DESIGN AND CONSTRUCTION OF A

SOYBEAN MILK FILTER PRESS

BY

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(91/2287)

A PROJECT SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE - NIGERIA.

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR OF ENGINEERING (B.Eng.) DEGREE IN AGRICULTURAL ENGINEERING.

MARCH '98

DECLARATION

I, BANSEKA HYCINTH S.T. hereby declare that this project is an original work of mine, and has never been presented elsewhere for the award of any degree. Information derived from published works of others have been acknowledged in the write up.

Banseka Hycinth T.

13/03/98

Date

CERTIFICATION

I the undersigned, hereby certify that I have read, approved and do recommend for acceptance by the School of Engineering and Engineering Technology this project work titled 'Design and Construction of A soybean milk Filter Press' by Banseka H.S.T.

13.03.98

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DEDICATION

This project is dedicated to my sisters,

Appolonia Ayen

Jane-Frances Yenlajai

Praxedes Mbiydzenyuy

Cecilia Nyuyleyadzem

Prudence Beri

ACKNOWLEDGMENT

I wish to express my profound gratitude to the Almighty God for giving me the wisdom and strength to carry out this work to completion.

My sincere thanks goes to my supervisor, Engr. Dr. D. Adgidzi who was always ready to read, criticise and offer alternative suggestion at every stage of this work.

I also wish to thank the Acting Head of Department Engr. Dr. A. Ajisegiri, the members of staff, both academic and non-academic and the entire students of the department of Agricultural Engineering for their academic and moral support throughout my stay in the Department.

My appreciation goes to the Cameroon Government for their financial support during my studies.

Finally I want to specially thank my parents Mr. Michael . Banseka and Mrs. Rose Banseka for their financial and moral support throughout my studies. My progress in life has been as a consequence of their encouragement and untiring prayers. May the Lord continue to Bless them.

ABSTRACT

The search for alternative sources of protein to augment the diet of malnourished African families is intensifying due to the high cost of animal proteins.

The soybean plant, with a protein content of about 40% is a cheap source of high quality plant protein, and its impact on African diets has earned it the name 'Gods sent bean' or the 'miracle seed'.

Soybean milk, a product of processed soybean has a nutritional composition comparable to that of animal milk, thus its use as an alternative to expensive animal milk.

The horizontal filter press designed is to make the filtration of milk from mash more efficient and hygienic.

The machine had a throughput of 6.286 l/hr when a mixture of one cup of soybean mash and one cup of water was used.

The production efficiency of the machine was 60.9%, and it was found that the rate of filtration increased with decreasing concentration of the mixture of mash and water.

The machine is portable, easy to operate and maintain, and needs installation on a solid foundation. With a total cost of ₦ 4385.00, the machine is cheap and economical available to the low income earners or rural dwellers for whom it is meant.

LIST OF SYMBOLS

NAME	SYMBOL	DESIGNATION
1) Alpha	α	Helix angle
2) Beta	β	Deflection angle
3) Rho	$\int$	Density
4) Mu	μ	Coefficient of friction
5) Nu	η	Efficiency
6) Pi	π	
7) Phi	ϕ	Angle of friction
8) Sigma	σ	Stress
9) Tau	τ	Torsional shear stress
10)Theta	θ	Angle.

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CHAPTER ONE

1.0 HISTORY OF SOYBEAN PRODUCTION

The early history of soybean, like that of most food crops is lost in obscurity. However, ancient Chinese literature reveals that the soybean was extensively cultivated and 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 Ussuriensis [10], growing wild in South East Asia. However, according to Fukuda (1933), Manchuria should be regarded as the center of origin since in shows great diversity of form in this area.

The first written record of this plant, according to Morse (1949) appears in Materia Medica, "The Heavenly Farmer", written by the Chinese Emperor Sheng-Nung in 2838BC. It was the most important cultivated legume and one of the five most sacred grains (soybean, rice, wheat, barley and millet) essential to the existence of Chinese civilisation.

Confucius, the great Chinese philosopher 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, or Manchurian bean because of its Eastern Asian origin. Since its spread to other parts of the world, soybean have become more popular.

From China the crop spread to neighbouring Asian countries - Korea, Japan and remained confined to Asia as a cultivated crop. When the German botanist Englebert Kaempfer visited Japan in 1961 and published his book Amoenitatum Exoticum in 1712 [10], Europeans started appreciating the importance of soybeans to Eastern diets.

In US literature, soybean was first mentioned in 1804 (Mease) when it was it was commercialised. Though introduced in Brazil in 1882 (Daffert, 1892), it took about 100 years to become an important crop.

Although attempts where made to grow soybeans in Nigeria as early as 1908, the first successful cultivation of the crop was in 1937, when the variety Malayan was introduced. Production then, was concentrated in the present areas of Benue, Kaduna and Niger states, as well as the Federal capital territory.

1.1 BIOLOGICAL DESCRIPTION OF SOYBEAN

The soybean is a member of the family Leguminosae, sub-family Papilionoideae and genus Glycine L. Cultivated soybean has been known by several botanical names, but in 1948 Ricker and Morse presented evidence that the correct botanical name should be Glycine Max (L) Merrill. Though most often referred to as Glycine Soja and Soja Max in earlier literature, the name Glycine Max has been used almost exclusively in scientific literature since 1948.

Cultivated soybean is a leguminous annual, normally bushy, erect and much branched with well developed roots. It is normally less than 75cm in height.

Almost all varieties are pubescent, with trifoliate leaves, each compound leaf consisting of three leaflets which begin to turn yellow and fall off as the pods reach maturity. The pods contain three or more small, hard, ovoid seeds usually unicoloured (yellow, green, brown, red [illegible] black), though occasionally bicoloured. Pale yellow is the most commercially acceptable colour of soybeans intended for human consumption.

1.2 GROWING SOYBEANS

With increasing research in soybean biotechnology, and consequent production of cultivators adapted to various environment, the range of soybean is worldwide. However, the soybean is a warm temperature, short day plant growing best in the dry-moist Savannah, that is, in regions similar to those for growing maize and sorghum.

A mean daily temperature of 30°C to 32°C is most acceptable. Whitt and Van Bavel (1955) estimated water use at 0.76cm per day peak periods, and found that a rainfall of between 500mm and 750mm spanning for a period of 90 to 180 days will meet this crop water requirement.

Soybeans need deep, well-drained fertile loam soils with good water holding capacity for good yield. The soil pH should be maintained between 5.5-6.5, as acidic soils reduce module bacteria acidity.

Provided there is sufficient moisture and rhizobium bacteria (inoculating organisms) are present, no fertilizer is really required to grow soybean. Mulching is highly recommended.

In the middle latitudes, 30°- 40° North and South, where most soybeans are grown, photoperiodicity is very important and governs planting date. The choice of planting date should be such that the plant makes plenty of vegetative growth during long days before being exposed to short days which initiate flowering. Thus in the Northern Hemisphere May is a better time for planting than June.

Soybeans grow poorly under shade or reduced light as bright sunlight aids rapid leaf growth and healthy plant development. It is however, very sensitive to drought.

Due to its high sensitivity to soil and climatic conditions, soybean varieties are numerous. The major factors determining which variety is planted where include nodulation, storability, shattering, buckling and vulnerability to insect pests and diseases.

Three varieties have been recommended for growth in Nigeria.

(ii) TGx 536 - 02D

(iii) TGx 849 - 313D

Based on how long it takes to mature they could be

(I) Short duration : 75 - 84 days

(ii) Medium duration : 85 - 94 days

(iii) Long duration : 95 - 110 days

The recommended growing period is between May and September.

The seeds could be planted 5 - 6 cm apart on rows 60 cm to 70 cm apart. For better yields the crop is best rotated or strip-cropped, intercropping increases the risk of overshading. Weed on time and watch out for fungal disease, frogeye leaf spot, which can cause up to 50% loss. The pods are harvested when they turn brown, tan or gray, under dry conditions, and stored at a moisture content of 13% or below.

1.3 WORLD PRODUCTION

World soybean production amounts to 107,350,000 metric tonnes (MT), with an average seed yield of 1841 KG/Ha. Presently, the US is the highest single producer (52440000 MT) accounting for about 50% of world production, followed by Brazil (24044000 MT) and China (10818000 MT). These three countries account for about 81% of the world production [16].

In Africa, Zimbabwe is the largest producer (176000 MT), followed by Egypt (136000 MT), South Africa (80000 MT), and Nigeria with an estimated production of 75000 MT [16]. However, in Africa, Nigeria has the largest area harvested (estimated at 215000 HA), but with one of the lowest yields (349 KG/Ha), [16].

1.4 COMPOSITION OF SOYBEAN

Unlike most oilseed species, soybean is a dual purpose plant, containing about 20% oil and 38% protein by weight. Soybean occupies a premier position as a world crop because it is the best plant source of good quality protein and high quality edible vegetable oil rich in unsaturated fatty acids. The approximate chemical composition of raw soybean is shown in Table 1.0.

Soybean, however, also contains some anti-nutritional components like :

a) trypsin inhibitors which cause growth inhibition and enlarged pancreas in animals..
b) Hemagglutinins which agglutinate red blood cells.
c) Goitrogen which causes enlargement of the thyroid gland, and
d) Urease which degrades urea to ammonia, which is toxic to animals.

These components can be inactivated by heat, thus heat treatment is an obligatory step in soybean processing.

