DESIGN AND CONSTRUCTION OF SOYBEAN GRINDER/MILK EXTRACTOR

BY

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A project report in the Department of Agricultural Engineering submitted to the school of postgraduate studies in partial fulfillment of the requirements for the award of post-graduate diploma (P.G.D) in food processing and storage of the Federal University of Technology (FUT) Minna, Nigeria.

CERTIFICATION

This thesis has been read and approved as meeting the requirement of the department of agricultural Engineering, Federal University of Technology (FUT) Minna for the award of post graduate diploma (P.G.P) in food processing and storage.

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DEDICATION

To my loving mother, wife and daughters – Alheri, Kauna, Dlama and Hetüwa.

ACKNOWLEDGEMENT

would like to express my sincere thanks to the following:

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ABSTRACT

A 200 litre per day prototype soybean grinder/milk extractor was developed to grind soybean and extract milk in a single process at Federal University of Technology Minna. The equipment is basically made up of a hopper, outer and inner can, feed pipe, grinding discs, filter, frame and electric motor. The equipment was designed and materials to fabricate it were locally sourced. Fabrication of the equipment was done locally. The efficiency was approximately 64%.

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CHAPTER ONE

1.0 INTRODUCTION

Soybean milk, a product obtained from processing soybean is a refreshing and nutritious drink National Research Institute (1988), Agriculture Extension Research and Liason Department Badeggi, assert that soybean milk protein is better than other protein source because no goitrogenic properties have been discovered to be associated with it so far. Thus it is even recommended for infant who are allegic to cow milk.

The crop (Soybean) itself was believed to have been introduced to Nigeria in 1908. National Cereal Research Institute (NCRI 1988) also indicated that most of the early agronomic research on the crop was carried out at Moor plantation, Ibadan. Success in the introduction of the crop in Nigeria is indicated by the astronomical increase in the production capacity from 50,000 metric tones in 1970 to 107,000 metric tones in 1987. Benue state account for the highest production. On the utilization of the crop, Soybean milk is among the various products of soybean, but its processing method in Nigeria is wholly traditional.

National Cereals Research Institute Badeggi (NCRI, 1988) described the traditional or home – scale method. It involves grinding of cleaned and dehulled soybean seed before mixing thoroughly with water. The mixture is then starined with muslin cloth and the filtrate is boiled for 15 – 20 minutes. Sugar and flavour such as vanilla, cocoa powder or any other favourite flavouring agent is added to taste and stored in the refrigerator, it is observed that the operation is time consuming, cumbersome and imposes drudgery on the processor, in order to alliviate these problems this project is aimed at design and construct a machine to grind and strain Soya milk from its paste respectively to produce the milk.

1.1 USES OF SOYABEANS

1. Though, a relatively new crop in Africa home utilization of soybean have been greatly diversified. Soybean can be consumed as a drink, solid food and cooking oil or used as animal feed. Products of soybean processing include soy flour, soymilk, soy cake, soy biscuit, soy oil, soy ogi, soy moin-moin, soy eba.

1.2 HISTORY OF SOYBEAN PRODUCTION

The early history of soybean, like that of most food crops is lost obscurity. However, ancient Chinese literature reveals that the soybean was extensively cultivated & of highly valued as a food crop centuries before written records were kept, it is believed to have been derived from a twinning slender plant glycine ussureieusis (1) growing wild in south east Asia (singh & e tal. 1987) the first written record of this plant appears in material medica, "The Heavenly Farmer" written by the Chinese Emperior Sheng – Nung in 2838 BC. It was the most important cultivated legume and one of the five most sacred grains (soybean, nice, wheat barley and millet, essential to the existence of Chinese civilization. Confucius, the great Chinese philosoper called the plant "Shu" and in ancient Chinese literature it is referred to as 'SOU' from which the present day 'SOY' in soybean seems to have been derived. It is also called Chinese pea (IITA, 1989) or Manchurian bean became of its Eastern Asia origin. Since its spread to other parts of the world, soybean have become more popular.

From China the crop spread to neigbouring Asia countries: Korea, Japan and remained confined to Asia as a cultivated crop. When the German botanust englebest kachipter visited Japan in 1961 and published his book Amoenitatum Exoticum (1), Europeans started appreciating the importance of soybeans to Eastern diets. In US literature soybeans was first mentioned in 1804 when it was grown mainly as a forage and pasture crop until the early part of the 20th century when it was commercialized. Though introduced in Brazil in 1882, it took about 100 years to become an important crop (1).

Soybeans are the most important Agricultural export cash crop in most countries of the world. For instance soybeans contribute more protein and oil to the United States food economy than any other. Its high protein level makes it valuable for human consumption. The bean yields valuable oil and by – products in form of cake used for fertilizer and animal meal. The uses to which the oil is put appears limitless. Principally, the oil is used in parts, vanishes, lacquers and enamels in the manufacture of linoleums, oil cloths and, other water – proof goods, rubber substitute, printing, lubricant and core oil in foundry operations. There is a very great demand for the oil in the soap-making industry in America. The soybean plant is very versatile as a raw material for numerous fresh fermented and dried products. The roots are often dug and dried for fuel. The leaves, stalks, pods and other refuse are used for feeding cattle.

1.3 THE LOCAL METHOD OF PROCESSING SOY MILK:

This is done using two methods:- Wet and Dry.

(a) Wet process – The beans are separated from Foreign material (whole beans are used), and the soaked overnight (usually for 24hrs). Some people use local tenderizer in soaking (i.e potash or kanwa) there after wet milling finally simmering. It is apparent that various combinations of the above procedure could lead to soymilk with various qualities. For instance the viscosity will depend on the size of the filter cloth used.

(b) The dry process – The hole beans are first separated from foreign material and thereafter boiled for several hour until they are well cooked. The beans are then cooked and the water drained. The coats are removed by floatation and the beans dried under atmospheric condition, the dried beans are finally ground using a mill. The powder obtained is sieved through a suitable sieve to obtained a fine powder that can store for several months limitations of the local wet process – the method is prone to waste due to inefficient and consequent poor filtration most importantly there is the problem of low protein content and an object unable beany odour. Another problem is that of storage the milk can not last more than 12 hours without refridgeration.

1.4 SOYAMILK PROCESSING

Soymilk is an aqueous extract of soybean. It is white in colour and has almost identical properties with cow milk.

The process of soymilk production is in three stages: namely, soaking, grinding to slurry and filtration. The traditional Chinese method involves soaking overnight, grinding to slurry on local millstone and finally filtration.

1.5 OBJECTIVE OF THE PROJECT

The objectives of the project are:

- ✓ To design, fabricate and test a grinder/centrifuge for grinding soaked dehulled soybeans and filter the soymilk at the same time from paste; which is portable, aesthetically attractive and simple to operate.
- ✓ To carry our technical and economic evaluation of the machine.

1.6 JUSTIFICATION OF THE PROJECT

The complete execution of the project will help farmers in the following ways:

- Eliminate drudgery associated with the manual methods.
- Reduce labour cost associated with the manual methods.
- Increase productivity and utilization.
- Provide efficient and hygienic technique than the traditional method.

CHAPTER TWO

LITERATURE REVIEW

Several scholars of Agricultural/Engineering profession have conducted research in area of designing and constructing of machines that are suitable for soyabean milk production so as to reduce the drudgery connected with the traditional methods and increase the quality and of soya milk production to meet increase market demand for the production. These scholars have experienced various results and problems and non- have come up with efficient portable and continuous flow soymilk production machine. All these machines developed operate in batch system and not economical to own for house hold use.

Previous work on soymilk production have been centered on the unit process of filtration, grinding separately in batches. Previous work on soymilk production have been centred on the unit process of filteration. A horizontal filtered press for soymilk was designed and constructed.

The press used a power screw and in corporately a system of gear for speed reduction as processing require & and very low speed to protect the filter cloth against pressure build up.

The machine is engine powered however, the machine is quite bulky, and heavy need experts installation and operation, and was quite costly to construct the machine is presently at International Institute of Tropical Agricultural (IITA). Ibadan soybean processing department.

Professor Babatunde supervised the design and construction of a manually operated soymilk filter press by a master degree student at the University of Ibadan. The screw press is vertical, uterlizing a power screw above, and a hydraulic jack at the bottom. The press was easier to maintain, less bulky, higher and cheaper than Oye's. However, it was still heavy, bulk, expensive and not easy to operate. Also the press plate used bends upwards at the edges due to the pressure of the pressing.

Gbabo (1991) constructed a prototype centrifuge to separate sugar crystal and palm oil at his Master degree project. But without grinder. And is a batch system, this attempt could not solve the problem of soymilk production Hassana (2000) evaluated performance and modified a soymilk filter press in the department of Agricultural Engineering Federal University of Technology, Minna.

The system built operate is separate grinding of the soaked bean and separate filtration using a press. And the grinder adopted is the traditional vertical type. This system is not in built, it is labourious and stand the risk of hygiene because of grinding separately and later transfer production to another machine press for filtration of milk which is not economical. In view of the problems associated with existing machines described above Banseka (1998) optimized the filter press by solving some of the problems enumerated, mechanizing the unit process of filtration through the design of machine that effectively and efficiently filtered soymilk from soybean mash and the machine constructed and simple, easy to operate and maintain and economically available to rural dwellers.

This project combines milling and filtration operations.

2.1 WET MILLING

If the feed material is wet, or can be wetted without harm, this method of operation may be considered. The feed stock is ground as a suspension in a carrier liquid stream-open water. Dust problems associated with dry milling are overcome and hydraulic classification techniques such as elutriation, sedimentation and centrifugation may be employed for separating desired size fractions.

Very often in food processing the milling is part of an extraction process, a soluble constituent of the feed being transferred to the liquid stream for recovery by evaporation, as in corn milling experience shows that power consumption is generally high with wet grinding. Mill wear may also be increased. Wet-milling tends to produce finer particles than those obtainable with dry milling operations. For, reason this mode of operation finds extensive application in ultra fine grinding applications.

2.1 THEORETICAL CONSIDERATIONS

Some researchers have been able to develop some theories and models to aid the design of machine soymilk centrifugal principle for soymilk processing.

Chapman (1963) under took a study of the necessary conditions and parameters that should be considered in the development of a separation system for solids from liquids and liquids from solids (e.g sugar crystals or soymilk form paste), based on the principle of centrifugal force. These parameters are:

- Mechanical factors such as strength, corrosion resistance and reliability of materials to be used for the design.

- Power consideration involving moment of inertia, acceleration and deceleration, high speed and spinning time.

- Process consideration entails output and regularity of materials, spinning before and after washing.

Hugot (1967) derived two equations for computing the capacity of machines, whose designs are based on the centrifugal force principle. The two equations defines theoretical and practical capacity in terms of volume of materials handled (basket content) and time per cycle for different basket shapes. These are:

Volumetric capacity for conical top and bottom basket:

V_E (Theoretical) = $0.000236D^2H$

V_P (Practical) = $0.000205D^2H$ ------------------ (1)

Where, Vt = Maximum theoretical content of liquid (Massecuit) of basket in ft (m).

Vp = Maximum practical content of (liquid) ofthe basket in ff^3 (m^3).

D = Diameter of basket in inches (cm)

H = Height of basket in inches (cm)

These two sets of equation indicate that the volumetric capacity is a function of the diameter and height of the basket.

Hugot second equation for capacity in terms of time per cycle is

$$C = \frac{D^3Hn^2}{K} \quad \text{----------------------- (2)}$$

Where, C = Capacity of machine, no of cycles per hour.

H = Height of basket in inches (cm)

N = Speed in revolution per minute of the basket.

K = Co efficient depending on the nature of liquid handle (massecuit)

In this case the relationship between capacity basket diameter, height and r.p.m shows that the capacity increases with increases in the other parameters defined.

Hugot expresses K in term of weight of sugar per hour. He further investigated and found that the co-efficient K value is negible in most cases because the nature of the massacuit is not considered in the equation and that it is large size and high rotational speed of basket that are obviously desirable to achieved high çapacity which is always required.

He also stated that a definite limit 80 speed however depends on strength of materials of the basket. Thus consideration of speed and strength of basket are similar to those for fly wheel rims and nothing would be gained by using thicker metal in the basket, since this would increase stresses.

Hugot also deduced that for a given peripheral speed a smaller diameter basket will develop a higher gravity factor since, centrifugal force (gravity factor) in directly proportional to the square of the velocity (v) and inversely proportional to the radius (n) of the basket.

$(Fc = V^2/R)$ ------------------------- (3)

Clayton (1968) developed a model for the computation of the capacity. He additionally considered crystal sizes and viscosity of the massecuit. The equation was:-

$$C = \frac{Kn^2D^3Hm^2V}{n} \quad \text{--------------------} (4)$$

Where, m = Linear dimension of the sugar crystals

n = Viscosity of the mollases.

v = Residual mallases (% Crystal)

C,K,n,D and H have been defined in Hugots equation.

