet temperature (T_1) - feed outlet temperature (t_2)

$$\Delta T_m = \frac{\Delta T1 - \Delta T2}{In(\Delta T1/\Delta T2)}$$

ΔT1=70-50=20 K

ΔT2=95-70=25 K

$$\Delta T_m = \frac{20-25}{In(20/25)} = \frac{-5}{-0.2231435513} = 22.41^{o}K$$

From design equation the area of the cylinder can be calculated using;

$$A = \frac{Q}{U\Delta T_m} = \frac{19826.29 JS^{-1}}{6000 JS^{-1}m^{-2}K^{-1} \times 22.41k} = 0.147m^2$$

A = 0.147m^2

Thus, the heat transfer area is 0.147 m^2.

For a rate of heat transfer at 1bar and 0°C - 800°C, specific heat capacity of steam is 4.2106$kJkg^{-1}K^{-1}$

Hence amount of steam required (m_{steam})

$$= \frac{Q_{steam}}{Cp_{steam}\,\Delta T_{steam}} = \frac{19810.065 Js^{-1}}{4.2106 KJ Kg^{-1}K^{-1} \times (95-70)K} = 0.188 kgs^{-1}$$

$m_{steam} = 0.188kgs^{-1}$ = 676.8$kg□^{-1}$

The shaft power required to drive an agitator can be estimated using the following equation

$$Np = powernumber = \frac{P}{D^5 N^3 \rho}$$

Where P is shaft power, N_p is power number, ρ is density of liquid, N is agitator speed and D is impeller diameter.

N = 1200 rpm

D = 1 m

ρ = 1.42 kgm^{-3}

Power number data for different type of impellers/turbines, under a given set of conditions are documented in various technical literature. In this study, a power number of 1.27 for a pitch blade turbine impeller is used.

Thus, P = 1.27×1.42 kgm^{-3} × $(20\ rps)^3$ ×$(1m)^5$ = 14427.2 W = 14.43 kW

Since the evaporator is in a cylindrical form, its volume is estimated from the formula of a cylinder:

$V = \pi \times r^2 \times h$,

where r and h represent radius and height of evaporator respectively. The height and diameter of the evaporator are chosen to be 4.5 and 2 m respectively [15].

Thus, volume (V) = 3.14 × $(1)^2$ × 4.5 = 14.13 m^3.

3.2.6. Mixer

In estimating the energy requirements of the mixer the focus is mainly on the power consumption of the agitator. The shaft power required to drive an agitator can therefore be estimated using the following generalised dimensionless equation:

$$Np = power\ number = \frac{P}{(D^5)(N^3)(\rho)}$$

Where P is shaft power, ρ is fluid density, N is agitator speed, and D is agitator diameter.

In this study, the fluid density is 1.42 kg/m^3. The agitator is estimated to have a diameter of 0.96 m and a speed of 5 rps, with a power number of 1.6. Thus;

$$Np = 1.6 = \frac{P}{(0.96^5)(5^3)(1.42)}$$

Therefore, P = 231.56 W = 0.231 kW

4. RESULTS AND DISCUSSIONS

A summary of the overall mass balance and power requirement around the various unit equipment are shown in Table 1 and Table 2 respectively.

Table-1. Summary of material balance

Equipment	Inputs (kg/h)					Outputs (kg/h)							
	Water	Prekese	Pulp	Extract	Sugar	Waste water	Washed Prekese	Pulp	Wood	Loss	Extract	Vapour	Drink
Washer	4000	1000				3980	1020						
Cutter		1020						528	492				
Miller	10		528					532		6			
Extractor	532		532								1064		
Filter				1065				126			939		
Evaporator				939							552	387	
Mixer (m^3)	33.24			0.35	0.39								33.98

Table-2. Summary of power requirement

Equipment	Power required (kW	
	Electricity	Saturated steam
Washer	34.29	
Miller	5.56	
Extractor		35.38
Filter	33.55	
Evaporator agitator	14.43	
Evaporator steam		19.81
Mixer	0.23	
Total power required	88.06	55.19

4.1. Design Specifications of Washer

Vertical agitation combines the natural cleaning power of water with the hydrokinetic energy developed when parts are agitated. The agitation produces a natural hydraulic purging action that forces solution between parts and in and out of cavities providing the highest degree of fluid exchange for the fastest cleaning. This makes the agitating parts washer ideal for cleaning parts with complex shaped geometries like prekese fruits. The specifications for agitated immersion washer is depicted in Table 3.