1.5 SOYBEAN PROCESSING AND UTILIZATION

At present soybeans do not yet play an important role in human nutrition because they are relatively difficult to tenderise by ordinary cooking, and have an objectionable beany taste to Africans.

With Africa facing increasing problems of malnutrition, particularly in areas of protein deficiency, caused fundamentally by ignorance and POVERTY, the soybean has been described as 'Gods sent bean' or 'miracle seed' by Africans as it is a cheap and available source of high quality protein. The high cost of living has made animal protein unaffordable to a majority of Africans.

Thus, 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 treatment is an inevitable unit process in soybean processing because of its beneficial effect on nutritive value due to inactivation of trypsin inhibitors and hemagglutinins.

Products of soybean processing include soy flour, 'soymilk', soycake, soy-biscuit, soy oil, soy ogi, soy moinmoin, soy eba, amongst others. It is also widely used to augment the nutritional quality of other food products as in bread. However, the focus of this work shall be on the processing of soybean to 'soymilk'.

1.5 'SOYMILK' PROCESSING

Milk is defined as a fluid secreted by the mammary glands of mammals for the nourishment of their young, for a period beginning immediately after birth [Micropaedia Britanica REF. VI (890)]. It is based on this definition that soymilk is used in quotes.

'Soymilk' is so called because of its milky appearance and comparable composition to milk from mammary glands [TABLE 1.1]..

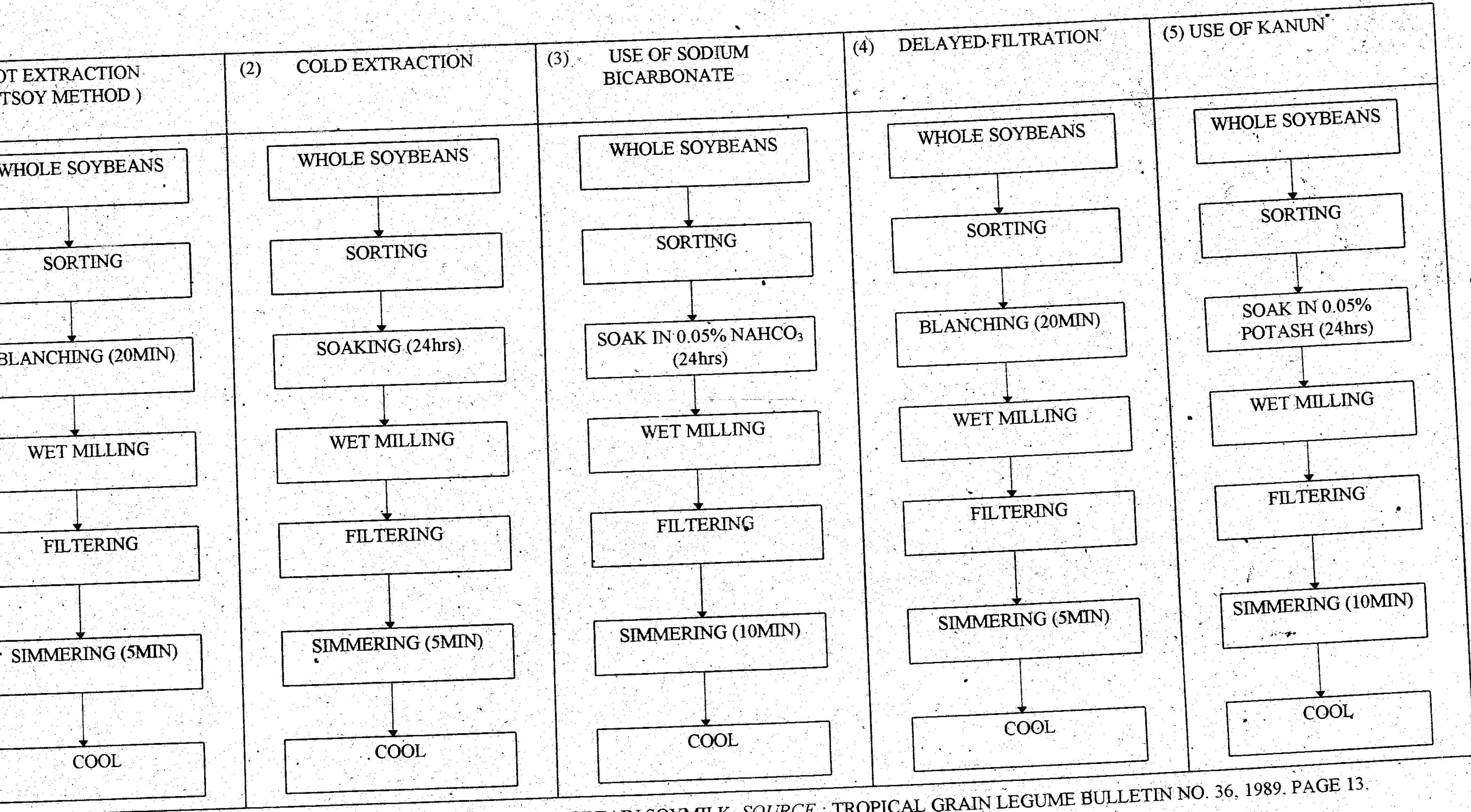
Work so far done and reported on techniques for 'soymilk' processing are summarised in figure 1.

Traditional or local processing of 'soymilk' is similar to cold extraction in figure 1, but for the fact that the filtrate is augmented with salt and sugar, boiled for at least 20 minutes, and flavoured before being allowed to cool. The cooled liquid is thus ready for consumption.

It must be stated here that the recommended mix by weight of milled soybean to water, before filtration, is one to five. It might vary depending on the concentration required.

Due to the lack of knowledge about, and need to minimize the use of chemical additives in 'soymilk' production [techniques 3 and 5, figure 1], and the burning hazards involved in hot processing [techniques 1 and 4] in rural households, this work will be directed at cold extraction technique.

Furthermore, in an experiment to determine the effect of processing technique on 'soymilk' yield and quality at IITA Ibadan, Ogundipe, Dashiell and Osho found that cold extraction produced the highest 'milk' yield, while quality varied depending on the soybean variety used. This further justifies my focus on this technique.



RE 1 : FLOW CHART OF THE PROCESSING TECHNIQUES USED TO OBTAIN SOYMILK. *SOURCE* : TROPICAL GRAIN LEGUME BULLETIN NO. 36, 1989, PAGE 13.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

Previous works on 'soymilk' production have been centered on the unit process of filtration.

Oye (1995) designed and constructed a horizontal filter press for 'soymilk'. The press uses a power screw and incorporates a system of gears for speed reduction as pressing requires a 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, needs expert installation and operation, and was quite costly (N50000) to construct. The machine is presently at IITA Ibadan soybean processing department.

In 1996, in an attempt to improve on Oye's work, Professor Babatunde L. supervised the design and construction of a manually operated 'soymilk' filter press by a masters degree student at the University of Ibadan. The screw press is vertical, utilising a power screw above, and a hydraulic jack at the bottom.

The press was easier to maintain, less bulky, lighter, and cheaper than Oye's. However, it was still heavy, bulky, expensive (N25000) and not easy to operate. Also the press plate used bends upwards at the edges due to the pressure of the pressing.

Engineer Gbabo, head of the fabrication workshop, NCRI Badeggi, attempted to construct a machine that incorporates the unit operation of milling and filtration. This attempt proved abortive as effective filtration could not be achieved due to difficulty of finding an efficient and reliable filter cloth.

In view of the problems associated with existing machines described above, this project will attempt to further optimise the filter press by solving some of the problems enumerated.

2.1 FILTRATION THEORY

Filtration is a mechanical separation technique in which a liquid is separated from a two phase solid-liquid system by imposing a screen in the flow path, which restraints 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 suspended 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 apertures necessary for filtration are provided by fabric filter clothes, meshes and screens of plastic or metals, or by beds of solid particles.

This project is centered on cake filtration. As filtration progresses, solid particles reaching the filter surface became trapped in it. A layer of cake gradually builds up on the filter surface and the resistance to flow through the filter progressively increases. Below is a diagram showing the principle of cake filtration.

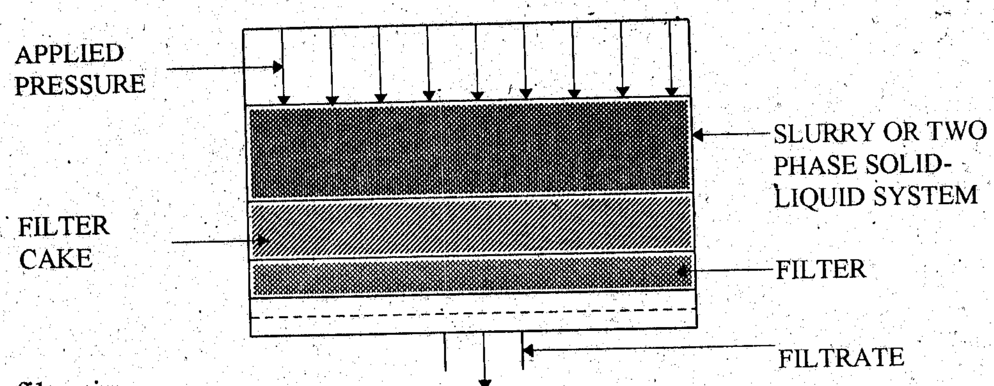


Fig 2.0 Cake filtration.