This was justified by the fact what since in high grade (1st and 2nd) massecuites, crystal sizes are large (approaching 1.00mm) and viscosities are low, not much difficulty in expected in achieving satisfactory capacity. On the other, with low grade massecuites, crystal sizes are small and viscosities are

Hugot (1970) derived an equation for the determination of stress per unit area of the basket due to centrifugal forces as:-

$$P = \frac{M w^2 r}{DH} \quad \text{--------------------} \ (5)$$

Where, P = Stress per unit area of basket 1bt ($^N/_m 2$)

W = Angular velocity of the basket.

M = Total mass of the basket and masscuit in Ib (Kg) (materials)

r = Radius of gyration.

D = Diameter of the basket in inches (cm)

H = height of basket in inches (cm)

He also developed an equation to determine the permissible thickness of the metal for the construction of the basket. This equation was:

$$e = K_1 D^3 n^2 \quad \text{-----------------} \ (6)$$

Where, K_1 = Numerical co efficient depending on the basket materials.

D = Diameter of basket in inches (cm)

n = Speed of basket in r.p.m

e = Thickness of metal for basket construction

Hugot also stated that the moment of inertia is an important parameter in the determination of the power requirement of the machine. He distinguished two principal values of moment of inertia.

These are:- Moment of intertia before loading and when fully loaded. Based on this, Hugot developed an equation expressed the total moment of inertia to be:

$$1 = 1_p + 1_s = 0.074D^4H\,(nD + 2.3) \quad \text{-------------------} \ (7)$$

These are:- Moment of intertia before loading and when fully loaded. Based on this, Hugot developed an equation expressed the total moment of inertia to be:

$$1 = 1_p + 1_s = 0.074D^4H \frac{(nD + 2.3)}{H} \quad \text{-------------------- (7)}$$

Where , 1 = Total moment of inertia.

1p = Moment of inertia before loading the machine.

1s = Moment of inertia due to the weight of the materials to be processed (masscuit).

D and H have been previously defined

Hugot studied the power requirement of machines using centrifugal principle and assumed that two types of power requirement are associated with such machines. These are power for starting required during the period of acceleration and power for starting required for running the machine at full speed. Equation derived by Hugot using these assumption where

$$Pa = 0.0066 \frac{D^4Hn^2}{t} \frac{(nD + 2.3)}{\sqrt{H}} \quad \text{-------------- (8)}$$

and $$Pr = \frac{D^4Hn^2}{276} (1 + 4n) \quad \text{----------------------- (9)}$$

Where, Pa = Power requirement at starting (acceleration) period in hp (KW).

Pr = Power requirement as full speed in hp (KW).

D = Diameter of basket in Ft .(m)

H = Interior depth of basket in it (m).

N = Full speed in r.p.m

T = Duration of acceleration period in min.

From the two equations, it could be clearly deduced that the power requirement of the machine both at starting and full speed increases with the diameter, depth and speed (r.p.m) of the basket and decreases with increase in acceleration period.

He further derived an equation expressing power exerted per unit weight of sugar masscuit both at starting (acceleration) and running as:

$$\frac{Pa}{Y} = \frac{KD}{t}\frac{(ND + 2.3)}{\sqrt{H}} \quad \text{---------------------} \quad (10)$$

$$\frac{Pr}{Y} = K^{11}(1 + 4n) \quad \text{---------------------} \quad (11)$$

Where, Pa = Power requirement in hp (KW)

Y = Unit weight in 1b or Kg.

Pr = Power requirement per unit weight of masscuit at running in hp/1b (KW/ Y Kg).

$K^{1} = \frac{D^4 Hn^2}{D^3 Hn^2}$ Where, K = Co-efficient depending on parameters shown in the equation

$$K^{2} = \frac{D^4 Hn^2}{D^3 Hn^2}$$

From this equation, Hugot deduced that the power requirement per unit weight of sugar increases with the sizes of the machine and the period to a smaller extent. On this basis, he started what smaller machines are more economically on the basis of power consideration relative to output. He however added that labour requirements will be greater than in the bigger machines because more number of machines will used for a given duty. Hence, he recommended that a compromise must be fund between cost of power and labour. Chapman (1960) confirmed Hugot conclusion by quoting figure from practical experimental trials. He however said that power was relatively cheap commodity hence the advantage of a larger machines will outweight the disadvantages of higher unit power consumption.

2.2 GRINDING AND FILTRATION THEORY

2.3 GRINDING

This is the unit operation in which the average size of agricultural produce are reduced by the application, of grinding compression or impact forces. When this force is applied to reduction in size of grain fed between two circular plates or stones, one of which is stationary and the other rotating is referred to as Burr milling.

The feed comes into contact with the axis of rotation and is sheared and crushed as it is transported to the edge of the plate. The plates are mounted vertically, made up of high carbon steel which produce the required hardness with adequate toughness.

The fitness of grinding is controlled by the nature of the surface of the plate and the clearance between the two plates. When using materials with high moisture content some materials may stick to the working part of the milk, this increase the temperature and reduce efficiency.

The energy required to reduce the size and solid materials can be calculated using Rittingness equation (Law)

$$E = K_R (1/d_2 - 1/d_1) \qquad (13)$$

Where, E = energy required permit mass of food (J/Kg)

K_R = Kittingers constant.

d_2 = Average size of the grinding particles (mm)

d_1 = Average initial size of the food, (mm)

The size of the end product is classified by using finess modules and this indicated by the uniformity of the end product calculated as the sum of the fraction retained above each sieve divided by the total weight of the sample.

$$\text{Finess module} = \frac{1 \times qo + 2 \times q_1 + 3 \times q_2}{q} = \text{------------} \qquad (14)$$

Where, q = Total weight of sample

q_o q_1 = Weight of sample retained over each sieve

And the end product is calculated by

$$\frac{\%\ \text{materials retained}}{10} = \text{uniformity (mm)}$$

This is given as:

$$\frac{\text{Course}}{10}\ ; \quad \frac{\text{Medium}}{10}\ ; \quad \frac{\text{Fine}}{10}$$

And the average size of the end product ds is given as:

$$ds = \frac{\mathcal{E}diqi}{100} \qquad (3)$$

Where, di = diameter of the sieve (mm)

2.4 FILTRATION THEORY

Filtration is a machanical separation technique in which a liquid is separated from a two phase solid - liquid system by imposing a screen in the flow path which restrainsts particles above a given size from passing through it. the fluid is subjected to a force which moves it past the particles.

The screen is called the filter. The particles suspensed in the fluid which will not pass through the apertures, are retained and build-up into what is called a filter cake, while the liquid product is called the filtrate. The fine aperture necessary to filtration one provided by fabric filter clothes, meshed and screen of phatic or metal or by beds a solid particles.

CHAPTER THREE

DESIGN ANALYSIS AND CALCULATIONS

3.0 DESIGN ANALYSIS

The process design analysis aims at evaluating the necessary design parameter, strength and size of materials of materials for consideration in the selection of the various machine parts in order to avoid failures by excessive yielding and fatigue during the required working life of the machine parts. The results of these analysis will be incorporated in the design calculation to prevent the possibility of under or over design of parts for the fabrication of the machine hence would minimize unnecessary costs.

3.1 POWER REQUIREMENT

The power that would be required to drive the machine (Internal Basket) is a function of grinding plate, its content, flanges, mass of the basket and the central shaft that will transmit power from the electric motor to the basket through pulleys and belts.

Hence the power required to grind the soybean and to rotate or drive the basket for grinding and separation of the soymilk and paste is expressed by the generally established equation:

$$P = F_T V \quad \text{.......................} \quad (1)$$

Where, P = Power required

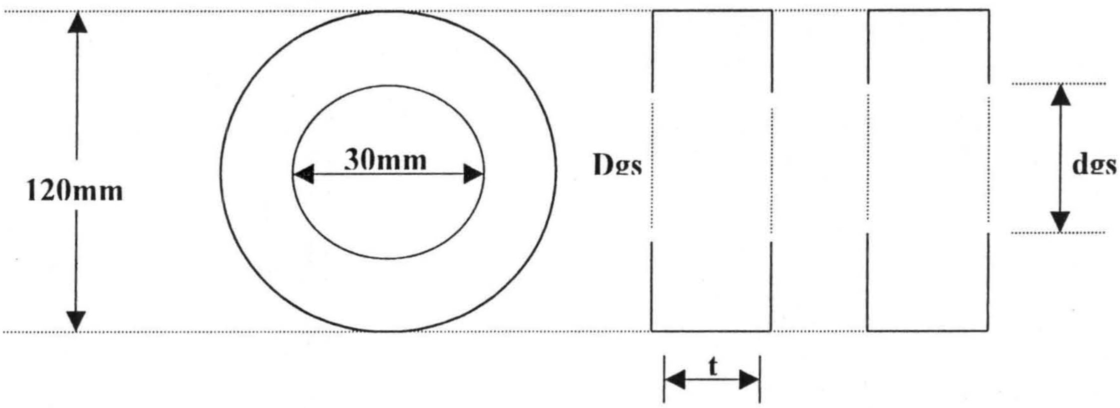
F_T = Total force of the grinder, basket, its content, the central shaft and flanges.

V = Velocity of the basket at full speed.

DESIGN CALCULATIONS

3.2 DESIGN OF GRINDING UNIT

3.2.1 GRINDING DISCS



Where, Dgs = Diameter of the grinding disc.

dgs = Hole diameter of the grinding disc.

This is obtained in the local market (casted) mild steel.

Popular size of burr mill is 27cm for which recommended speed is taken from 650 to 750 r.p.m. Taking speed of centrifuge to be 1400 r.p.m which is expected to run at high speed for thorough separation, combining these speeds to be obtained from the grinder/milk extractor simultaneously, averagely speed of 1000 r.p.m (assumed) for the soybean grinder/milk extractor is taken,

Source: PANDEY (1994) PAGE 102

3.2.2 To determine power required to grind soybean grains:

Average energy and force required to fracture soybeans under quasi - static loading:

For soybean at 16% (M.C) moisture content the average force required is 10 Ibs which in MOSHENIN gives us: 10 x 4.448 N = 44.48N. This is the force required to fracture one bean.

For soybean at 16% M.C, the average energy required to fracture one bean is 0. 279 (in – 1bs) which on conversion gives us 0.279 x 1.356 J = 0.378 J. This is the energy required to fracture one bean (Moshenin, 1970) page 651. See Appendix A attached.

Assumption: Number of beans to be crushed at 1 r.p.m = 21

Therefore, average force = 21 x 44.48N

= 934.10N

Power required = Force & velocity (FV)

$$= \frac{F \times \prod DN}{60} \quad \text{-------------- (2)}$$

Where, F = Force = 934.10N

D_2 = Diameter of machine pulley = 0 .075m (calculated)

D_1 = Diameter of engine pulley = 0.05m (given).

N = No of revolution of pulley (assumed).

= 1000rpm

Therefore power, $= \frac{934.10 \times \prod \times 0.075 \times 1000}{60}$

$= 2836.8$ watts

$= 2.836$ Kw

For energy: for one bean

$= 0.279 \times 1.356$ J

$= 0.378$J.

Changing it to hp $= 2.837$ Kw $=$

$= 1.34$ hp x 2.837 Kw

$= 3.8$ hp

1hp $= 0.746$Kw

1Kwh= 1.34 hp.

3.2.3 Surface area of grinding disc,

$$AgD = \frac{\prod D^2}{4} - \frac{\prod d^2}{4} \text{ --------------- (3)}$$

Where: D = Diameter of grind disc.

d = Hole diameter of the grinding

$$= \frac{\prod \times (120 \times 10^{-3})^2}{4} - \frac{\prod \times (30 \times 10^{-3})^2}{4}$$

Ag D $= 0.0131\text{m}^2 - 0.0007069\text{m}^2$

Ag D $= 0.011\text{m}^2$

For design purposes, let mass of dehulled soybean, (Mdb) = mass of 21 beans to be crushed at 1 rpm = 0.0032kg.

Weight $= M \times g$

Mass; $\quad M = $ mass

$\quad g = $ acceleration due to gravity

$\quad = 9.81\ ms^{-2}$

Therefore, weight of dehulled soybean,

$$Wdb = mdb \times g \text{ ------------ } (4)$$

$$wdb = 9.51 \times 0.0032kg$$

For this design let wdb = 0.0314kg taking the resistance of soybean to crushing, Rdb = energy required for 21 beans as calculated = 7.94J

hp = 0.1323 watts

Total force acting on grinding disc, (Fgb)

Fgb) = 934.10N as calculated.