Table-3. Agitated immersion washer specifications

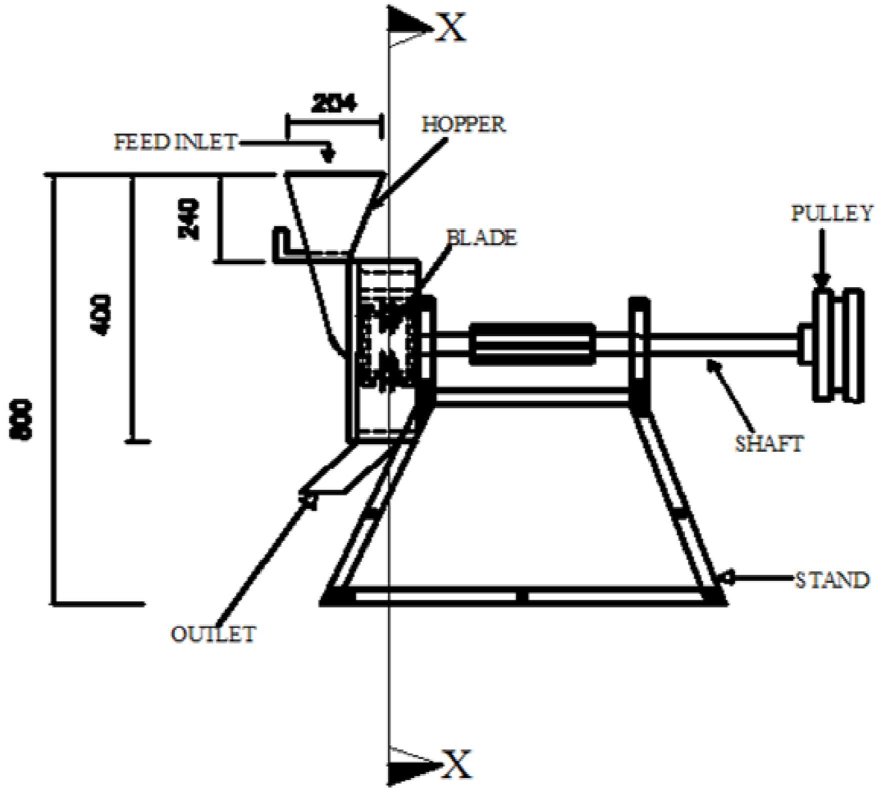
Parameters	Specifications
Vessel capacity (m^3)	56.5
Agitator speed (rpm)	180
Agitator diameter (m)	1
Vessel diameter (m)	4
Height (m)	4.5
Agitator power requirement(kw)	34.29

4.2. Design Specifications of Hammer Mill

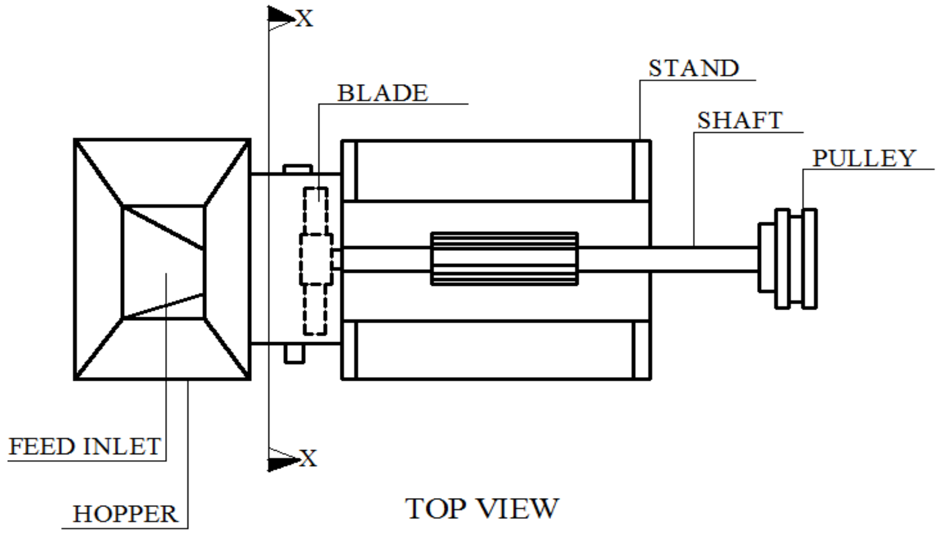
Table 4 depicts a summary of the mill characteristics derived from calculations. The engineering drawing of a hammer mill is shown in figure18. In the milling unit the power of the motor was arrived at from calculation as 2.62 hp and the diameter of the grinding chamber also arrived at as 90 mm whiles the energy need to crush a kilogram of feed obtain as 13.18 kJ/kg and the volume and height of the hopper were obtained as 5.816m^3 and 2.4m respectively. The engineering drawing of a hammer mill is shown in Figure 3.