When the force or pressure differential (Δp) is constant, the volume of filtrate V passing through $1m^2$ of a filtering surface during time t, and the duration of filtration t are related by the equation

$$V^2 + 2VC = Kt \qquad \text{----------------(1)}$$

Where

C = filtration constant characterising the hydraulic resistance of the filtering partition, (M^3/m^2).

K = filtration constant allowing for the condition of the filtration process and the physicochemical properties of the sediment and the liquid, (m^2/s)

t = duration of filtration, (s).

The constant K and C will be determined experimentally during testing.

The rate of filtration, dV/dt ($m^3/m^2.s$), at a given moment will be calculated thus:

$$dV/dt = k/(2(V + C)) \qquad \text{-------------(2)}$$

2.2 PROBLEM DEFINITION

All the unit processes for traditional production of 'soymilk' are manual but for milling due to the availability of mills. The other unit process requiring high input of human energy per unit time is filtration, which is still mostly done manually.

Thus, mechanising filtration will go a long way to standardising 'soymilk' production process.

2.3 JUSTIFICATION

Due to the high incidence of malnutrition in Africa, the high protein, ease of growth, adaptability and economic availability of soybeans makes it an ideal supplement for the predominantly carbohydrate diet of most Africans.

However, because of the anti-nutritional factors present in it, raw soybeans do not support human or animal growth. The soybean or its products need to be well worked or heat treated prior to consumption. Since raw soybeans are difficult to tenderise by ordinary cooking, they do not yet play an important role in African diets. Consequently, simple mechanical methods for processing soybean into its various products (soymilk,........) need to developed and introduced into small-scale industries and rural households.

Since this project targets rural dwellers, traditional 'soymilk' production technique will be my guide. The unit process of filtration in this technique involves the application of pressure with bare hands on soybean mash in a muslin cloth. This is unhygenic as dirt and germs trapped on the palms of the hand get transferred to the 'milk' product, thus adversely affecting its quality.

Also the 'milk' yield will vary as the compressive strength of the person carrying out the pressing. Varying quantities of 'milk' will remain trapped in the cake as filtration progresses. High quality 'milk', and maximum and standardised 'milk' yield can be obtained by eliminating the use of hands through use of a mechanical device for filtration.

2.4 OBJECTIVES

This project is aimed at mechanising the unit process of filtration in 'soymilk' production through.

1. Design of a machine that will effectively and efficiently filter 'soymilk' from soybean mash, and
2. Construction of this machine such that it will be simple, easy to operate and maintain, and economically available to rural dwellers.

The machine is thus expected to produce maximum yield or quantity of

TABLE 1.0 : Nutritional composition of soybean.

NUTRIENTS	AVERAGE WEIGHT per 100g RAW SOYBEAN[g]
Moisture	7
protein	35-45
Oil	18-22
carbohydrate	12-14
Crude Fibre	3.7-5.0
Ash	4.6-5.4
Calcium	0.25
Phosphorus	0.7
Iron	0.007
Potassium	1.53
Sodium	0.319
Nicotene	0.0021

TABLE 1.1: Comparative nutritional composition of cow, human, and soybean milk.

ITEM								
MILK	WEIGHT [g]	WATER [g]	PROTEIN [g]	FAT [g]	VIT A [g]	VIT B [g]	Ca [g]	ZINC [g]
COWS	224	213	8.0	8.0	-	1.84×10^{-3}	0.288	0.001
SOY	263	243	8.9	4.0	105	1.28×10^{-3}	0.055	0.0004
HUMAN	248	216	2.4	11	592	0.16×10^{-3}	0.080	0.0004

CHAPTER THREE

DESIGN

3.0 POWER SCREW THEORY

A manually driven power screw is the power unit of this machine.

Power screws are mechanical devices by means of which a large amount of mechanical advantage can be obtained. They are used to convert rotational motion to translatory motion.

Power screws have the disadvantage of high frictional losses and low transmission efficiency, but with the advantage of simplicity in design, heavy load carrying capacity, high accuracy and smooth, quiet and slow power flow.

Power screws are often subjected to a combination of stresses. The common forms are the square, ACME and buttress threads.

Square threads, with zero profile angle have the highest efficiency, but are costly to manufacture.

Where unidirectional power transmission is required, the buttress thread is the best alternative as it also incorporates the high efficiency and simplicity of the square and Acme threads respectively. However, buttress dies are scarce.

The Acme thread with a 15° profile angle is easy to manufacture and relatively available at workshops. Thus this design will utilise an Acme thread.

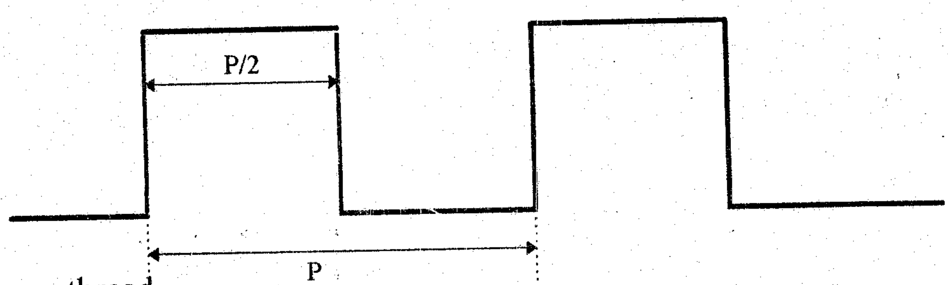


Fig 3.1 square thread

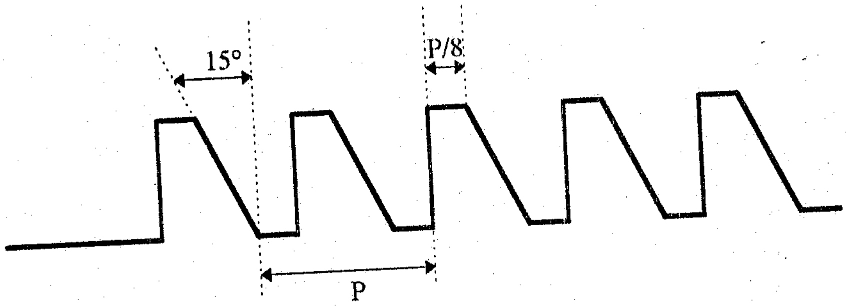


Fig 3.2. Buttress thread

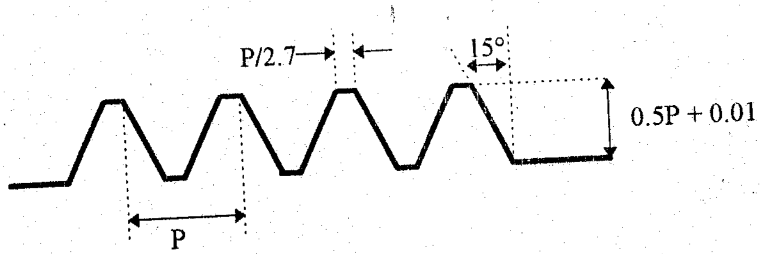


Fig 3.3. Acme thread

P, the thread pitch is the distance between a point on one thread and the corresponding point on an adjacent thread regardless of whether the screw has single or multiple thread.

While the lead is the displacement of the nut or screw resulting from one full turn of either of them for single thread the lead = pitch.

The design calculations will thus focus on the single thread Acme screw.

3.1 DESIGN CALCULATIONS

3.1.0 DESIGN OF PRESS PLATE

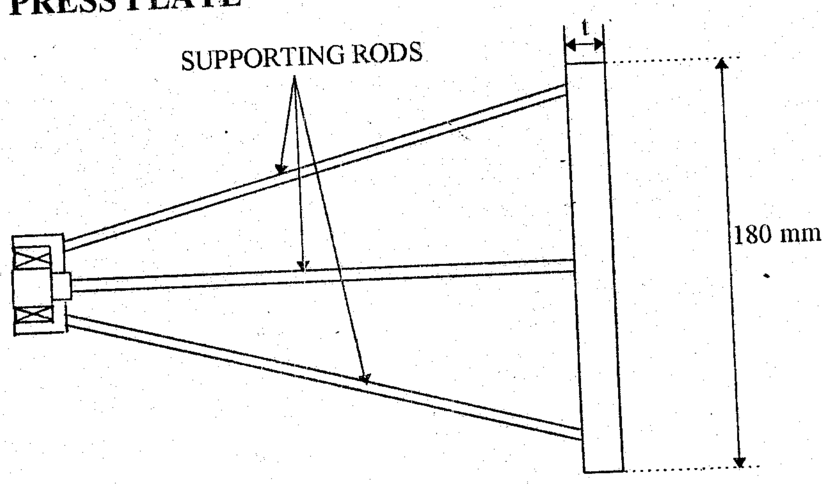


Fig. 3.4 Press Plate.