Pressure on grinding disc, $Pgb = \frac{Fgb}{AgD}$ ---------------- (5)

$$Pgb = \frac{934.10N}{0.011m^2} = 84918.18\ {}^{N}/m^2$$

3.2.4 DESIGN CALCULATION FOR CENTRIFUGE:

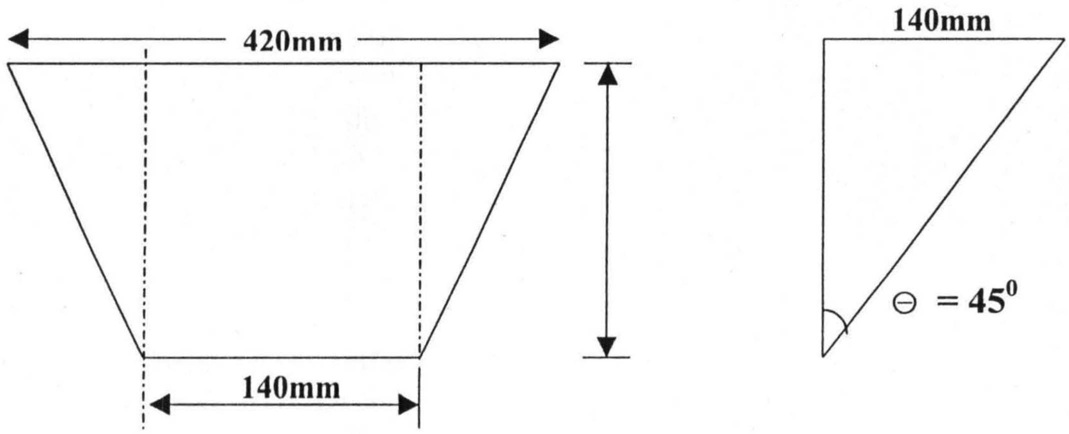


Fig. 3.2

Given

$$\text{Tan } 45 = \frac{140}{h} \quad \text{---------------------- (6)}$$

$$h = \frac{140}{\tan 45} = \frac{140}{1} = 140\text{mm}$$

Essential design calculations are made in order to determine and select the appropriate strength and sizes of the component parts of the prototype of the machine. This is done with the aid of the results and established formula in the design analysis.

Based on this information some of the following data were selected with adequate reasons while others were obtained by experiment and from text books.

- ✓ Expected volumetric capacity of centrifuge = $0.277m^3$ /8hrs /day
- ✓ Diameter of internal basket: small = 140mm (assumed).

  Large = 420mm

  - ✓ Tolerance height of basket selected to prevent spillage of soymilk and discharges the paste from top inside the basket - 0.14m.
  - ✓ Density of soybean obtained $1310kg/m^3$
  - ✓ Diameter of base plate selected to withstand stress due to centrifugal effect – 0.14m (from grinding stone diameter giving tolerance).
  - ✓ Speed of motor selected = 1500 rpm
  - ✓ Expected speed of machine = 1000rpm

- ✓ Selected diameter of motor pulley - 0.05m
- ✓ Shear stress of steel B.S 499 and C.P 112 England = 115×10^6 N/m^2.
- ✓ Expected time to process = 25minutes.
- ✓ Density of stainless steel (Holman, 1989) = $7833kg/m^3$
- ✓ Selected diameter of flange = 0.12m
- ✓ Selected thickness of flange = 0.003m
- ✓ Density of mild steel (Ryder, 1978) = $6800kg/m^3$
- ✓ Shear stress or stainless steel = 115×10^6 N/m^2 (Holman, 1989)
- ✓ Co-efficient of friction between V-belt and pulley for power transmission tanned with mineral compound = 0.3

3..2.5 **Volume of material to be processed per batch.**

Considering the volumetric capacity of the machine to be $0.27m^3$/day and since each batch is expected to take 25minutes (including time for loading and discharging) to process, the volume of material to be processed per batch is:

$$Vb = \frac{Vd \times T_b}{T_T} \text{ ---------------- (7)}$$

Where, V_b = Volume of materials to be processed per 8hr/day = 0.277m3

T_T = Total time required to process the expected quantity of materials = 8hrs = 480 minutes.

Tb = Expected time to process one batch = 25 minutes .

Substituting values in equation!

$$Vb = \frac{0.277 \times 25}{480} = 0.01443m^3$$

3.2.6 HEIGHT OF INTERNAL BASKET

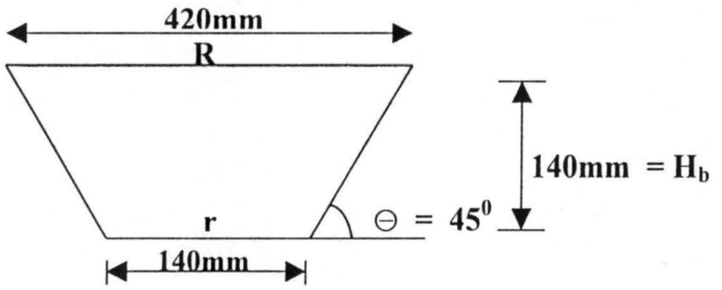


Fig. 3.3

The height of the internal centrifugal basket is a function of its volumetric capacity per batch and the diameter as shown in the formula

Volume of a frustrum

$$V = 1/3 \prod Hb (R^2 + Rr + r^2) \text{ --------------- } (8)$$

$$Hb = \frac{3Vm}{\prod (R^2 + Rr + r^2)}$$

Volume of cylinder:

$$V = \frac{\prod D^2 H}{4} \text{ ---------------------- } (9)$$

$$Hb = \frac{4Vm}{\prod D^2 b}$$

Where, Hb = Height of basket

Vm = Effective volume of materials

$Vm = 0.01443m^3$

Db = The diameter of the basket

Rb = The larger radius of basket

rb = The smaller radius of basket

$$Rb = \frac{420}{2} = 210mm = 0.21m$$

$$rb = \frac{140}{2} = 70mm = 0.07m$$

Substituting values in equation -------------------- (9)

$$Hb = \frac{3\ Vm}{\prod (R^2 + Rr + r^2)} = \frac{3 \times 0.01443}{\prod (0.21^2 + 0.21 \times 0.07 + 0.07^2)}$$

$$Hb = \frac{0.04329}{\prod\ (0.441 + 0.0147 + 0.0049)} = 0.216321m$$

3.2.7 Mass of soymilk and paste per batch

The mass of soybean per batch for processing is related to its density and volume of material to be processed and is expressed as:

$Ms = Vm\ \wp gb$ ----------------------- (10)

Ms = Mass of grounded soybean

Vm = Volume of materials in the basket = $0.01443m^3$ (calculated)

$\wp gb$ = Density of grinded soybean, substituting values in equation ---- (10)

$$Ms = 0.01443 \times \wp gb$$

3.2.8 Mass of grinded soybean per day

$$Mds = \frac{Ms \times T_T}{T_b} \text{ ---------------------- (11)}$$

Where, Mds = Expected mass of grinded soybean to be processed per day.

Ms = Mass of grinded soybean

3.2.9 Calculating for the thickness of the grinding disc (tgd):

Using S = 0.24 W/t^2 from Banseka (1998), and making 't' the subject of the formula.

$$tgd = \sqrt{0.24 \; W/s} \text{ ---------------------- (10)}$$

Where, tgd = t = thickness of the disc

W = Weight of dehulled bean

S = Ultimate stress, for carbon steel

= 850 N/mm^2 from colin (1982)

Substituting the given values into the formula:

$$tgd = \sqrt{0.24} \left(\frac{3.2g}{850 \; N/mm^2} \right) = 0.489898 \times 0.003765$$

$$= 0.0018445mm \text{ (minimum)}$$

3.3.0 Calculating for the volume of the grinding disc (Vgd)

$$VgD = Agd \times tgd \text{ ------------------- (13)}$$

Where,

tgd = thickness of the disc

AgD = Surface area grinding disc

Vgd = $0.011m^2$ x 0.0018445 =

= $0.0000203m^3$

3.3.1 Mass of grinding disc, (Mgd):

Mgd = Sst x Vgd ---------------------- (14)

Where, Sst = Density of carbon steel

= 7810 Kg/m^3 (from colin 1982)

Mgd = 7810 x 0.0000203

= 0.158543 Kg

3.3.2 Weight of grinding disc; (wgd):

Wgd = Mgd x g --------------------- (15) = 0.158543 x 9.81

= 1.555N

Since there are two discs – stationary and movable disc, it implies that the total weight of the disc, (WTd)

WTd = 2 x wgd = 2 x 1.555 = 3.11N

Since the average size of soybean after soaking for 16hrs, a day or two is 9mm diameter, the clearance between the plates (given) = 12.42mm to accommodate certain quantity of beans at a time. From, clearance of (12.42mm) + thickness of disc (0.0018445mm) approximately, the housing of the grinding disc could be 30mm.

T_T = Previously defined = 480 minutes

T_b = Previously defined = 25 minutes

Substituting values in equation $Mds = \frac{Ms \times 480}{25}$ --------------- (16)

3.3.3 POWER REQUIREMENT

The power requirement of the machine is a function of the total force in the internal basket with its content and recommended velocity of the basket thus the power requirement for processing soymilk.

$P = F_T V$ -------------------- (17)

Where, $F_T = (Ms + Mf + Mb + Mp + Mbs + Mc + Mgd)g$ ------ (18)

V = Velocity of internal basket ------------------------- (18)

$= \prod dbs\ N$ ------------------------ (19)

Substituting equation ----------------- (18) in (17)

$P = (Ms + Mf + Mp + Mb + Mbs + Mc + Mgd)v$

Where, P = Power required in watts

Ms = Mass of the central shaft

Mf = Mass of the two flange

Mb = Mass of the three bolts used in fastening the internal basket flange to the central basket flange.

Mp = Mass of the machine pulley (diameter = 0.075m)

Mbs = Mass of the internal basket

Mc = Mass of the content (material) in the basket.

Mgd = Mass of the two grinding discs

N = Revolution per minutes of internal basket (750 – 1000rpm)

g = Acceleration due to gravity 9.81m per sec^2

Neglecting the mass of the shaft since the actual size of the shaft cannot be determined until the remaining parameter can be determined --------------- (17) becomes:

$$P = (Mf + Mp + Mb + Mbs + Mc + Mgd)g\prod dbsN \text{ ----- } (20)$$

Before calculating the power requirement of the machine, the various masses will be determined first.

3.3.4 Mass of the two grinding disc

Mass of grinding disc, Mgd $= Ss_t \times Vgd$ ---------------- (21)

Where, Ss_t = Density of carbon steel =

= 7810 Kg / m^3, from colin (1982)

∴ Mgd = 7810 x 0.0000203

Mgd = 0.158543 Kg (2)

= 0.158543 x 2

= 0.3131Kg

3.3.5 Mass of Flanges

The mass of the two flanges is a function of its density and volume:

Mf = Nf Vf ----------------------- (22)

$$= \frac{Ne_f \prod d_f^2\ t_f}{4} \text{ ------------------------ } (23)$$

Where, Mf = Massa of flanges

N = Number of flanges = 2

e_f = Density of flange (stainless steel) Holman (1989)

= $7{,}833 Kg/m^3$

V_f = Volume of flange = $\frac{\prod df^2\, tf}{4}$

d_f = Diameter of flange = 0.12m

t_f = Thickness of a single flange = 0.003m.

Substituting values in equation ---------------------- (22)

$$Mf = \frac{2 \times 7,833 \times \prod (0.12)^2\, 0.003}{4}$$

$= 0.531604Kg$

$= 0.53Kg$

3.3.6 Mass of machine pulley

The mass of the machine pulley is

$$Mp = e_p\, Vp \text{ -------------------- (23)}$$

Where, Mp = Mass of pulley

e_p = Density of pulley (mild steel) ryder (1978) = $6800Kg/m^3$

d_p = Diameter of machine pulley = 0.075m (calculated).

t_p = Thickness of pulley = 0.016m

Substituting values in equation ----------------------- (23)

$$Mp = \frac{6800 \times \prod (0.075)^2 \times 0.016}{4}$$

$$= 0.481Kg$$

$$M = 1.97Kg$$

3.3.7 Mass of bolts

The mass of the bolts used in fastening the basket flange and that central shaft flange is calculated as follow:

$$Mb = N_b \ V_b \text{ --------------------- } (24)$$

$$= \frac{N \ eb \prod d_b^2 \ L_b}{4}$$

Where, N = Number of bolts = 3

e_b = Density of bolt = $6800m^3/Kg$

d_b = Diameter of std. bolt to be used (neglecting the head)

= 0.0125m.