Table-4. Hammer Mill specification

Parameters	Specifications
Power of motor (hp)	2.62
Rotor speed (rpm)	1300
Number of blades	8
Dimension of blade (mm)	910 × 240×460
Capacity (kg/h)	1020
Diameter of grinding chamber (mm)	254
Energy input (kJ/kg)	13.18
Shaft speed (rpm)	1500



a) Cross sectional view



b) Top view

Figure-3. Hammer mill

4.3. Design Specifications of Extractor

Various extractors are available for solid-liquid extraction. Selection of equipment is affected by various factors including flow rate, residence time, number of stages, cost, and viscosity. The kettle brew extractor was selected in this study and the design specifications were based on various design equations. Table 5 shows the specifications of the kettle brew extractor.

Table-5. Kettle Brew Extractor specifications

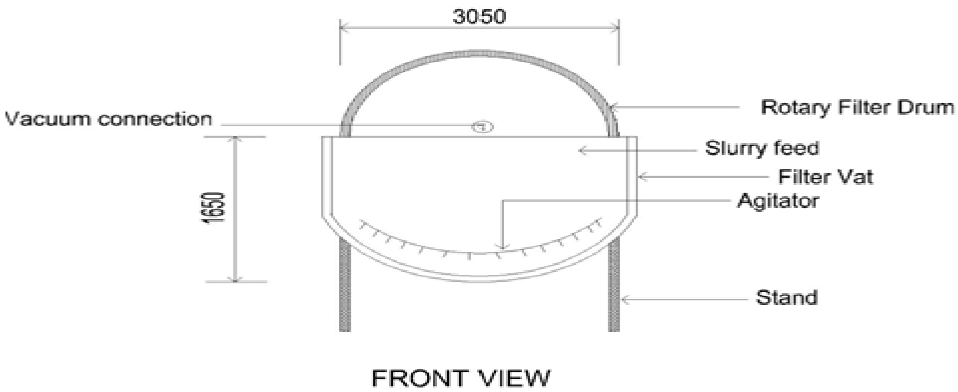
Parameter	Specifications
Rate of heat transfer (kW)	35.38
Capacity (m^3)	7.1
Height	1
Steam pressure (bar)	1
Steam temperature (^{o} C)	150
Diameter (m)	3
Area (m)	23.6

4.4. Design Specifications of Filter

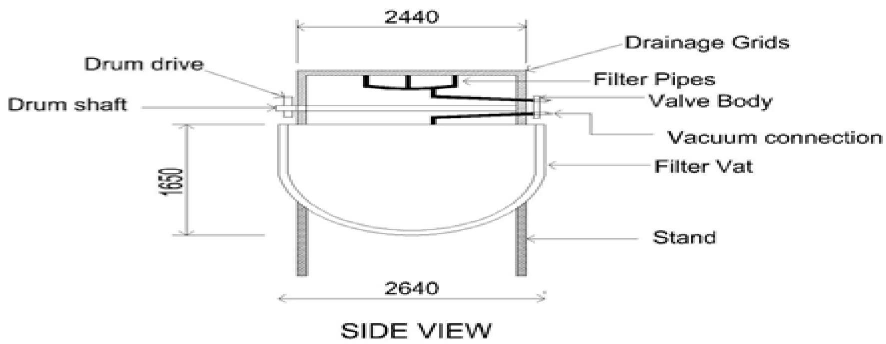
For the design of filters, it is necessary to establish a filtration time (the time between filling the filter to the time at which it proceeds to download the cakes). In this work, a filtration time of 5 minutes was proposed. At this time, the rotary-drum filter is to filter 20 m^3/h of prekese extract at 20 °C. Accordingly, from the calculations, the designed capacity is 5.9 m^3 with a height of 1.32 m and area of 19 m^3 (Table 6). Engineering drawing of the rotary drum vacuum filter is shown in Fig 4.

Table-6. Rotary vacuum drum filter specification

Parameter	Specification
Drum drive (kW)	11.18
Agitator drive (kW)	22.37
Height (m)	1.32
Capacity (m^3)	5.97
Drum diameter (m)	2.4
Area (m^3)	19



a. Front view



b. Side view

Figure-4. Engineering drawing of filter drum (dimensions in mm).