Material used : Steel; Grade : C40 or 40C8

From [2],

Ultimate Stress, $\sigma_{ut} = 700N/mm^2$

Yield Strength, $\sigma_y = 0.65 \times \sigma_{ut}$ ---------------(3)

$= 0.65 \times 700N/mm^2$

$\sigma_y = 455N/mm^2$

Taking,

mass of soybean mash (milled soybean + water) + bag = 20Kg

$\Rightarrow$ Weight of (mash + bag), $W_{mb} = (20 \times 9.81)N$

$= 196.2N$

For the design, use $W_{mb} = 200N$

Diameter of press plate, $d_{pp} = 180mm$ (assumed);

Surface Area of press plate, $A_{pp} = \pi/4(d_{pp})^2$

$A_{pp} = \pi/4 \times (180 \times 10^{-3})^2 m^2$

$A_{pp} = 0.0254m^2$

Taking the resistance of soybean mash to pressing, R_{sm} as

$R_{sm} = 200N$

$\Rightarrow$ Total force acting on the press plate F_{pp}, is thus

$F_{pp} = W_{mb} + R_{sm}$

$F_{pp} = (200 + 200)N$

$F_{pp} = 400N$

Pressure on the plate, $P_{pp} = F_{pp}/A_{pp}$

$P_{pp} = (400/0.0254) N/m^2$

$= 15719.0 N/m^2$

$P_{pp} = 1.572 \times 10^{-2} N/mm^2$

The formula for calculating the thickness of the plate, t, is given in [1] as :

$$S = 0.24W/t^2 \text{ -------------(4)}$$

Where t = thickness of plate, mm

S = maximum tensile stress in plate, N/mm^2

W = total force on press plate, N.

From (4), making t the subject of the formula :

$$t^2 = 0.24W/S$$

$$t = [\ 0.24W/S\ ]^{1/2} \text{ -----------(5)}$$

But $W = F_{pp}$, $\Rightarrow W = 400N$

$S = \sigma_{ut}$, $\Rightarrow S = 700N/mm^2$

Substituting in equation (5) :

$$t = [\ 0.24 \times 400/(\ 700\ )\ ]^{1/2} \text{ mm}$$

$$= [\ 0.137\ ]^{1/2} \text{ mm}$$

$$t = 0.37 \text{ mm} \qquad [\text{ minimum thickness }]$$

For this design use gage 8 sheet metal [US standard] of thickness

$$t_{pp} = 0.1759''$$

$$= (\ 0.1759 \times 25.4\ ) \text{ mm}$$

$$t_{pp} = 4.37 \text{ mm}$$

Volume of press plate, $V_{pp} = A_{pp} \times t_{pp}$

$$= 0.0254 \times 4.37 \times 10^{-3} \text{ m}^3$$

$$V_{pp} = 1.1 \times 10^{-4} \text{ m}^3$$

From Density = mass/volume ------------(6)

and Density of steel, $\int st = 7790 \text{ Kg/m}^3$

$\Rightarrow$ mass = Density $\times$ Volume

$= (7790 \times 1.1 \times 110^{-4})$ Kg

$m_{pp} = 0.865$ Kg

Weight of press plate, $W_{pp} = m_{pp} \times g$

$= (0.865 \times 9.81)$ N

$W_{pp} = 8.5$ N

3.1.1 DESIGN OF SUPPORTING RODS

Three rods share uniformly the force on the press plate, and the weight of the press plate as shown in figure 34above. Thus,

Load shared, $W_L = (400 + 8.5)$ N

$W_L = 408.5$ N

Load on each rod, $W_x = W_L/3$

$= 408.5/3$

$W_x = 136.17$ N

Allowable compressive stress (axial stress) of steel, $\sigma_{cs} = 128$ N/mm^2

But from, stress = Force/Area -------------------(7)

$\Rightarrow \sigma_{cs} = W_x/(\pi/4\,(d_x)^2)$ where d_x = minimum diameter of rod.

$d_x^2 = 4 \times W_x/\pi \times \sigma_{cs}$

$d_x = [4 \times 136.17/\pi \times 128]^{1/2}$ mm

$d_x = 1.16$ mm

For this design, take diameter of each rod, d_r as

$d_r = 8.0$ mm

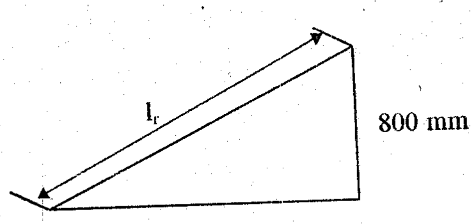


Fig 3.5 Supporting rods. l_r = length of supporting rod.

Based on the triangle above, it can be seen that

$$l_r^2 = 150^2 + 80^2$$

$$l_r = [\ 28900\ ]^{1/2}$$

$$l_r = 170 \text{ mm}$$

Volume of each rod, $V_r = A_r \times l_r$

$$= \pi/4(d_r^2) \times l_r$$

$$= \pi/4 \times (\ 8 \times 10^{-3}\ )^2 \times 0.17 \text{ m}^2$$

$$V_r = 8.545 \times 10^{-6} \text{ m}^3$$

From (6) and using steel for rods

$$\int st\ = m_r/V_r$$

$$m_r = \int st\ \times V_r$$

$$= 7790 \times 8.545 \times 10^{-6} \text{ Kg}$$

$$m_r = 0.0667 \text{ Kg}$$

Weight of each rod, $W_r = m_r \times g$

$$= 0.0667 \times 9.81 \text{ N}.$$

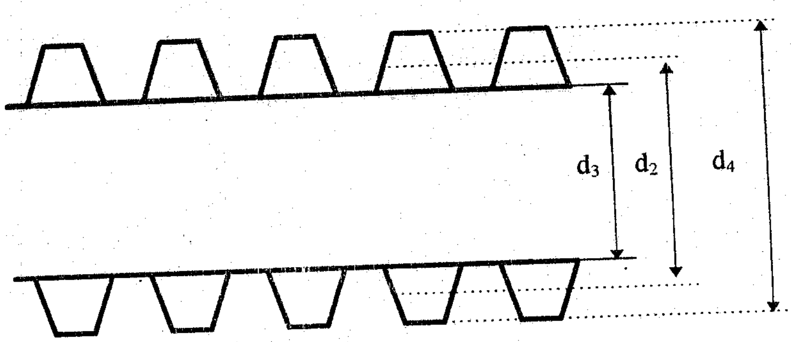
$$W_r = 0.653 \text{ N}$$

Combined weight of rods, $W_R = (\ 3 \times 0.653\ )$ N

$$W_R = 1.96 \text{ N}$$

3.1.2 DESIGN OF POWER SCREW

Fig 3.6 Power screw.



We first determine the minor diameter, d_3, of the screw by considering the effect of axial force alone, increased by 30% for calculation purposes [2].

The total load on the power screw, W_{TL} is

$$W_{TL} = W_{mb} + W_{pp} + W_R$$

$$= [\ 400 + 8.5 + 1.96\ ]\ N$$

$$= 410.46\ N$$

For the design use $W_{TL} = 450$ N

Taking W_{TL} as the force, the design force F_d is thus .

$$F_d = W_{TL} + 30/100\ W_{TL} \text{ ---------------(8)}$$

$$= W_{TL} + 0.3\ W_R$$

$$= W_{TL}\ (\ 1.3\ )$$

$$= 1.3 \times 450$$

$$F_d = 585\ N$$

Using grade 40C8 mild steel in hardened state as power screw material.

$$\Rightarrow \sigma_{ut} = 700\ N/mm^2$$

$$\text{From (3) } \sigma_y = 455\ N/mm^2$$

The allowable stress, σ_{AL}, is given in [2] as

$$\sigma_{AL} = 0.45 \times \sigma_y \text{ ----------------(9)}$$

$$= 0.45 \times 455\ N/mm^2$$

$$\sigma_{AL} = 204.75\ N/mm^2$$

From (7) : $\sigma_{AL} = F_d/A_s$ --(10)

where A_s = cross sectional area of power screw

$$A_s = \pi/4(d_3)^2$$

Substituting in (10) :

$$= F_d/(\pi/4(d_3)^2)$$

$$d_3^2 = 4 \times F_d/(\sigma_{AL} \times \pi)$$

$$d_3 = [\,4 \times 585/\pi \times 204.75\,]^{1/2}\ \text{mm}$$

$$d_3 = 1.907\ \text{mm} \quad [\text{ minimum }]$$

Using an Acme thread with a trapezoidal cross-section, and a profile angle of 30°; from table 6.12, [2],

Adopt $d_3 = 18.5$ mm

Pitch $P = 5$ mm

Pitch diameter $d_2 = 21.5$ mm

Nominal diameter $d = 24.0$ mm

Major diameter $d_4 = 24.5$ mm

Thus the actual cross-sectional area of the power screw designed, is given as

$$A_s' = \pi/4(d_3)^2$$

$$= \pi/4 \times (18.5))^2\ \text{mm}^2$$

$$A_s' = 268.8\ \text{mm}^2$$

Actual induced stress, $\sigma_a = F_d/A_s'$

$$= 585/268.8\ \text{N/mm}^2$$

$$\sigma_a = 2.18\ \text{N/mm}^2$$

From above, equation (9) : $\sigma_{AL} = 204.75\ \text{N/mm}^2$

Since $\sigma_a < \sigma_{AL} \Rightarrow$ DESIGN IS SAFE.