L_b = Length of std. bolt used = 0.05m

Substituting values in equation ---------------------- (24)

$$Mb = \frac{3 \times 6800 \times \prod (0.0125)^2 \ 0.05}{4}$$

$$= 0.125Kg$$

3.3.8 Mass of Internal basket

The internal basket is made up of the circumference (stainless steel sheet). The base and a central pipe as shown:

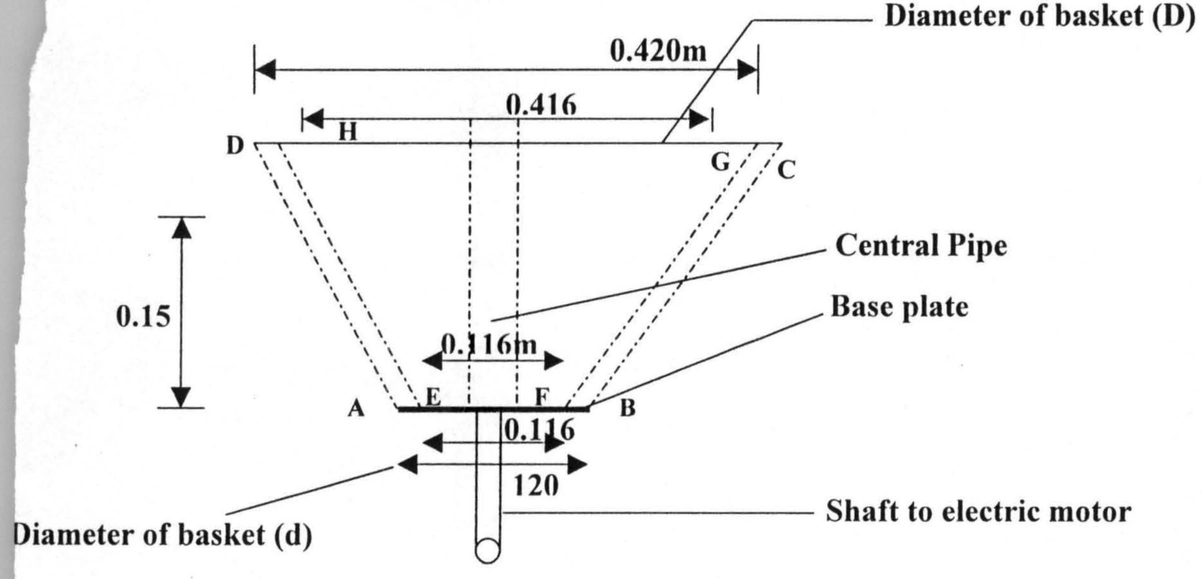


Fig. 3.4

Sketch of internal basket (perforated) as above.

Thus the mass of the internal basket is:

Volume of a frustration $= 1/3 \prod h (R^2 + Rr + r^2)$ --------------- (25)

Volume (ABCD) $= 1/3 \prod (0.15) \left[(0.21)^2 \text{ x } (0.21 \text{ x } 0.06) + (0.06)^2\right]$

$= 9.4719 \text{ x } 10^{-3} \text{ m}^3$

Volume (EFGH) $= 1/3 \prod (0.15) \left[(0.208)^2 + (0.208 \text{ x } 0.058) + (0.058)^2\right]$

$= 9.2193 \text{ x } 10^{-3} \text{ m}^3$

Volume required = Volume (ABCD) - Volume (EFGH)

$= (9.4719 \text{ x } 10^{-3} - 9.219310^{-3}) \text{ m}^3$

$= 2.526 \text{ x } 10^{-4} \text{ m}^3$

Density (e) $= \dfrac{\text{Mass (m)}}{\text{Volume (V)}}$

$$M = 7800 Kg/m^3 \times 2.526 \times 10^{-4} m^3 = e = \frac{M}{V} \therefore M = eV$$

$$e = \frac{M}{V} \text{ -------------------------- (26)}$$

Mass (m) $= e \times V$ (density x volume)

$= 7800 Kg/m^3 \; 2.526 \times 10^{-4} m^3$

$= 1.97 Kg$ mass of conical internal basket circumference (kg)

$$Mb_s = Mcb + Mbp + (mcp) \text{ ------------------------- (27)}$$

$$= S\,(Vcb + Vbp + Vcp) \text{ ------------------------ (28)}$$

$$= S\,\left(\prod dcb\,hcb\,tcb + \frac{d^2bp\,tbp}{4} + dcp\,hcp\,tcp\right) \text{ --------- (29)}$$

Where, Mbs = Mass of internal basket (Kg)

Mcb = Mass of internal basket circumference (Kg)

Mbp = Mass of base plate (Kg)

Mcp = Mass of the central pipe (Kg)

S = Density of stainless steel sheet = $7833 Kg/m^3$

Vcb = Volume of materials for internal basket circumference.

Vbp = Volume of materials for the base plate.

Vcp = Volume of material for the central pipe.

dcp = Diameter of internal basket

= D = 0.42m (assumed)

= d = 0.14m (obtained from market)

hcb = Height of the internal basket = 015m (calculated and approximate)

tcb = Assumed thickness of internal basket = 0.003m (from calculation)

dbp = Diameter of base plate = 012m (market)

tbp = Thickness of base plate = 0.004m (market)

dcp = Diameter of central pipe 0.075m (assumed)

hcp = Height of central pipe =

tcp = Thickness of central pipe = 0.004m (assumed)

Substituting values equation ------------------ (27)

Mbs = 7833

$$\left(\prod 0.14 \times 0.15 \times 0.03 + \frac{\prod (0.14)^2 \times 0.004}{4} + 0.1 + \prod \times 0.075 \times 0.1 \times 0.004 \right)$$

= 7833 [5.3851314 x 10^{-4}

= 4.21817343 Kg.

3.3.9 Mass of content of internal basket

The mass of content m_c in the internal basket has been previously given as 0.0032Kg for 21 dehulled soybean.

3.4.0 Power requirement for processing soybean milk

Substituting values in equation ---------------------- (20)

$P \quad = (M_f + M_p + M_b + Mb_s + M_c + Mgd)\, g \prod db_s N$

$P \quad = (10.53Kg + 0.481 + 0.125 + 1.97 + 0.0032 + 0.3171)$

$$\frac{9.81 \times \prod 0.14 \times 9.81 \times \prod \times 0.14 \times 1000}{60}$$

$P \quad = 3.4263 \times 71.91$

$P \quad = 246.38$ watt, Therefore, power = power to grind bean + power to centrifuge with content =

$P \quad = 0.2464$ Kw + 2.836Kw

$P = 3.0824$Kw $= 3.0824 \times 1.34 = 4.1304$hp given, 1Kwh = (equal to) 1.34hp

Selection of electric motor capacity:

The computation of power requirement for soymilk processing above. An electric motor with a capacity of 4.5kp in considered necessary to drive the machine.

3.4.1 Diameter of central shaft

The diameter of the central shaft is determined for the highest power requirement using the established formula in the design analysis:

$$d \quad = \left(\frac{16Mt\ dbs}{\prod Ss}\right)^{0.33} \text{------------------------ (30)}$$

Substituting Mt $= \frac{Fd}{2} = \frac{Mgdbs}{2}$ in equation ---------------- (30)

$$ds \quad = \left(\frac{16Mh_T\ gdbs}{2 \prod Ss}\right)^{0.333} = \left(\frac{16Mh_T\ gdbs}{2 \prod Ss}\right)^{0.333}$$

Where, ds is expected diameter of shaft

Mh_T = Is highest total mass of basket and its content = 2.522 + (262.6 mass of hopper calculated) = 265.122 N (Kg)

g - is acceleration due to gravity = 9.81m / sec

dbs = is diameter of internal basket = 0.14m

Ss = Permissible shear stress of shaft (stainless steel) Holman (1969) =

= 115 x 106 N / m^2

Substituting values from -------------------- (30)

$$d = \left(\frac{16 \times 265.122 \times 9.81 \times 0.14}{2 \times \prod \times 115 \times 10^6} \right)^{0.333}$$

$d = 0.020131m.$

$Mh_T = Mb + mdb + mbt + mf$ --------------------- (31)

Where, Mh_T = Highest total mass of basket and its content

mb = mass of basket (empty)

mdb = mass of dehulled bean (21)

mbt = mass of 3 bolts

mgd = mass of one grinding disc

mf = mass of one flange

$Mh_T = 1.97 + 0.0032 + 0.1255 + 0.158543 + 0.265 = 2.522Kg.$

$d = 0.020m$

Using a safety factor of 50% of the calculated value.

$ds = (0.020)\ (0.5) + 0.020$

$= 0.01 + 0.020$

$ds = 0.03m$

Hence a shaft of diameter 0.030m is considered.

3.4.2 SECOND POLAR MOMENT OF AREA OF THE SHAFT

The second polar moment of area of the shaft is $J = \dfrac{ds^4}{32}$ ---------------- (32)

Where, J = is second polar moment of area

ds = is diameter of shaft = 0.030m

Substituting values in equation -------------------- (32)

$$J = \prod \left(\frac{0.030}{32}\right)^4$$

$= 7.952156404 \times 10^{-8}\ m^4$

3.4.3 TORSIONAL STRESS OF SHAFT

The torsional stress on the shaft is determined as:

$$T = \frac{Mtds}{2J} \text{ ------------------------- (33)}$$

$$T = \frac{Mgds}{4J}$$

Where, T = is torsional stress on shaft in N / m^2

Mt = is twisting moment (torgue) of shaft $= \dfrac{Mgds}{2} = \dfrac{\prod D_s^3\ Ls}{8}$ --------- (34)

Ls = is diameter of shaft of shaft = 0.030m

J = is second polar moment of area = $7.952156404 \times 10^{-8}\ m^4$

e_s = is density of shaft = $7833 Kg/m^3$

Substituting values in the equation

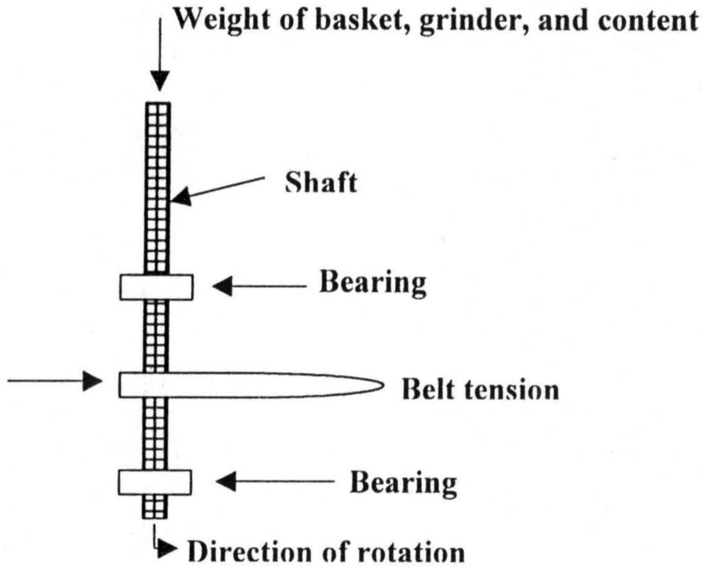
$$T = \frac{es \prod d_s^3 Lsg}{16J} \quad \text{------------------------ (35)}$$

$$= \frac{7833 \times \prod \times (0.030)^3 \times 0.40 \times 9.81}{16 \times 7.452156404 \times 10^{-8} m^4}$$

$$T = \frac{2.607178476}{1.272345025 \times 10^{-6}}$$

$$= 2049112.8 N / m^2$$

FORCE DIAGRAM



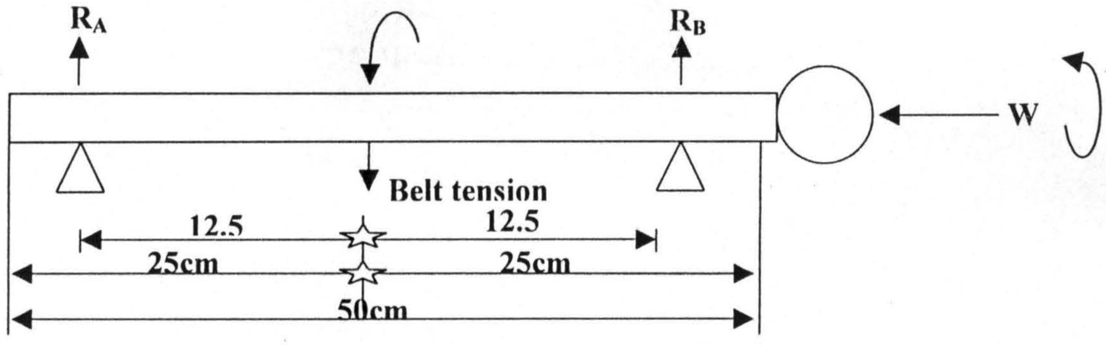


Fig. 3.6

3.4.4 HOPPER DESIGN

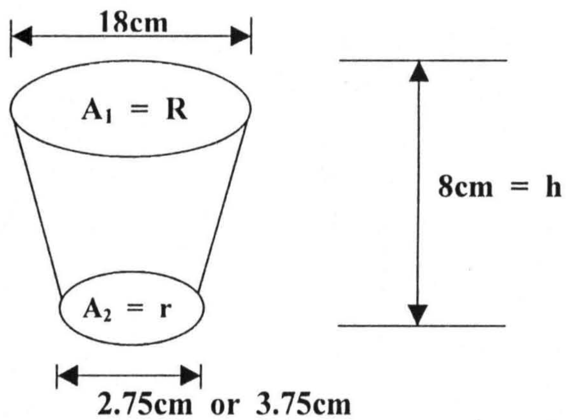


Fig 3.7

The hopper is dimensioned as seen above this hopper is at the of the frustum shaped housing (i.e of grinder/centrifuge), it serves the purpose through which dehulled bean are fed into the grinder/centrifuge.