4.5. Design Specifications of Evaporator

Due to the intensive mixing action within the bow wave, temperature sensitive products are prevented from over-heating and fouling on the heat transfer surface can be reduced or eliminated. Agitated Thin Film Evaporators are designed with a cylindrical shape and with an internal rotor that is used to spread a thin layer of liquid film on the inner side of a metallic wall, while a utility stream (e.g. steam or hot oil) provides heat flowing in the external jacket [16-18]. The mixing in the liquid phase is assured by the blades that during their rotation produce a thin-film and a bow wave in front of the blade where the excess liquid is directed and mixed. ATFE are widely used in the food [19, 20] pharmaceutical and bio-based industry as concentrators and separators [14] due to their short residence times and relatively high heat transfer coefficients. From the calculations in this study, the volume of the evaporating vessel was obtained as 14.13m^3 (Table 7). From calculation the power needed to power the agitator was obtained as 19.35 horse power, hence the agitated thin-film evaporator should have a diameter of 2 m and it should have a volume of 14.13 m^3 to be able to process 939.14 kgh^{-1} of the prekese extract into a syrup of viscosity 330-2400 cP. The engineering drawing of the evaporator is shown in Figure 5.

Table-7. Evaporator Specification

Agitated thin-film evaporator	Specifications
Rotor speed (rpm)	1200
Vessel capacity (m^3)	14.13
Evaporator diameter (m)	2
Agitator height (m)	4.5
Impeller diameter (m)	1
Agitator power (kW)	14.43