Determination of Torque and Equivalent Stress

using a single thread screw, then from Ref. [3]

Pitch = Lead

$\Rightarrow$ Lead = 5 mm

Helix angle, α, is calculated in [3] from the equation

$$\tan \alpha = \text{Lead}/\pi \times d \quad \text{---------------(11)}$$

Substituting :

$$\tan \alpha = 5/\pi \times (21.5)$$

$$\tan \alpha = 0.074$$

$$\alpha = \tan^{-1} (0.074)$$

$$\alpha = 4.23°$$

Using a steel screw bronze nut assembly, the coefficient of friction μ_s for steel to bronze is given in Table 2.2 [2], as

$$\mu_s = 0.12$$

Angle of friction, ϕ_f is calculated in [2] using the formula :

$$\tan \phi_f = \mu_s \text{ -----------------(12)}$$

$$\phi_f = \tan^{-1} (\mu_s)$$

$$= \tan^{-1}(0.12)$$

$$\phi_f = 6.84°$$

For an Acme thread, the Torque required to raise the load, T_f, is calculated in [4] by the equation

$$T_f = \frac{F_d \times d_2(\cos\theta \tan\alpha + \mu_s)}{2(\cos\theta - \mu_s \tan\alpha)} \text{ --------------(13)}$$

where T_f = frictional torque

F_d = load to be moved

θ = half the profile angle (15A)

μ_s – coefficient of friction

d_2 = mean or pith diameter

α = helix angle

Substituting values into equation (13) :

$$T_f = \frac{585 \times 21.5 \times [\cos 15° \tan 4.23° + 0.12]}{2[\cos 15° - 0.12 \tan 4.23°]}$$

$$= \frac{585 \times 21.5 \times [0.966 \times 0.074 + 0.12]}{2[0.966 - 0.12 \times 0.074]} N - mm$$

$$= [\frac{585 \times 21.5 \times 0.1915}{2 \times 0.957}] N - mm$$

$$T_f = 1258.14 N - mm$$

From Ref. [2], the polar section modulus, Z_p, of the power screw is given as

$$Z_p = \pi/16(d_3)^3 \text{ --------------(14)}$$

$$\Rightarrow Z_p = \pi/116 \times (18.5)^3 \text{ mm}^3$$

$$Z_p = 1243.212 \text{ mm}^3$$

The torsional shear stress, τ, caused by the turning moment or torque, T_f is given in Ref. [2] as :

$$\tau = T_f/Z_p \text{ --------------------(15)}$$

$$= 1258.14/1243.212 \text{ N/mm}^2$$

$$\tau = 1.01 \text{ N/mm}^2$$

Ref. [2] gives the formula for equivalent stress, σ_{eq}, as

$$\sigma_{eq} = \sqrt{(\sigma^2 + 3\tau^2)} \text{--------------------(16)}$$

$$= \sqrt{(2.18 + 3(1.01)^2)}$$

$$= \sqrt{(7.81)}$$

$$\sigma_{eq} = 2.795 \text{ N/mm}^2$$

$$\sigma_{eq} = 2.8 \text{ N/mm}^2$$

But, $\sigma_{AL} = 294.75$ N/mm^2

Since $\sigma_{eq} < \sigma_{AL} \Rightarrow$ DESIGNED SCREW IS SAFE TO OPERATE.

3.1.3 CHECK FOR TORSIONAL DEFLECTION

Considering the power screw as a uniform round, solid bar, the torsional

$$\beta = 32T_f L_s/\pi G d_3^4 \text{ ------------------------(17)}$$

where β = deflection (angle of twist), radians

T_f = applied torque

L_s = length of screw shaft subjected to twisting

d_3 = minor diameter of power screw

G = modulus of rigidity of material used (steel)

As a rule of thumb, the torsional deflection should be less then or equal to 1° in a length of shaft equal to twenty diameters, [4].

Thus the length of shaft subjected to twisting is calculated in [6] as :

Data

T_f = 1.258 N-m

$d_3 = 18.5 \text{ mm} = 18.5 \times 10^{-3} \text{ m}$

$G = 79.3 \times 10^9 \text{ N/m}^2$

$L_s = 20d_3$

Substituting in equation (17).

$$\beta = \frac{32 \times 1.23 \times 20d_3}{\pi \times 79.3 \times 109 \times d_3^4}$$
$$= \frac{32 \times 1.23 \times 20d_3}{\pi \times 79.3 \times 10^9 \times (18.5 \times 10^{-3})^3}$$
$$= \frac{805.12}{1577386.956}$$
$$= 0.0005 rad$$
$$= (\frac{0.0005 \times 180}{\pi}) rad$$
$$= 0.029°$$
$$\beta = 0.03°$$
$$Since \beta < 1° \Rightarrow Ls = 20d_3$$
$$Ls = 20 \times 18.5 mm$$
$$L_s = 370 mm$$

3.1.4 SCREW STABILITY

The moment of inertia of the screw section is given in Ref. [6] as :

$$J = \pi d_3^4/64[\ 0.375 + 0.625d/d_3\ ] \text{ --------(18)}$$

Substituting values :

$$J = \pi \times (1.85)^4/64[\ 0.375 + 0.625 \times 24/18.5\ ]$$

$$J = (\ 5749.85 \times 1.186\ )\ mm^4$$

$$J = 6818.24\ mm^4$$

The radius of gyration of the screw, K, is given in [6] by the equation :

$$K = \sqrt{J/A_s'} \text{ ------------------------(19)}$$

$$K = \sqrt{6818.24/268.8}\ mm$$

$$K = \sqrt{25.365}$$

$$K = 5.04\ mm$$

[5] gives the equation for slenderness ratio i as :

$$i = C\ L_s/K \text{ ----------------------(20)}$$

where C = end condition factor [C = 1.0 for free rotation and fixed translation], L_s and K have their usual meanings.

Substituting

$$i = 1 \times 370/5.04$$

$$i = 73.6$$

From table 1.0, Ref. [5], the allowable stress reduction factor ϕ, is determined by linear interpolation. For steel grade 40, 30, 20

$i_1 = 70$ $\qquad\qquad$ $\phi_1 = 0.81$

$i_2 = 73.6$ $\qquad\qquad$ $\phi_2 = ?$

$i_3 = 80$ $\qquad\qquad$ $\phi_3 = 0.75$

Interpolating :

$$\phi_2 = \phi_1 + (i_2 - i_1)/(i_3 - i_1) \times (\phi_3 - \phi_1)$$

$$= 0.81 + (73.6 - 70)/(80 - 70) \times (0.75 - 0.81)$$

$$= 0.81 + 3.6./10\ (-0.06)$$

$$= 0.81 + (-0.0216)$$

$$\phi_2 = 0.7884$$

The maximum allowable safe stress, σ_{mA}, for screw to be stable, is calculated in Ref. [5] using the equation

$$\sigma_{mA} = \phi_2 . \sigma_{AL} \text{ ---------------------(21)}$$

Substituting

$$\sigma_{mA} = 0.7884 \times 204.75 \text{ N/mm}^2$$

$$\sigma_{mA} = 161.42 \text{ N/mm}^2$$

But $\sigma_a = 2.18$ N/mm^2 (from earlier calculations)

Since $\sigma_a < \sigma_{mA} \Rightarrow$ SCREW IS STABLE AND WILL NOT BUCKLE

3.1.5 SCREW EFFICIENCY

The transmission efficiency of a power screw, η, is given in Ref. [4] as :

$$h = \left(\frac{\text{Torque Required To Move load without friction}}{\text{Torque}}\right) \text{ ------(21)}$$

$$= \frac{F_d \times d_2 / 2[\dfrac{\cos\theta \tan\alpha + 0}{\cos\theta - 0\tan\alpha}]}{F_d \times d_2 / 2[\dfrac{\cos\theta \tan\alpha + \mu_s \tan\alpha}{\cos\theta - \mu_s \tan\theta}]}$$

$$= \frac{\cos\theta \tan\alpha / \cos\theta}{\cos\theta \tan\alpha + \mu_s / \cos\theta - \mu_s \tan\alpha}$$

$$= \frac{\tan\alpha(\cos\theta - \mu_s \tan\alpha)}{\cos\theta \tan\alpha + \mu_s}$$

But $\theta = 15°$; $\alpha = 4.23°$, $\mu_s = 0.12$

$$\Rightarrow \eta = \frac{\tan 4.23(\cos 15° - 0.12 \tan 4.23)}{\cos 15° \tan 4.23 + 0.12}$$

$$= \frac{\tan 4.23 \times 0.957}{0.1914}$$

$$= 0.3698$$

$$= 0.37$$

$$\eta = 37\%$$

3.1.6 CHECKING FOR SELF-LOCKING

for screw system to self-lock, Ref. [2] gives the following conditions :

(i) $\alpha < \phi_f$

(ii) $\eta < 50\%$

From calculations, for screw designed

$\alpha = 4.23°$; $\phi_f = 6.87°$; $\eta = 37\%$

Thus :

$\alpha < \phi_f$ and $\eta < 50\%$

$\Rightarrow$ SCREW DESIGNED IS SELF-LOCKING

3.1.7 POWER REQUIREMENT

The power required, H, is given in Ref. [6] by the equation :

$H = T_f.\omega$ -------------------(23)

where T_f = torque

ω = angular velocity

But $\omega = 2\pi n/60$

where n = speed (rpm)

maximum speed human strength can achieve cranking is given in Ref. [7]

as: n = 250 rpm

Since T_f = 1.1253 Nm

$$H = 32.23 \text{ W}$$

$$H = (32.23/745.7) \text{ hp}$$

$$H = 0.043 \text{hp}$$

However, Ref. [7] gives the maximum torque applied by a human cranking perpendicular to the plane of the crank as 4.52 N-m. Thus, maximum power supplied by a human being is

$$H_m = T_m \times 2\pi n/60$$

$$= (4.52 \times 2 \times \pi \times 250/60) \text{ W}$$

$$= (118.33/745.7) \text{ hp}$$

$$H_m = 0.16 \text{ hp}$$

Since $H < H_m \Rightarrow$ Machine can be operated manually.