The volume of the hopper is given as:

$$V = 1/3 \prod h \ (R^2 + Rr + r^2) \text{ ---------------------- } (36)$$

Where, V = Volume of hopper

h = Height of hopper

R = Larger or upper radius of hopper

r = Smaller or lower radius of hopper

Therefore, $V = 1/3 \prod \times 0.08m \times (0.18^2 + 0.18 \times 0.375 + 0.0375^2)$

$V = 0.084\ (0.0324 + 0.00675 + 0.00141)$

$V = 0.00341m3$

The hopper is made of mild steel sheet with density 7850Kg/m3.

Hence, $e = \frac{m}{V}$ Where, m = mass

e = density

$m = e \times V = 7850 \times 0.00341 \times 9.81$

$= 262.6N$

3.4.3 RADIAL DEFORMATION IN SHAFT

The radial deformation tendency in the shaft is calculated as:

$$\varnothing = \frac{YL}{Gr} \text{ ---------------------- (37)}$$

Where, Ø – is the radial deformation or angle of twist in radians.

Y = is the torsional stress in the shaft = :

$= 4.1 \times 10^7\ N / m^2$

G = is modulus of rigidity of the shaft. Holman (1989)

$= 8.0 \times 10^{10}\ N/m^2$

r = is radius of shaft $= \frac{d}{2} = \frac{0.030}{2}$

$= 0.015m$

$$\varnothing = \frac{4.1 \times 10^7 \times 0.40}{8.0 \times 10^{10} \times .015}$$

$$= \frac{16400000}{12 \times 10^7}$$

$= 0.136667$ radians

3.4.6 STRAIN ENERGY:

The strain energy in the shaft due to torsion is –

$$U = \tfrac{1}{2} Y \varnothing \quad \text{------------------------------} \quad (59)$$

Where, U = is strain energy in Joules

Y = is torsion in shaft

$= 4.1 \times 10^7$

$\varnothing$ = is radial deformation

$= 0.136667$ radians

Substituting values in equation:

$$U = \frac{4.1 \times 10^7 \times 0.36667}{2}$$

$= 2801673.5$

$= 2801.67$ KJ

3.4.7 SPEED OF THE INTERNAL BASKET

The linear speed of the internal basket is

$$V = \prod N\, dbs \quad \text{---------------------------} \quad (60)$$

Where, V = is speed of internal basket

N = is revolution per minute of internal basket

$= 1000$ (rpm)

dbs $=$ is diameter of internal basket

$= 0.14m$

Substituting values in equation -----------------------

$$V = \frac{\prod \times 1000\ (0.14)}{60}$$

$$= 7.331 m / sec$$

3.4.8 RADIAL ACCELERATION

The radial acceleration of the basket is

$$a = \frac{w^2 dbs}{2} \quad \text{-------------------------- (61)}$$

Where, a $=$ is radial acceleration of the internal basket

w $=$ is angular velocity of the internal basket

$$= \frac{2\prod N}{60} = 0.105N$$

dbs $=$ and N have been previously defined with values 0.14m and 1000 rpm respectively.

Substituting values in equation ------------------------ (61)

$$= \left(\frac{2\prod N^2}{60}\right)^2 \left(\frac{0.14}{2}\right)$$

$$= \left(\frac{2 \times \prod \times 1000}{60}\right)^2 \left(\frac{0.14}{2}\right)$$

$$= 10969.1\ (0.07) =$$

$= 767.84 \ m/sec^2$

3.4.9 HIGHEST CENTRIFUGAL DEVELOPED

The centrifugal force as a result of the rotation of the internal basket is

$$Fc = Mw^2r \text{ --------------------------- } (62)$$

$$Fc = \frac{Ms \ \ w^2dbs}{2} \text{ --------------------- } (63)$$

Where, Fc = is centrifugal developed at the highest speed of the internal basket.

Ms = has been previously defined to be the total mass of the internal basket and its assembly = 28.94 for grinded soybean (milk + paste) (chosen since it will generate the highest centrifugal for because of its highest mass).

W = has been previously defined

= 0.14m

Substituting values in ------------------------------ (63)

$$Fc = 2.522 \times \frac{2\prod \times 1000^2}{60} \ \frac{0.14}{2}$$

$$= 2.532 \times 104719.76 \times 0.07$$

$$= 18487.23 = 18.487 \text{ KN}$$

3.5.0 **STRESS IN THE INTERNAL BASKET**

The stress in the internal basket as a result of the action of the centrifugal force on the wall of the basket is calculated using the formula expressed by Kreg (1975):

$$rb = \frac{Mw2r}{dbsh} \text{ ------------------------------ (64)}$$

Substituting $r = \frac{d}{2}$ and $w = \frac{2\prod N}{60}$

Equation ------------------------ (64) becomes

$$r_b = \left(\frac{2\prod N}{60}\right)^2 \frac{MT}{2\prod hb} \text{ --------------------- (65)}$$

Where, rb = is the stress of the walls of internal basket in N/m^2

M_T = 2.522kg

N = 1000rpm

h = is the height of internal basket = 0.15m

Substituting values in equation -------------------- (65)

$$rb = \left(\frac{2\prod x\ 1000}{60}\right)^2 \left(\frac{2.522}{\prod 2\ x\ 0.15}\right)$$

$$= 10969.1 \text{ x } 2.67593$$

$$= 29352.49 \text{ N/m2}$$

$$= 29.353 \text{ KN}$$

3.51 EXPECTED THICKNESS OF INTERNAL BASKET WALL TO WITHSTAND THE STRESS

Kreg (1975) stated that the expected, thickness of any materials to withstand a centrifugal force could be calculated using formula.

$$tbs = \frac{r_b \, db_s}{2S_s} \text{ -------------------- (65)}$$

Where, tbs = is expected thickness of internal basket wall.

rb = is stress that is developed and acts on the wall of the basket.

dbs = is diameter of internal basket 0.14m

S_s = is shear stress of stainless steel used for construction of the basket.

= $115 \times 10^{e} N/m^2$.

Substituting values in equation:

$$tbs = \frac{29352.49 \times 0.14}{2 \times 115 \times 10^6} = \frac{470485}{23 \times 10^7}$$

$$= 0.00001786673m$$

Thus the exact thickness of the internal basket wall to withstand the stress so considering a safety factor of 50% due to the expected high speed of rotation of the basket.

$$tbs = (0.000020 \ (0.5) + 0.000020$$

$$= 0.00004m$$

But the thickness of material chosen for fabrication of the basket is 0.0004m

3.5.2 SIZE OF MACHINE PULLEY

The size of the machine pulley is determined appropriately in order to enable the machine work at the required speed as follows:

$$N_1 D_1 = N_2 D_2 \quad \text{------------------------} (67)$$

$$D_2 = \frac{N_1 D_1}{N_2} \quad \text{------------------------} (68)$$

Where, N_1 = is rpm of electric motor = 1,500

D_1 = is selected diameter of electric motor = 0.05m

N_2 = is required r.p.m of machine (internal basket) = 1000

D_2 = is diameter of machine pulley

Substituting values in equation ----------------------------

$$D_2 = \frac{1500 \times 0.05}{1000} = 0.075m$$

3.53 LENGTH OF V – BELT REQUIRED FOR POWER TRANSMISSION

The length of V – belt required is calculated as follows:

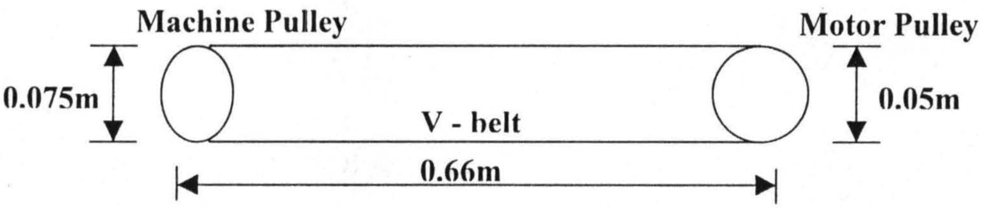


Fig. 3.8

Sketch of power transmission system using V – belt.

$$L_T = \frac{\prod}{2}(D_2 + D_1) + 2_c + \frac{(D_2 - D_1)^2}{4} \quad \text{-----------------} (69)$$

Where, LT = Is length of left required in m

D1 = Is diameter of electric motor pulley = 0.05m

D2 = Is diameter of machine pulley = 0.075m

C = Is center to center spacing of the machine and electric motor pulley = 0.66m.

Substituting values in equation ---------------- (69)

$$LT = \frac{\prod}{4}(0.075 + 0.05) + 2\,(0.66) + \frac{(0.075 - 0.05)^2}{4}$$

$$LT = \frac{\prod}{2}(0.125) + 1.32 + 3.90625 \times 10^{-5}$$

$$LT = 0.19638 + 1.32004$$

$$LT = 1.52m$$

Due to provision of belt adjustment, length of belt required is 1.60m

3.5.4 ANGLE OF CONTACT BETWEENT BELT AND THE MACHINE OR ELECTRIC MOTOR PULLEY

The angle of contacts between the belt and the two pulleys are calculated as follows:

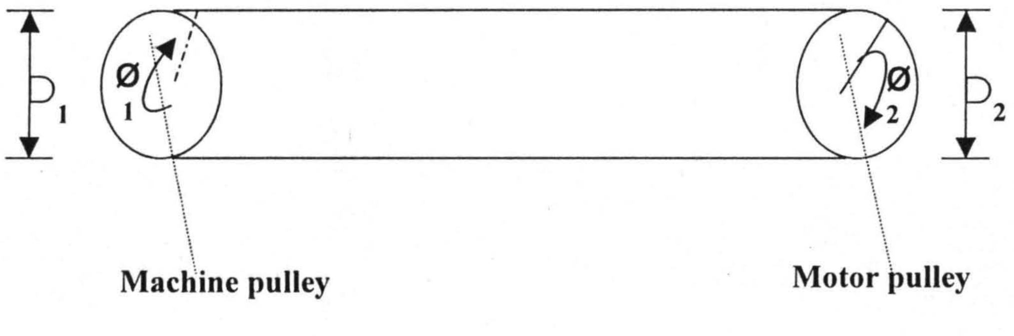


Fig. 3.9

Sketch of power transmission system showing angle contact between belt and pulley.

$$\varnothing_1 = 180^0 + \text{Sin} \frac{(D_2 - D_1)}{2c} \text{ -------------------- (70)}$$

$$\varnothing_2 = 180^0 + \text{Sin} \frac{(D_2 - D_1)}{2c}$$

Where, $\varnothing$ = Is angle of contact between belt and machine pulley

$\varnothing_2$ = Is angle of contact between belt and electric motor pulley.

D_1 = Has been previously defined = 0.05m

D_2 = Has been previously defined = 0.075m

C = Has been previously defined = 0.66m

Substituting values in equation -------------------------

$$\varnothing_1 = 180^0 + \text{Sin}^{-1} \frac{(0.075 - 0.05)}{2\,(0.66)}$$

$$= 180^0 + \text{Sin}^{-1}\ 0.089394$$

$$= 181.09^0$$

Substituting values in equation ------------------------- (70)

$$\varnothing_2 = 80^0 - 2\ \text{Sin}^{-1} \left(\frac{0.075 - 0.05}{2\,(0.66)}\right)$$

$$\varnothing_2 = 1800 - 2\ \text{Sin} -1\ 0.0189394$$

$$\varnothing_2 = 177.830$$

3.5.5 BELT TENSION

The tension the belt is expressed as follows:

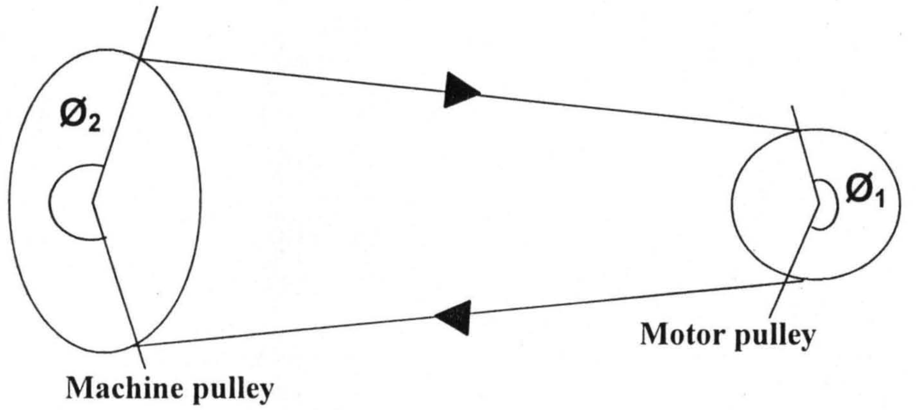


Fig. 3.10: Sketch showing tensions in belt

$$\frac{T_1}{T_2} = e^{\mu Ø} \text{ ----------------------------- (71)}$$

$$W = \frac{T_1 - T_2 \; V}{60} \text{ -------------------- (72)}$$

Where, T_1 = Is the tension of belt on the tight side in N

T_2 = Is the tension on the slack side in N

μ = Is coefficient of friction between belt and pulley = 0.3

V = Is velocity of belt DN in m/sec substituting values in equation.