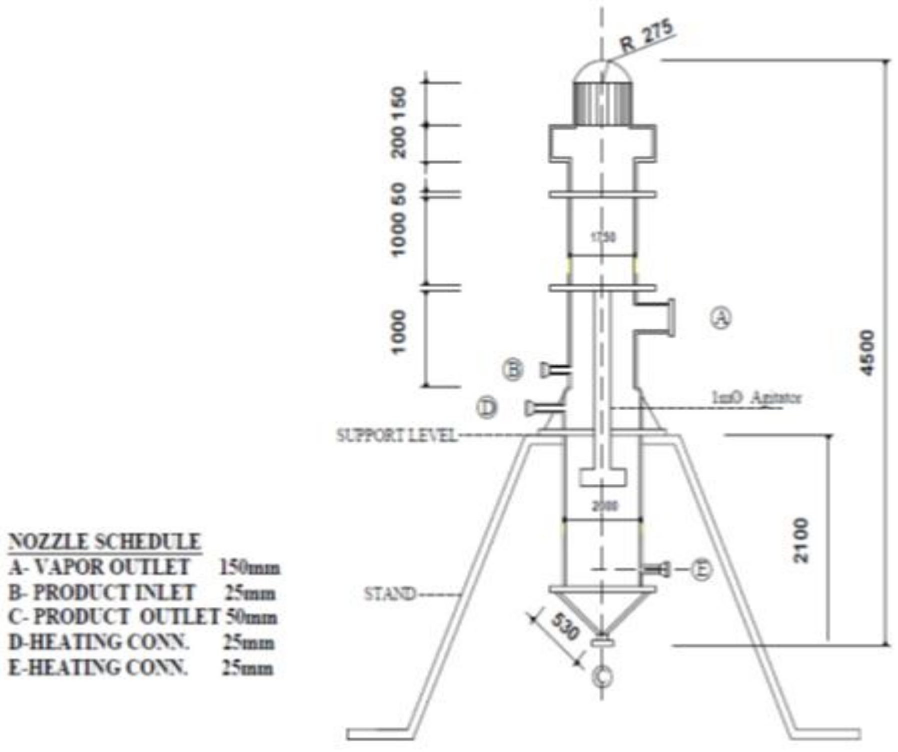


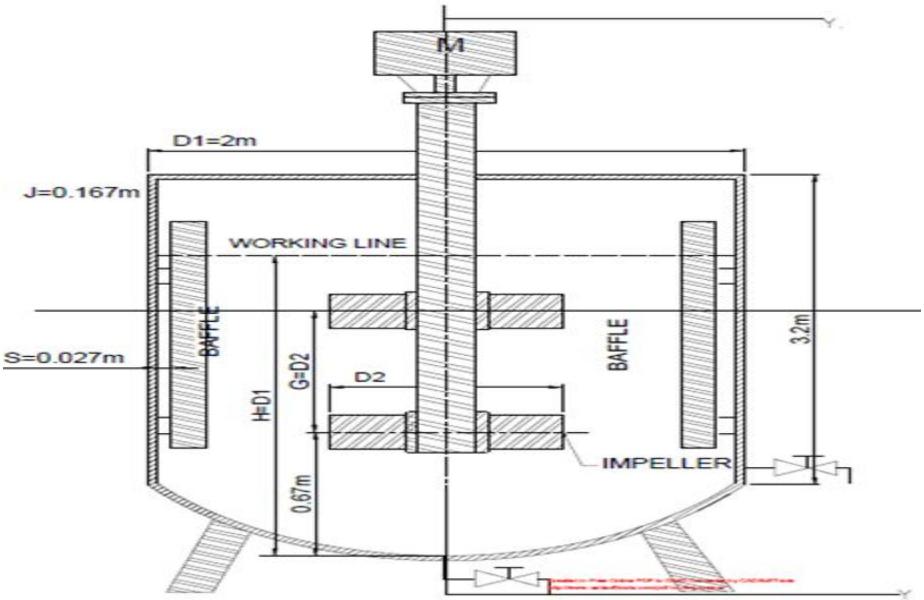
Figure-5. Cross sectional view vertical agitated thin-film evaporator

4.6. Design Specifications of Mixer

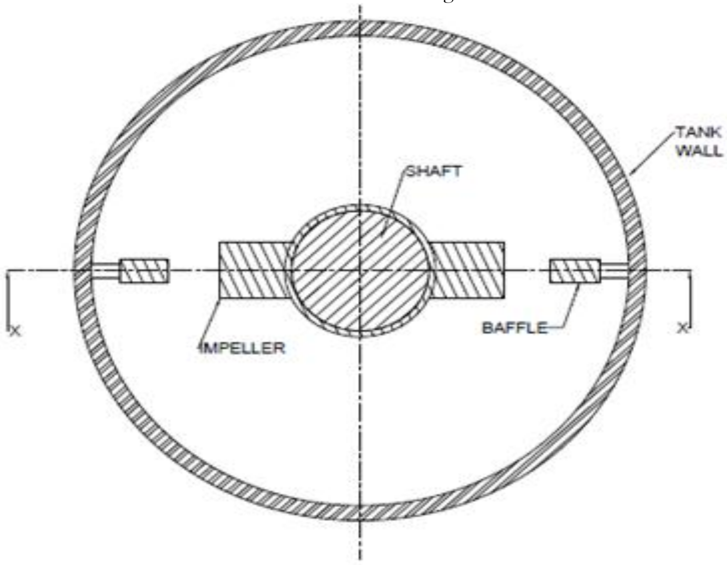
Mixing is generally helpful for intensification of mass and heat transfer [18]. From the design calculations the volume of the mixing tank was obtained as 10m^3 and the diameter of the mixing tank 2m and height 3.2m and the agitator power was obtained as 0.231 kW (Table 8). The Engineering drawing of mixer is shown in Figure 6.

Table-8. Design specifications of a mixer

4-Picthed blade mixer	**Specifications**
Rotor speed (r_{pm})	300
Number of blades	4
Vessel capacity (m^3/hr)	10
Tank diameter (m)	2.0
Tank height (m)	3.2
Impeller diameter (m)	0.96
Baffle width (m)	0.167
Baffle clearance (m)	0.027
Agitator power (kW)	0.231



a. Side view of the mixing tank



b. Top view of the mixing vessel

Figure-6. Engineering drawing of mixer

5. CONCLUSION

This study proposes the various designed equipment, needed for the production of prekese functional fruit drink. The designed unit equipment makes it possible to process the prekese fruits in order to maintain its antioxidant properties and other health-benefit properties which makes it suitable as a functional fruit drink. The equipment comprised a washer, a cutter, a miller, an extractor, a filter, an evaporator, and a mixer. The equipment had been sized and engineering drawings prepared. Electricity had been identified as the major source of energy to the various unit operations except the evaporator and extractor which are also powered by heat energy. With prekese feed flow rate of 1000 kg/h, the total electrical power requirement was determined to be 88.06 kW and steam power requirement was 55.19 kW. The capacity of the washer, miller, extractor, filter, evaporator and mixer were respectively 56.5 m^3, 1020 kg/h, 7.1 m^3/h, 5.97 m^3/h, 14.13 m^3/h and 10 m^3/h.

6. RECOMMENDATION

Validation of the designed equipment could be carried out and where necessary, modifications made. The designed equipment provide useful means for value addition to *Tetrapleura tetraptera* (Prekese) fruit and up-scaling of the functional fruit drink processing, which is encouraged to be pursued.

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