3.1.8 NUT DESIGN

Assuming the load of the power screw to be uniformly distributed over the nut, the required number of threads N, on the nut is calculated in [8] using the equation :

$$Q = 0.785(d^2 - d_3^2)P_b N \text{ -------------(24)}$$

where

Q = load moved

P_b = safe bearing pressure (steel/bronze system)

d and d_3 have their usual meanings.

NB: All dimensions in equation (24) are in imperial units.

But $Q = F_d$

$$F_d = 585 \times 4.45 \text{ lbf}$$

$$\Rightarrow Q = 2603.25 \text{ lbf}$$

$$d = (24/25.4) \text{ inches}$$

$$= 0.945°$$

$$= 0.728''$$

$$P_b = 1600 \text{ psi}$$

Substituting in (24)

$$2603.25 = 0.785(0.945^2 - 0.728^2) \times 1600 \times N$$

$$9134.62 = 1600 \times N$$

$$N = 6$$

Thus the minimum number of threads in the nut if it is to safely bear the load of the screw designed in [6].

$\Rightarrow$ minimum Nut length, $L_N = N \times$ pitch

$$L_N = N \times P \text{ -------------------(25)}$$

$$= 6 \times 5 \text{ mm}$$

$$L_N = 30 \text{ mm}$$

For N = 6,

$$P_b' = (9134.62/N) \text{ psi}$$

$$= (9134.62/6) \text{ psi}$$

$$= 1522.4 \text{ psi}$$

$$P_b' = 10.5 \text{ Mpa}$$

Since $P_b = 11.0$ mpa

$\Rightarrow P_b' < P_b$, thus Nut designed can bear screw safely.

<u>NUT HEIGHT</u>

Nut outside diameter, D_n is given in [6] by the equation

$$D_n \geq \sqrt{4F_n/\pi S_p} + d^2 \text{ -----------------(26)}$$

where $F_n = 1.3F_d$

$$d = 24.0$$

$$S_p = 34 \text{ Mpa (for bronze)}$$

$$\Rightarrow D_n \geq \sqrt{[(4 \times 1.3 \times 585)/(\pi \times 34 \times 10^6) + (0.024)^2]}\ \text{m}$$

$$D_n \geq \sqrt{[2.848 \times 10^{-5} + 5.76 \times 10^{-4}]}\ \text{m}$$

3.1.9 BEARING SELECTION

For an anti-friction bearing with inherent capacity to carry high loads (both radial and thrust), operated at low speeds, the deep groove ball bearing is most suitable.

Based on the dimensions of the screw, choose a bore of 15 mm for the bearing.

Bore = 15 mm

From SKF bearing table 9.58, [2], read

Bore, d_b = 15 mm

Outside diameter, d_b = 35 mm

Bearing width, B = 11 mm

Bearing mass, B_m = 0.045 Kg

Type Designation Number : 6202 (SERIES 02)

From Ref. [6], the load rating of 02-series bearing 6202 = 5.87 KN

bearing shoulder dimensions :

d_s = 17.5 mm; d_H = 31 mm

Bearing life, L_B is calculated in [2] from the equation.

$L_B = (C/P)^K$ ------------------(27)

where L_B = life of bearing in millions of revolution

C = basic dynamic load rating, (Newton)

P = load on bearing, (Newton)

K = exponent (K = 3 for ball bearings)

Thus $L_{BH} = 100000/60n \times (C/F_d)^K$ -------------(28)

L_{BH} = operating bearing life in operating hours

n = speed (revs/min)

But L_{BH} = 300 to 3000 hours for agricultural and domestic machines, [2].

Taking $L_{BH} = 3000$

$n = 250$ rpm

$F_d = 5.85$ N

$K = 3$

Substituting

$$3000 = 1000000/60 \times 250\ (C/5.85)^3$$

$$18 \times 25/10 = (C/5.85)^3$$

$$(45)^{1/3} = C/5.85$$

$$C = (5.85 \times 3.56)\ N$$

$$C = 2081\ N$$

$$C = 2.081\ KN$$

But the maximum load rating, C_m for series 02, type 6202 bearing is :

$$C_m = 5.87$$

Since $C_m > C \Rightarrow$ Bearing selected is suitable.

$$D_n \geq \sqrt{[6.045 \times 10^{-4}]}\ m$$

$$D_n \geq 0.0246\ m$$

$$D_n \geq 24.6\ mm$$

For this design, use $D_n = 40$ mm

Net thickness, $t_n = D_n - d/2$

$$= (40 - 24/2)\ mm$$

$$= 16/2\ mm$$

$$t_n = 8.0\ mm$$

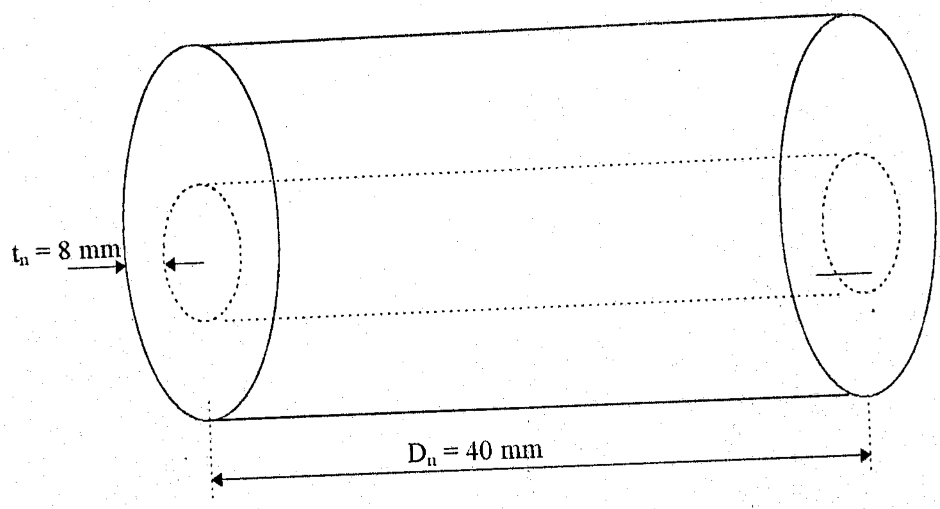


Fig 3.7 Nut

3.1.10 HANDLE DESIGN

The stress at the surface of a round solid shaft subjected to torsional loading is calculated in Ref. [6] using the equation :

$$\tau_{xy} = 16T/\pi d_x^3 \text{ -----------------(29)}$$

where τ_{xy} = torsional stress

d_x = shaft diameter

T = turning torque or torsional moment

<u>DATA</u>

$$\tau_{xy} = \tau = 1.01 \text{ N/mm}^2$$

$$T = T_f = 1257.14 \text{ N-mm}$$

Substituting in (29)

$$1.01 = (16 \times 1258.14)/(\pi \times d_x^3)$$

$$d_x^3 = ((16 \times 1258.14)/(3.14 \times 1.01)) \text{ mm}^3$$

$$d_x = (6344.21)^{1/3} \text{ mm}$$

$$d_x = 18.51 \text{ mm} \qquad \text{[minimum]}$$

From table 5.2, [4], select standard shaft diameter closest to and greater

$$\Rightarrow d_x = 20 \text{ mm}$$

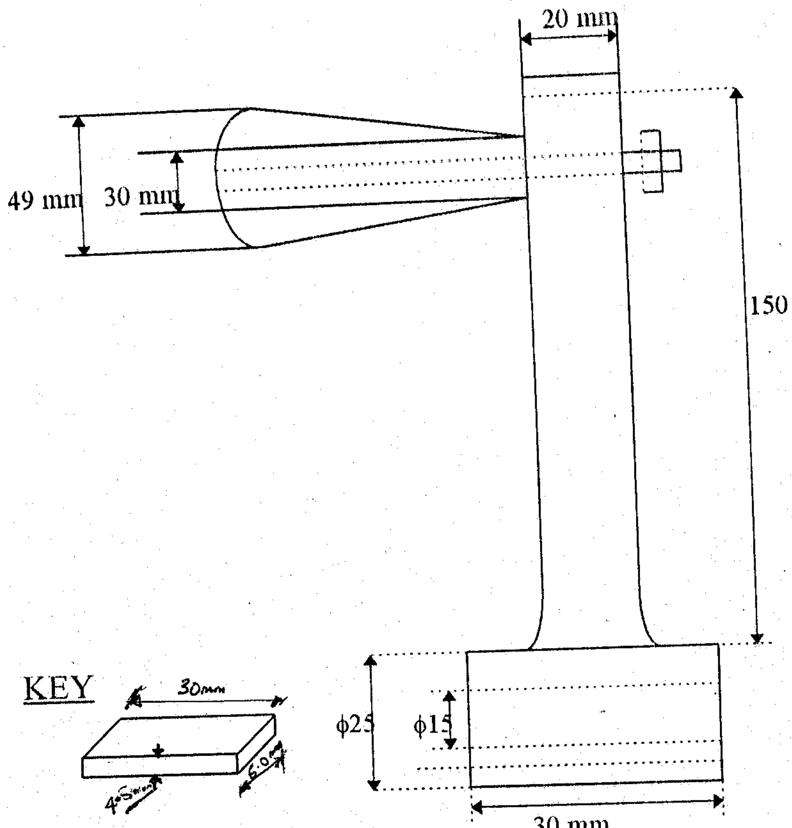


Fig 3.8 Handle.