Ø = Is the angle of contact between pulley and belt in radians

$$\frac{T_1}{T_2} = (0.3) \; \frac{181.09}{180}$$

Substituting values in equation -------------------- (72)

$$\left(\frac{T_1 - T_2}{60}\right) \prod DN$$

$$= \left(\frac{T_1 - T_2}{60} \right) \frac{(\Pi \times 0.075 \times 1000)}{60}$$

$$= \left(\frac{T_1 - T_2}{60} \right) (3.9275)$$

$$W = \left(\frac{T_1 - T_2}{60} \right) V \text{ ------------------- } (72)$$

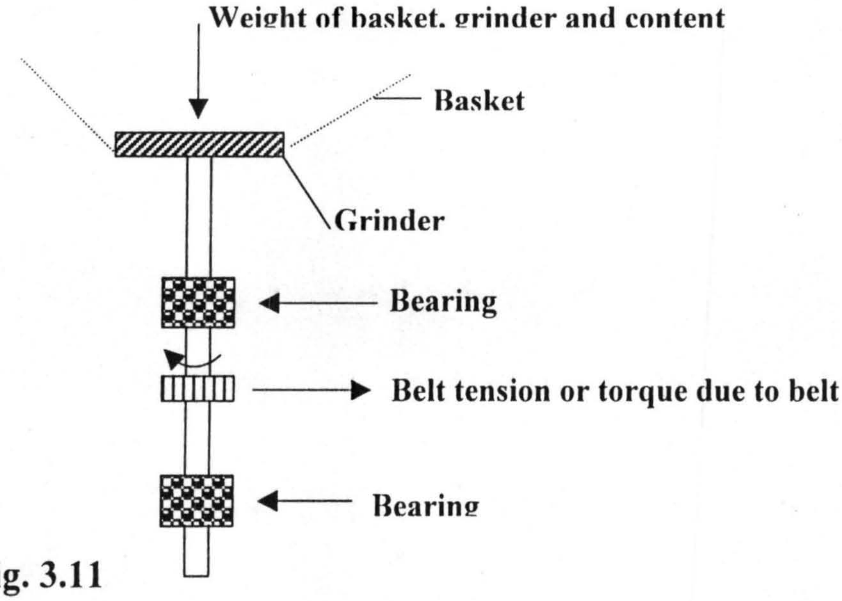


Fig. 3.11

$$\text{Torque} = \frac{\text{Power}}{\text{Velocity of shaft (rad/s)}} \text{ ------------------------- } (73)$$

$$\text{Torque produced by belt} = T_1 - T_2 \frac{(\text{Diameter of driving pulley})}{2}$$

$$= T_1 - T_2 (R) \text{ ------------------------- } (74)$$

Where, R = The radius of the driving pulley

$$\text{Radius of pulley} = \frac{0.075\text{m}}{2} = 0.0375\text{m}$$

Velocity of shaft = Assumed to be: 1000 rpm

Velocity $= 1000\text{rpm} \times 0.104\text{rad/s}$

$= 104.7$ rad/s

Total power = Grinding power x Centrifuging power required.

$= 2.837$ Kw + 0.25Kw (calculated)

$= 3.087$Kw

$T_1 - T_2$ = ? Where, T_1 = Belt tension side

T_2 = Belt slack side

Effective pull of the belt = $T_1 - T_2$

$$T_1 - T_2 = \frac{1000 \times \text{power}}{\text{Velocity (m/s)}} \quad \text{-------------------------} \quad (75)$$

$T_1 - T_2$ = P (effective pull)

$$\text{Power} = \frac{PV}{1000}$$

$$\text{Power} = \frac{(T_1 - T_2)V}{1000}$$

$$\text{Power} \times 1000 = (T_1 - T_2)V$$

$$\frac{\text{Power} \times 1000}{V} = \frac{(T_1 - T_2)V}{V}$$

$$\frac{\text{Power} \times 1000}{V} = \frac{(T_1 - T_2)\ V}{V}$$

$$T_1 - T_2 = \frac{\text{Power} \times 1000}{V\ (\text{m/s})}$$

$$= \frac{3.087 \times 1000}{\frac{\prod DN}{60}} = \frac{3.087 \times 1000}{\frac{\prod \times 0.075 \times 1000}{60}}$$

$$= \frac{3087}{3.927}$$

$T_1 - T_2 \quad = 786.096N$

Torque $\quad = T_1 - T_2 \left(\frac{D}{2} \right)$ ----------------(76)

Where, D = Diameter of driving pulley.

= 786.096 (0.035)

= 27.5134Nm

$\frac{T_1}{T_2} = e^{N Ø_1}$ ----(77) Where, N = Coefficient of friction

Ø = Angle of contact (radian)

$Ø_1$ = Arc of contact for electric motor

$Ø_1$ = 181.09^0

Converting to radian

= 181.09 x 0.1047

$Ø_1$ = 18.960 radians

Using cast iron, steel dry for the pulley and rubber belt:

Ų = 0.30

Source: (machine design by P.C Sharma & et al page 158 (1998).

$$\frac{T_1}{T_2} = e^{0.30 \times 18.960}$$

$$\frac{T_1}{T_2} = 25.59$$

Therefore, $T_1 = 25.59T_2$

$T_1 - T_2 = 786.096N$

$T_1 = \boxed{786.096 + T_2}$

$T_1 = 25.59T_2$

$25.59T_2 = 786.096 + T_2$

$25.59T_2 - T_2 = 786.096$

$24.59T_2 = 786.096$

$\therefore T_2 = \frac{789 - 096}{24.59} = 31.92N$

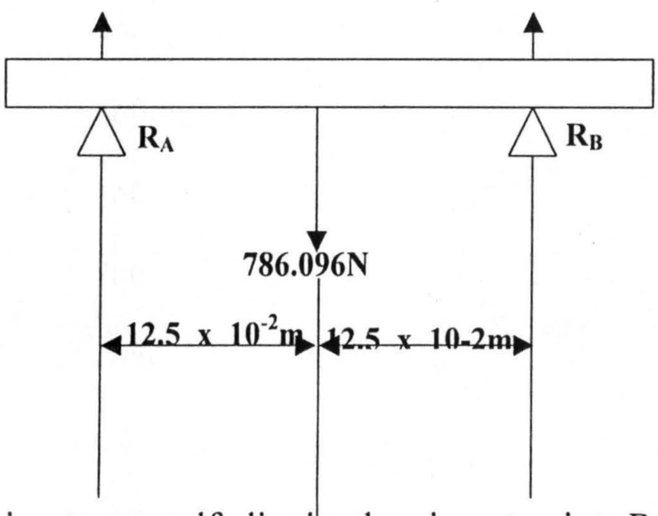
$T_1 - T_2 = 786.096N$

$T_1 - 31.92 = 786.096$

$T_1 = 786.096 + 31.92N$

$T_1 = 818.016N$

SHEAR FORCE DIAGRAM



Since we are going to use self aligning bearing at points RA and RB, the load will be assumed to be simple supported at these points.

For the reactions at points A and B:

Weight of shaft

Radius of shaft - 0.015m

Length of shaft - 0.5m

Density (f,g shaft steel) - 7861Kg/m3

Volume $= \lambda r^2 L$ ------------------------------- (78)

Where,

V = Volume $= \lambda r^2 L$ $= \lambda \times 0.\text{-}15^2 \times 0.5$

r = Radius = 0.030m

L = Length = 0.5m

Therefore, weight of the shaft = Volume x Density = (VP)

Weight = 0.0003534 x 2861kg/m^3

= 2.778kg

$\therefore$ A + B = Effective pull of belt (T_1 - T_2) ------------------ (79)

$R_A + R_B = 786.096$ N

Taking moment about A:

Force x Distance from point of support:

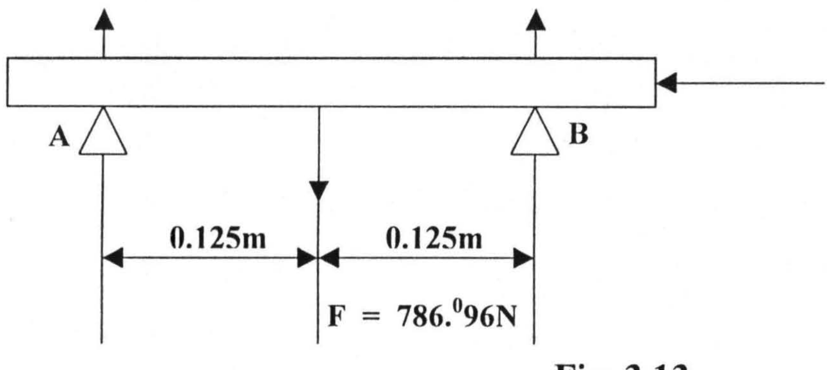


Fig. 3.13

$\longrightarrow +$

M_A: $786.096 \times 0.125m - R_B \times 0.25m = 0$

$98.262 - 0.25 R_B = 0$

$\therefore R_B = \dfrac{98.262}{0.25} = 393.048N$

$R_A + R_B = 786.096N$

$\therefore R_A = 786.096 - R_B$

$= 789.096 - 393.048$

$= 393.048N$

Shear force diagram

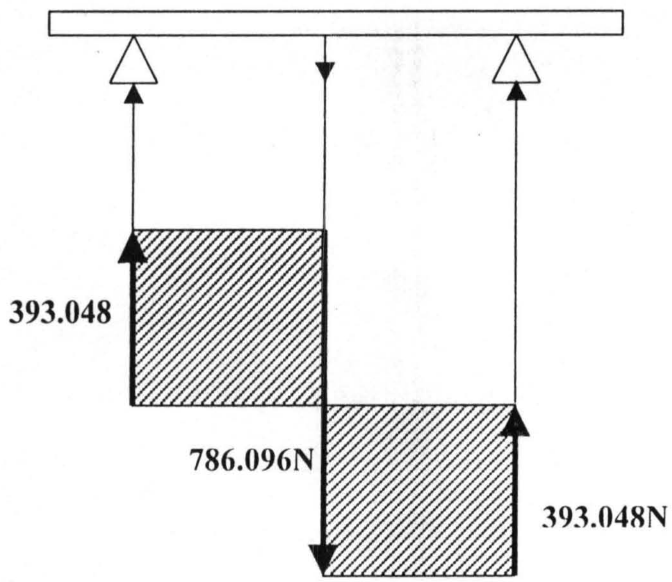


Fig. 3.14

Bending Moment

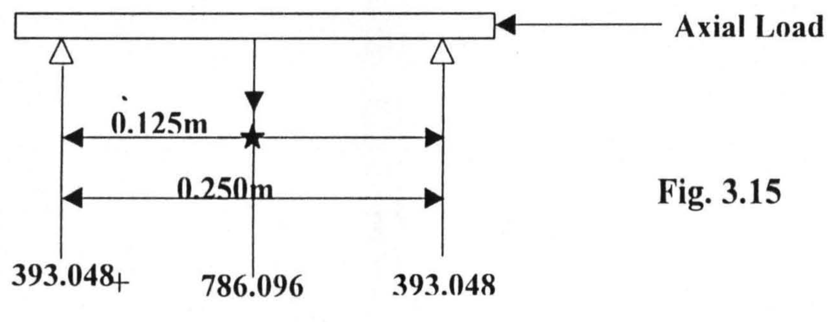


Fig. 3.15

$\xrightarrow{+}$

$M_C: = R_A \times 0.125m$

$= 393.048 \times 0.125 \quad = 49.131NM$

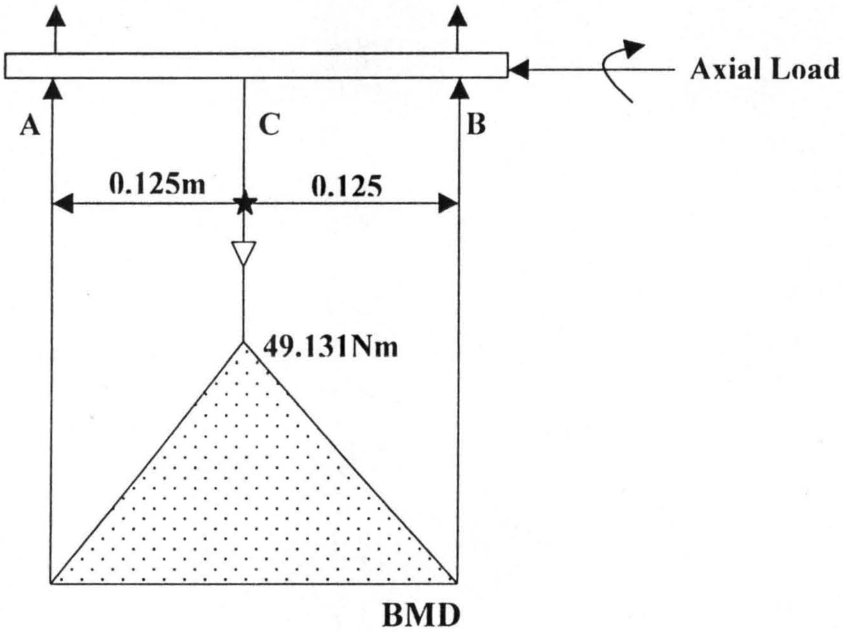


Fig. 3.16

Maximum bending moment $= 49.131Nm$

$F_C = \dfrac{\vartheta F_a}{A}$ Where, F_C = The direct stress due to axial load

ϑ = Constant = 1, since there is no column effect.

Fa = Axial load on shaft

A = Area of cross section of shaft.

$$\text{Maximum shear stress } (F_s) = \left(\frac{(Ks\ 16Mt)^2}{\lambda d^3} + \frac{1}{4} \frac{(Kb \times 32Mb}{\lambda d^3} + \frac{\vartheta\ 4Fa)^2}{\lambda d^2} \right)^{1/2}$$

Source: Machine design, page 12, shaft & axle Sharma et al

Where, (Fs) maxi = Maximum shear stress (N/m^2)

Ks = Shock factor = 1.2 (1.0 – 1.5)

Kb = Fatigue factor = 1.8 (1.5 – 2.0)

Mt = Maximum torgue = 27.5134Nm

d = Diameter of shaft = ?

Mb = Maximum bending moment –

Fa = Maximum axial load: Grinding disc =

0.1585 + bolt =

0.125 + Flange =

0.265 + Basket =

1.92 + Content =

0.0032kg x 9.81

= 24.2471N

ϑ = Constant for our purpose assume it to be = I.

Design stress = 55 MN/m^2 assumed because the shafts hardly have design specifications (see page 10 for shaft & axle, machine design Sharma (1998) & et al)

Taking, Ks = 1.2

Kb = 1.8

$$Fs = \left(\frac{(Ks\ 16\ Mt)^2}{\lambda d^3} + \frac{1}{4} \frac{(Kb \times 32\ mb}{\lambda d^3} + \frac{\vartheta\ 4Fa)^2}{\lambda d^2} \right)^{1/2} \qquad \text{---------------- } 80$$

$\therefore 55 \times 10^6\ N/m^2$ =

$$\left(\frac{(1.2 \times 16 \times 27.5)^2}{\lambda d^3} + \frac{1}{4} \frac{(1.8 \times 32 \ \times \ 49.131 + }{\lambda d^3} \frac{1 \times \ 4 \times \ 24.247)^2}{\lambda d^2} \right) ½$$

$$(55 \ \times \ 10^6)^2 \ =$$

$$\left(\frac{(1.2 \times 16 \times 27.7)^2}{\lambda d^3} + \frac{1}{4} \frac{(28.29.95}{\lambda d^3} + \frac{96.988)}{\lambda d^2} \right)^2$$

$$(55 \times 10^6)^2 \ =$$

$$\left(\frac{(528)^2}{\lambda d^3} + \frac{1}{4} \frac{(2829.95}{\lambda d^3} + 96.988) \right)^2$$

Multiply both sides of the equation by ½:

$$5 \times 10^6) \ 2 \times \frac{1}{2} = \left(\frac{(528)}{\lambda d^3} \ \times \ 2 \times \frac{1}{2} \ \frac{1}{4} \ \frac{(2829.95 \times 96.988d)}{\lambda d^3} \right)^{2 \times \frac{1}{2}}$$

$$55 \times 10^6 \quad = \frac{528}{\lambda d^3} + \frac{5}{5} \ \frac{2829.95 \ + \ 96.988d}{4\lambda d^3}$$

Multiplying both sides by λd^3

$$55 \times 10^6 \times \lambda d^3 \quad = \ 528 + 2829.95 \ + \ 96.988d$$

$$55 \times 10^6 \ \lambda d^3 \quad = \ 3357.95 \ + \ 96.988d$$

$$3357.95 \quad = \ 55 \times 10^6 \ \lambda d^3 \ - \ 96.988d$$

$$3357.95 = (55 \times 10^6 \lambda d^2 - 96.988)d$$

$$55 \times 10^6 \lambda d^3 - 96.955d - 335.95 = 0$$

Using numerical method & solving for non – linear equation. The value of

d = 0.027mm

3.56 FORCE OF THE KEY IN THE MACHINE SHAFT

The key used in connecting the machine pulley to the shaft experiences a force as indicated in the sketch:

The force is calculated as shown:

$$F_K = \frac{2Mt}{ds} \text{ ---------------------- (81)}$$

Where, F_K = Is total mass of basket and it's assembly = (highest considered)

d = Is diameter of internal basket = 0.14m

ds = Is diameter of shaft.

Thus substituting values in the equation --------------------(73)

$$F_K = \frac{M_T \, dbsg}{ds} \text{ ----------------- (82)}$$

3.5.7 DIMENSIONS OF KEY

The appropriate key to be used is calculated as follows:

$$WL = \frac{FK}{S_s} \text{ --------------------------- (83)}$$

Where, W = Is selected width of key =

L = Is length of key in m.

Ss = Is permissible shear stress of key (steel) = 115×10^6 N/m^2

FK = Is force that acts on the key =

Safety factor facts 20%

3.5.8 CRUSHING STRESS OF KEY

$$r_c = \frac{4Mt}{dt_1} \qquad \text{----------------------- (84)}$$

Substituting (84) Mt ----------------------------------

ds = Diameter of shaft = 0.015

t = Is selected thickness of key = 0.005m

L = Is length of key = 0.0615m

3.5.9 INITIAL PRETENTION IN EACH BOLT OF THE FLANGE CONNECTION

The initial pretention in each bolt is calculated using the formula

$$Mt = F \text{ in } \frac{(D + d)}{4} \qquad \text{------------------------- (85)}$$

$$fi = \frac{4Mt}{fn\,(D+d)} \qquad \text{---------------------- (86)}$$

mt = twisting moment torque to be transmitted which in equal to the internal basket and its content torque.

fi = Is coefficient of friction between the force of the flanges, Mitchell (1989) = 0.1.

n = Number of bolts = 4

df = Is outer diameters of friction face of flange = 0.12m

d = Is inner diameter of friction face of flange.

3.6 BEARING

Three suitable rolling content bearings are selected to be the load on the shaft that transmits power to the internal basket.

The bearing size depends on the shaft size (30mm diameter) and is selected from established standard table obtained from Fermer (1978).

Hence bearing No. NU304 is selected.

ESTIMATE FOR THE DESIGN AND FABRICATION OF THE GRINDER / SOYMILK EXTRACTOR: TABLE 3.1

S/No	Material Description	Quantity	Rate	Amout
			₦	₦ K
1.	Drawing papers	3	10	30
2.	Tracing paper	3m	170	510
3.	Plan printing	6	300	300
4.	Channel Iron (50mm x 50mm x 100mm)	1	1,500	1,500
5.	Stainless steel (3mm thick) or Galvanized sheet	1	3000	3000
6.	Oil paint	1	700	700
7.	Bolt and nuts (17mm)	6	15	90
8.	Bolt and nuts (13mm)	30	10	300
9.	Screw and nuts (12mm)	6	10	60
10.	Roller contact bearings (25mm internal hole size θ)	2	300	600
11.	Electrode (guage 12)	1/2pkt	250	250
12.	V – Belt (length =)	2	100	200
13.	Flat bar (Width = 50mm)	1	400	400
14.	Electric motar	1	10,000	10,000
15.	Iron rod (15 x 6mm) (40cmlong)	1	200	200
16.	Elbow joint	1	40	40

17.	Galvanized pipe (37 x 500mm)	60cmlong	200	200
18.	Shaft (25mm dia)	40cm long	500	500
19.	Bushing (25mm dia)	2	100	200
20.	Grinding Wheel (120 dia & 10mm)	2	250	500
21.	Separation filter (muslin)	2	250	500
22.	I- Joint (37. 5dia)	1	50	050

GRAND TOTAL **₦20,130**

CHAPTER FOUR

FEATURES OF THE MACHINE

The machine is mainly made up of the following components as shown in fig 3.17

- **Hopper:** - This holds Soyabean seeds. It is a frustrum with a feed pipe attached at lower and low diameters are 150mm and 55mm respectively. While the total height of the hopper is 160mm.
- **Outer can:** The outer can, a cylinder prevents loss of separated milk. It is 34cm in diameter and high of 20cm. It houses an inner perforated can and also accommodates the feed pipe at its center.
- **Inner can:** This can is a perforated frustrum. A grinding disc is fastened to the base which is coupled to a power transmission shaft. The whole assembly rotates at 1000rpm to generate high centrifugal force. Separation of the soymilk from the paste takes place in the inner can.

Feed pipe assembly: A 37.5mm diameter galvanized pipe is used as a feed pipe.

It directs materials from the hopper to the grinding assembly. The pipe is welded to the hopper and a flange at the top and bottom respectively. A stationary grinding disc is attached to the flange. External and internal threading are also provided of the feed pipe assembly for grinding clearance adjustment between the discs.

Grinding discs: This is a 120mm diameter and 10mm thick cast iron with grooves (burh). A pair is provided one of them is attached to the adjustable feed pipe while the lower one is attached to the rotating inner frustrum and pipe assembly, wet soybean seeds are ground in this assembly.

Separation filter: This is a sieve made of muslin cloth. It is lined as fastened around the inner part of the inner can. It separates the soy-milk from the paste as a result of the centrifugal force generated in the inner can when the machine is working.

Power transmission unit: This consists of a 3.8hp electric motor, belt and pulley. The electric motor generates and supply power to the grinding disc and frustrum assembly with the up of pulley belts and shaft.

Frame: The frame is made of angle iron. The whole machine is fastened to it with the aid of bolts and nuts.

Sketch of soybean grinder/milk extractor.

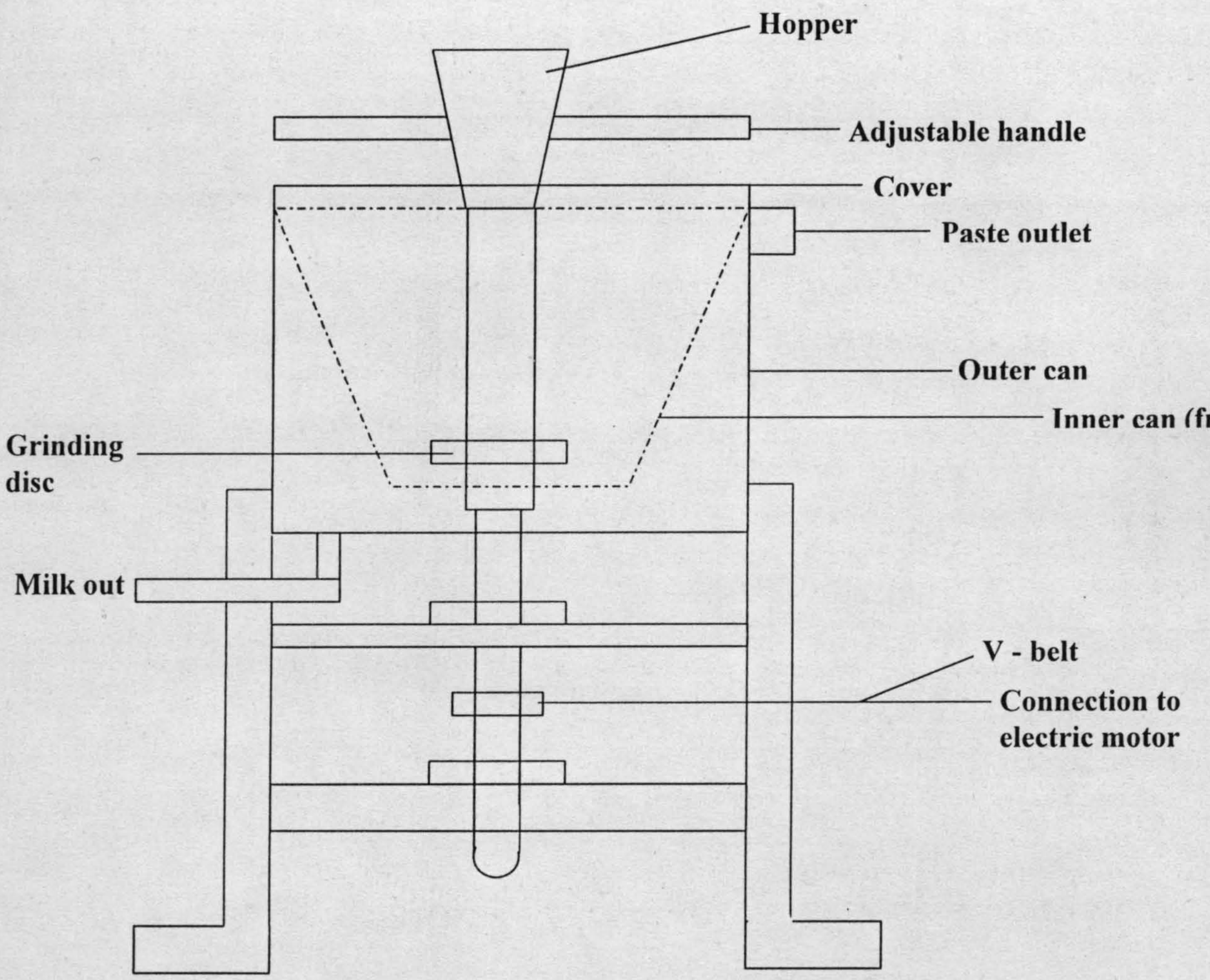


Fig 3.17

MODE OF OPERATION OF MACHINE

Cleaned, soaked and dehulled soybean grains are fed into the hopper after putting on the machine for 2 minutes. The materials are directed down to the disc assembly through the feed pipe. Feed rate and paste fines is controlled by adjustment of the handle on the feed pipe little quantity of water is also added at intervals. The rotation of the disc at (1000rpm) along with the filter lined on the inner perforated can generation of centifugal force for separation of the milk from the paste. The separated milk in liquid form flours through the perforated frustrum and muslin cloth and collected through a bottom outlet while the slurry or residue is discharged through the top of the outer stationary can due to the action of the centrifugal force.