Keyway

using a rectangular parallel key. From reference (21),

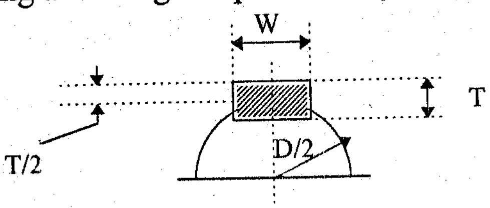


Fig 3.9 Key

If D = shaft diameter

$$\Rightarrow W = D/4 \text{ and } T = 3/4\ W$$

But D = 24 mm

W = D/4

= 24/4

W = 6 mm

T = 3/4W

= 9/2 mm

Length of key, $L = 30$ mm

Hand Grip

From reference (7)

Average length of human palm, $L_p = 6.1''$

$$L_p = 154.94 \text{ mm}$$

Thus Diameter of hand-grip, D_H is given thus :

$$\pi D_H \leq L_p$$

$$D_H \leq (154.94/\pi)$$

$$D_H \leq 49.3 \text{ mm}$$

Thus use a taper from ϕ30 mm at small end to ϕ49.0 mm at the big end.

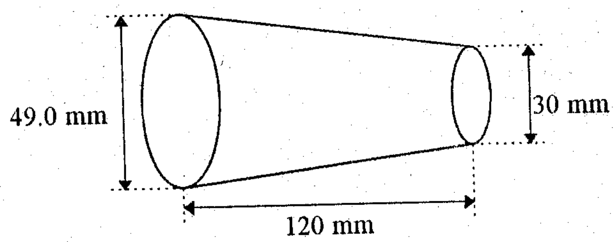


Fig 3.10 Wooden hand grip.

From reference [7], the length of the hand grip is given as :

$$L_H \leq 6.0''$$

$$\Rightarrow L_H \leq 152.4 \text{ mm}$$

Use $L_H = 100$ mm

Using wood as material.

Central bolt : Length, $L_b = 130$ mm

diameter, $\phi_b = 10$ mm

3.1.11 CYLINDER WALL DESIGN

Assuming the cylinder to be thin walled, closed at one end, the allowable stress is given in [1] as :

$$\sigma_\theta = pD_i/2t \text{ ---------------------(30)}$$

where σ_θ = allowable tensile stress

p = pressure within the cylinder

t = thickness of the cylinder wall

D_i = inside diameter of the cylinder

Using D_i = 190 mm, and grade 40C8 steel as material, we know that

$$\sigma_\theta = \sigma_{AL}$$

$\Rightarrow$ From (9) : $\sigma_\theta = 204.75 \text{ N/mm}^2$

$$p = \sigma_{eq}$$

$$p = 2.77 \text{ N/mm}^2$$

Substituting into (30) :

$$204.75 = (2.77 \times 190)/2t$$

$$t = [(2.77 \times 190)/(2 \times 204.75)] \text{ mm}$$

$t = 1.29$ mm, From table

Select gage 14 sheet steel of thickness, $t_a = 1.984$ mm

$\Rightarrow$ actual thickness of material used, $t_a = 1.984$ mm

3.1.12 FRAME DESIGN

First we calculate the total load to be borne by the frame.

(i) Weight of cylinder :

Volume of steel used for cylinder wall, V_{cw} is calculated thus :

$$V_{cw} = [\pi D_i^2/4 + \pi D_i L] \times t_a \text{ -------------(31)}$$

where L = length of the cylinder

D_i and t_a carry their usual meanings.

Taking L = 465 mm

Substituting in (31)

$$V_{cw} = [\pi \times 190^2/4 + \pi \times 190 \times 465] \times 1.984 \text{ mm}^3$$

$$= \pi \times 190[190/4 + 465] \times 1.984 \text{ mm}^3$$

$$= 606930.7 \text{ mm}^3$$

$$V_{cw} = 6.07 \times 10^{-4} \text{ m}^3$$

Since $\int st = 7790 \text{ Kg/m}^3$

$\Rightarrow$ Weight of cylinder, $w_{cw} = \int st \times V_{cw} \times g$

$$= (7790 \times 6.07 \times 9.81) \text{ N}$$

$$W_{cw} = 46.38 \text{ N}$$

(ii) Screw Weight :

Nominal diameter, d = 24 mm

Total length of power screw shaft, L_p = 422.5 mm

Shaft volume, $V_{ss} = [\pi/4(24)^2] \times 422.5 \text{ mm}^3$

$$V_{ss} = 191134.5 \text{ mm}^3$$

$$V_{ss} = 1.91 \times 10^{-4} \text{ m}^3$$

$$\int st = 7790 \text{ Kg/m}^3$$

weight of screw shaft, $W_{ss} = \int st \times V_{ss} \text{ X } g$

$$= 7790 \times 1.91 \times 10^{-4} \times 9.81 \text{ N}$$

$$W_{ss} = 14.61 \text{ N}$$

(iii) Bearing Load :

mass of bearing = 0.045 Kg

Weight of bearing, $W_b = 0.045 \times 9.81$

$$W_b = 0.44 \text{ N}$$

Take weight of bearing and housing, W_{bh} = 1.0 N

(iv) Supporting Rods and Press Plate Loads :

Weight of rods, W = 1.96 N

weight of press plate, $W_{pp} = 8.5$ N

(v) Handle Weight

Wooden grip weight = W_w

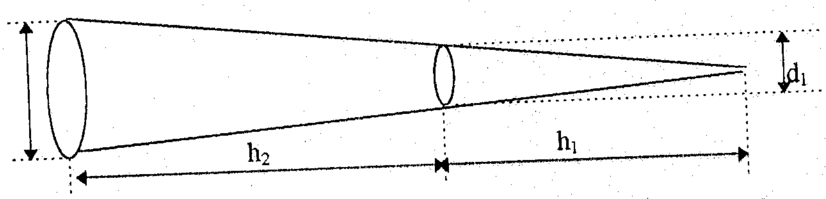


Fig. 3.11 Hand grip.

$$d_2/(h_1 + h_2) = d_1/h_1$$

$$49/(h_1 + 100) = 30/h_1$$

$$49h_1 = 30h_1 + 3000$$

$$19h_1 = 3000$$

$$h_1 = 157.9$$

$$h_1 = 157.9 \text{ mm}$$

$$\text{Volume, } V_w = 1/3\pi[r_2^2(h_1 + h_2) - r_1^2 h_1]$$

$$= 1/3\pi[(24.5)^2 \times 257.9 - (15)^2 \times 157.9]$$

$$= \pi/3 \times 119276.975 \text{ mm}^3$$

$$= 1.25 \times 10^{-4} \text{ m}^3$$

$$W_w = V_w \times \int_w \times g$$

Density of Iroko wood, $\int_w = 688$ Kg/m^3

$$\Rightarrow W_w = (1.25 \times 10^{-4} \times 688 \times 9.81) \text{ N}$$

$$W_w = 0.843 \text{ N}$$

Weight of bolt, $W_b = V_b \times \int st \times g$

$$V_b = \pi/4 \times \phi_b \times L_b$$

$$= \pi/4 \times 10^2 \times 130 \text{ mm}^3$$

$$= 10210.18 \text{ mm}^3$$

$$= 1.021 \times 10^{-5}\ m^3$$

$$W_b = 0.78\ N$$

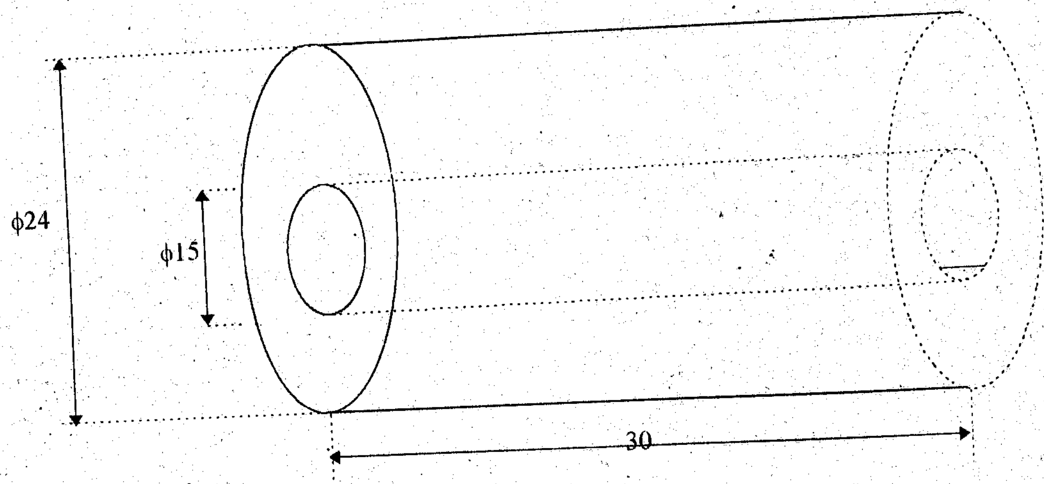


Fig 3.12 Nut

Volume of section shown above, $V_H = \pi/4(24 - 25)^2 \times 30$

$$V_H = 1908.52\ m^{m3}$$

Weight, $W_{HH} = (V_{HH} \times \int st \times 9.81)\ N$

$$= 1.908 \times 10^{-6} \times 7790 \times 9.81$$

$$W_{HH} = 0.146\ N$$

Vertical arm

Volume, $V_{HV} = \pi d_x^2/4 \times 150\ mm^3$

Weight, $W_{HV} = [(\pi \times 20^2/4 \times 150) \times 7790 \times 9.81 \times 10^{-9}]\ N$