CHAPTER FIVE

5.0 TESTS RESULTS AND DISCUSSIONS

The soybean was pre-cleaned by removing stones, dirts, broken beans etc. One cup of the pre-cleaned soybean was dropped into six cups of boiling water and this was not covered to prevent it from foaming. It continued to boil for twenty minutes (pre-heat treatment). The soybean was then drained, cooled and dehulled. The cooled dehulled soybeans was milled to a smooth paste using little water, this was collected into a bowls from the outer can outlet from bottom of the machine while the separated paste comes out from upper outlet of the can properly filtered. Boil the milk for 5 – 20 minutes to remove odour. Allow it to cool before use.

Finally, a test was carried out to determine the efficiency of the grinder/extractor. The moisture content of the soybean was first determined.

TEST AND RESULT

Two test were conducted. 1kg of soybean (TGX 1448 – 2E) was used with $0.05m^3$ (5kg) of water in each test. 3.2 litres and 4.35 litres of soymilk was obtained in the first and second tests respectively before some problems were observed. Time spent to obtain 3.2 litres was 4 minutes while time spent for the second test was 6 minutes. The consistency (concentration) of the milk were also a little less than the one prepared manually.

Table 5.1

S/No	Weight of Soybean (Kg)	Volume of milk obtained (litres)	Time spent (minutes)
1.	1	3.2	4.0
2	1	4.3	6.0

EXPERIMENT WITH BUCHNER FUNNEL (MANUAL) AS FOLLOWS:

TABLE 5.2

No of Soybean Seeds	Weight of dehulled (soaked) Bean (kg)	Weight of dry bean (kg)	Volume of water added (litres)	Volume of milk (litres)	Time (hr)	Paste (Kg)
21	3.2g	2.4g	10Mls (cm^3)	5.2Mls cm^3	1hr	3g
6,563	1kg	-	3.125	1.63		

MACHINE EFFICIENCY ($\cap p$):

$$\cap p = \frac{\text{Liquid output (Milk)}}{\text{Liquid input}} \times 100, \quad \cap p = \frac{Mo}{Mi} \times 100$$

Where, $\cap p$ = Efficiency

Mo = Mass of milk

Mi = Liquid in

$$\cap p = \frac{Mo}{Mi} \times 100 = \frac{3.2 \text{ Litres}}{5 \text{ Litres}} \times 100 = 64\%$$

Manually

$$\cap p = \frac{Mo}{Mi} \times 100 = \frac{1.63 \text{ Litres}}{3.125 \text{ Litres}} \times 100 = 52\%$$

The following problem were observed during the test.:

- There was little paste escape from the milk outlet mixing with milk
- Grinding bean/paste repeated to obtain fine grinding
- Through paste out let there was little escape of milk into paste.
- During the grinding operation there was leakage of milk underneath machine.

CHAPTER SIX

6.0 CONCLUSION

From the design test carried out on the machine it was observed the:

- The grinder/extractor mills and filters at the same time in a single process
- The machine is simple and easy to operate. Most parts of the machine were joined by bolts thus easy to disassemble and maintain.
- The efficiency of the machine was higher compared to the traditional method (manual)
- The quality of milk obtained the machine can be guqrabteed since the whole process takes place on a single unit.
- Less power requirement about 3.8hp therefore little or no fatigue on the operator.
- The cost of the machine, it is economically available to low income earners and the rural dwellers.

6.1 RECOMMENDATION

In the grinding /filtering unit, there should be a rubber seal before the bearing to stop water leaking through the bearing. The grinding / filtering should be done at least twice or increasing grinding surface of disc to give a smooth paste and good filtration before discarding the paste. This gives a higher output of the required quantity. The paste can be used for Akara, Moimoi, Soap etc. the University and Federal Government should encourage the means of making the machine available for utilization by local farmers.

Use tougher Muslim cloth with finer pores to stop contamination of paste with milk.

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APPENDIX (A)

Table A-6

Energy and force required to initiate fracture in grains under quasi-static loading at a crosshead speed of 0.050 in/min (Bilanski, 1965)

pr of Grain	Moisture %	Kernel position	Energy (in-lbs) Ave.	Energy (in-lbs) Min.	Force (lbs) Ave.	Force (lbs) Min.
Soybeans ✓	1.0	Hilum horizontal	0.034	0.025	13	11
		Hilum vertical	0.029	0.021	12	7
	6.0	Hilum horizontal	0.038	0.033	13	11
		Hilum vertical	0.047	0.042	12	11
	10.0	Hilum horizontal	0.083	0.050	12	8
		Hilum vertical	0.089	0.063	9	7
	16.0	Hilum horizontal	0.279	0.166	10	9
		Hilum vertical	0.150	0.083	7	6
Corn	1.0	Germ side down	0.200	0.167	32	28
		Kernel on edge	0.023	0.017	12	10
	8.0	Germ side down	0.496	0.334	90	72
		Kernel on edge	0.043	0.033	43	28
	17.0	Germ side down	0.606	0.508	71	64
		Kernel on edge	0.043	0.033	22	18
Wheat	1.0	Crease down	0.046	0.025	13	9
		Crease on side	0.040	0.033	11	9
	8.0	Crease Down	0.098	0.076	13	12
		Crease on side	0.058	0.042	12	9
	18.0	Crease down	0.107	0.092	10	8
		Crease on side	0.114	0.077	9	8
Barley	1.0	Crease down	0.035	0.025	14	12
		Crease on side	0.028	0.025	7	6
	10.0	Crease down	0.045	0.042	13	11
		Crease on side	0.042	0.042	14	12
	17.0	Crease down	0.051	0.042	12	11
		Crease on side	0.041	0.029	10	8
Oats	1.0	Crease down	0.077	0.063	9	7
		Crease on side	0.111	0.073	8	5
	10.0	Crease down	0.105	0.083	8	7
		Crease on side	0.151	0.075	9	7
	16.0	Crease down	0.117	0.083	9	8
		Crease on side	0.143	0.121	10	9

Table A-7 Specific gravity of fruits and vegetables

oduct	Specific gravity	Reference
ple		
Delicious	0.83	Cooper, 1962
Delicious	0.83	Mohsenin *et al.*, 1965
Golden delicious	0.75	Cooper, 1962
Golden delicious	0.81	Mohsenin *et al.*, 1965
Golden delicious	0.79–0.84 0.81	PSU, Unpublished
McIntosh	0.74	Cooper, 1962
McIntosh	0.81	Mohsenin *et al.*, 1965
McIntosh	0.77–0.80 0.78	PSU, Unpublished
Melba	0.71	Cooper, 1962
Melba	0.79	Mohsenin *et al.*, 1965
Melba	0.76–0.81 0.80	PSU, Unpublished
Rome beauty	0.79	Cooper, 1962
Rome beauty	0.82	Mohsenin *et al.*, 1965
Rome beauty	0.82–0.87 0.84	PSU, Unpublished
Stayman	0.82	Cooper, 1962
Stayman	0.86	Mohsenin *et al.*, 1965
Stayman	0.82–0.89 0.86	PSU, Unpublished

Product	Specific gravity	Reference
Lisbon	0.92	Turrel & Slack, 1948
Marsh Grapefruit	0.81	Turrel & Slack, 1948
Citrus-Orange		
Valencia	0.93	Turrel & Slack, 1948
Washington Naval	0.95	Turrel & Slack, 1948
Coffee	1.01–1.09 1.05	Eschenwald, 1959
Pear		
Maxine	0.98–1.00 0.99	PSU, Unpublished
Peach		
Elberta	0.99–1.01 0.99	PSU, Unpublished
Red Haven	0.98–1.03 1.00	PSU, Unpublished
Plum	0.99–1.08 1.05	PSU, Unpublished

Hayat

Table A–30 Selected Conversion Factors
(SI) System of Units
(Symbols are given in parenthesis)

Length	
t (12 in.)	3.048×10^{-1} (m)
h	2.54×10^{-2} (m)
Area	
uare foot (144 in²)	9.290×10^{-2} (m²)
uare inch	6.452×10^{-4} (m²)
Volume	
allon U.S. (231 in³)	3.785×10^{-3} (m³)
ubic foot	2.83×10^{-2} (m³)
Mass and Force	
pound mass	4.535×10^{-1} (kg)
pound force	4.443 (N)
dyne	1×10^{-5} (N)
Slug	14.593 kg
Speed	3.048×10^{-1}
ft/sec	
foot/min	5.08×10^{-3} (m/s)
inch/sec	2.54×10^{-2} (m/s)
Acceleration	
foot/sec²	3.048×10^{-1} (m/s²)
inch/sec²	2.54×10^{-2} (m/s²)
32.141 ft/sec²	9.807 (m/s²)
Density	
Slug/ft³	515.3788 (kg/m³)
pounds/ft³	1.602×10^{1} (kg/m³)
pounds/in³	2.763×10^{4} (kg/m³)
pounds/U.S. gallon	1.198×10^{2} (kg/m³)
Pressure	
pound force/ft²	4.788×10^{1} N/m² (Pa)
pound force/in² (psi)	6.895×10^{3} N/m² (Pa)
inch of water (60°F)	2.488×10^{2} N/m² (Pa)
inch of mercury (60°F)	3.377×10^{3} N/m² (Pa)
atmosphere (760 mm Hg, 0°C)	1.013×10^{5} N/m² (Pa)

(continued)

1 dyne/cm² =
1 slug = 32.17 lb = 14.593 kg
1 lb = 3.108×10^{-2} slug
1 lb/ft³ = 3.108×10^{-2} slug/ft³ = 16.02 kg/m³

Table A–30 (continued)

Energy	
Btu	1.055×10^{3} joule (J)
calorie	4.197 joule (J)
foot pound-force	1.356 joule (J)
watt hour	3.6×10^{3} joule (J)
Power	
Btu/hr	2.931×10^{-1} watt (W) = J/s
foot pound-force/min	2.260×10^{-2} watt(W) = J/s
horsepower (550 ft-lb/sec)	7.457×10^{2} watt (W) = J/s
Viscosity	
centipoise (dynamic)	1×10^{-3} N.s/m² (Pa-s)
pound mass/foot-second (dynamic)	1.488 N.s/m² (Pa-s)
pound force-sec/ft² (dynamic)	4.788×10^{1} N.s/m² (Pa-s)
square foot/sec (kinematic)	9.29×10^{-2} (m²/s)
Flow Rate	
pound mass/min	7.560×10^{-3} (kg/s)
cubic feet/min	4.719×10^{-4} (m³/s)
gallon U.S./min	6.309×10^{-5} (m³/s)
Thermal Units	
Conductivity:	
Btu-in/hr-ft²–°F	1.441×10^{-1} (W/m–°C)
	1.441×10^{1} $\frac{W-cm}{m^2-°C}$
Btu-ft/hr-ft²–°F	1.73 (W/m–°C)
Conductance:	
Btu/hr-ft²–°F	5.678 (W/m²–°C)
Flux density:	
Btu/ft²	1.136×10^{4} (J/m²)
Heat capacity and specific heat:	
Btu/lb mass	2.326×10^{3} (J/kg)
Btu/lb mass °F	4.187×10^{3} (J/kg–°C)