$$W_{HV} = (4.712 \times 10^{-5} \times 7790 \times 9.81)\ N$$

$$= 3.6\ N$$

Total Handle weight, $W_H = W_w + W_b + W_{HH} + W_{HV}$

$$= 0.843 + 0.78 + 0.146 + 3.6$$

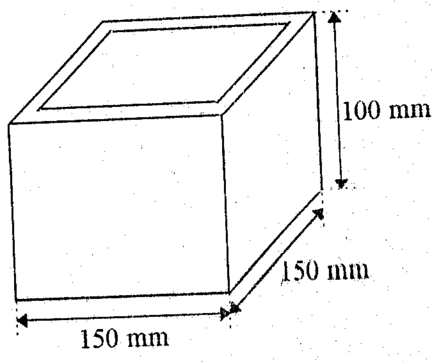
$$= 5.369\ N$$

$$W_H = 5.4\ N$$

(vi) Weight of Inlet and Discharge units

For Inlet :

Fig 3.13 Inlet chute.



Volume of inlet, $V_i = [150 \times 100] \times 5 \times t_i$

The inlet includes the inlet cover.

T_i = thickness of sheet used

$\Rightarrow t_i = 1.984$ mm

$\Rightarrow t_i = 1.984$ mm

$\Rightarrow V_i = (150 \times 100) \times 5 \times 1.984\ mm^3$

$V_i = 1.488 \times 10^{-4}\ m^3$

Weight of inlet, $W_i = V_i \times \int st \times g$

$= (1.488 \times 10^{-4} \times 7790 \times 9.81)$ N

$W_i = 11.4$ N

For Discharge Unit

Weight of discharge = W_o

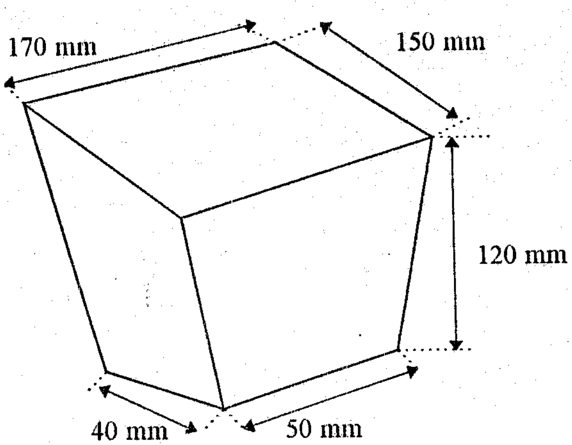


Fig 3.14 Outlet.

Volume of outlet, $V_o = A_o \times t_o$

$$=\{[(170 + 50) + (150 + 40)] \times 120\} \times 1.984 \text{ mm}^3$$

$$= [(220 + 190) \times 120] \times 1.984$$

$$= 97612.8 \text{ mm}^3$$

$$V_o = 9.76 \times 10^{-5} \text{ mm}^3$$

Weight, $W_o = V_o \times \int st \times g$

$$= (9.76 \times 10^{-5} \times 7700 \times 9.81) \text{ N}$$

$$= 7.46 \text{ N}$$

Weight of outlet and Discharge units, $W_{i/o}$ is :

$$W_{i/o} = W_i + W_o$$

$$= 11.4 + 7.46$$

$$W_{i/o} = 18.9 \text{ N}$$

(vii) Total vertical load on frame, W_{TV} is given by

$$W_{TV} = W_H + W_{i/o} + W_{ar} + W_{ss} + W_{bh} + W_{pp}$$

$$= 5.4 + 18.9 + 46.38 + 14.61 + 1.0 + 8.5$$

$$= 5.4 + 18.9 + 46.4 + 14.6 + 9.5$$

$$W_{TV} = 94.8 \text{ N}$$

Total horizontal load on frame, W_{TH} is :

$$W_{TH} = F_d$$

$$= 585 \text{ N}$$

Total load on frame, W_T is thus :

$$W_T = W_{TH} + W_{TV}$$

$$= 585 + 94.8$$

$$= 679.8 \text{ N}$$

$$W_T = 680 \text{ N}$$

(viii) Frame Design Calculations

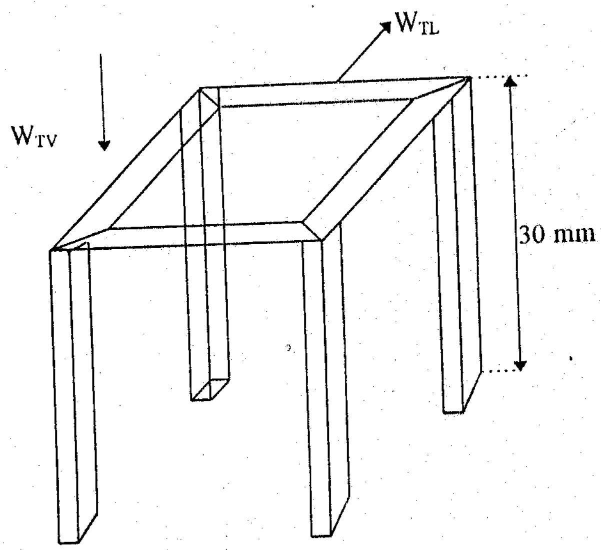


Fig 3.14 Frame.

for axially and laterally loaded frame, reference [9] gives the condition for design as :

$$f_c/p_c + f_{bc}/p_{bc} \leq 1 \text{ ------------------------------(32)}$$

where f_c = actual direct axial stress

f_{bc} = actual direct bearing stress

p_{bc} = allowable bending stress

p_c = allowable axial stress.

But $f_{bc} = M/Z$ --(33)

where M = moment

Z = sectional modulus

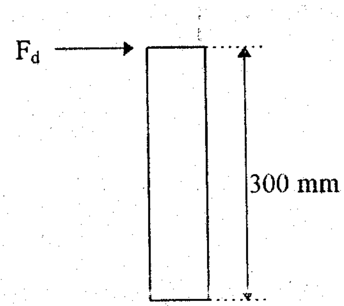


Fig 3.15 Leg.

$$M = F_d \times 300$$

$$= 585 \times 300 \text{ Nmm}$$

From table 3.2, reference [2], select angle bar standard ISA 35 × 35. Thus,

reading from table :

thickness, $t_o = 4.0$ mm

sectional Modulus, $Z = 1.2\ cm^3$

Cross sectional Area, $A_x = 2.66 \times 10^2\ mm^2$

Thus, substituting in (33), we have :

$f_{bc} = (177500/(1.2 \times 10^3)\ N/mm^2$

$f_{bc} = 146.25\ N/mm^2$.

$$f_c = \frac{\text{Vertical Load on each Leg } (p_v)}{Area \text{ of Frame } (A_s)} \quad \text{-------- (34)}$$

$P_v = (680/4)$ N (NB. There are four legs)

$P_v = 170$ N

Substituting in (34)

$f_c = P_v/A_X$

$= (170/2.66 \times 10^2)\ N/mm^2$

$f_c = 0.639\ N/mm^2$

$p_c = 0.6 \times \sigma_y$ --------------------------(35)

$\sigma_y = 455\ N/mm^2$ (for steel)

$\Rightarrow p_c = 0.6 \times 455\ N/mm^2$

$p_c = 273\ N/mm^2$

$p_{bc} = 165\ N/mm^2$

Substituting in equation (32) (left hand side) :

$f_c/p_c + f_{bc}/p_{bc} = 0.639/273 + 146.25/165$

$= 0.002341 + 0.8864$

$f_c/p_c + f_{bc}/p_{bc} = 0.889$

$f_c/p_c + f_{bc}/p_{bc} \leq 1$

Since $0.889 \leq 1$

$\Rightarrow$ Design is okay.

Thus, use ISA 35 × 35 angle bar for the frame.

CHAPTER FOUR.

TESTING.

4.1 PROCEDURE

A test to determine the filtration rate of the machine was done first. Here, the machine was operated for 15, then 45 seconds and the volume of filtrate collected at the end of each of these periods was recorded in a table.

A test was run to compare the performance of the machine with the traditional manual filtration technique. Here, the machine was operated for a given time (20 seconds) and the volume of filtrate collected recorded. Then, filtration was done manually also for 20 seconds and the volume of the filtrate also recorded. These results were used to compare the performance of the machine with the manual technique.

Thirdly, a test was done to determine the efficiency of the machine. Here, the moisture content of the soybean was determined first. The soybean mash was then pressed without addition of water. The mass of filtrate collected was recorded. This was repeated with three samples and the average of these readings taken. The efficiency was thus calculated as the ratio of the filtrate to the mass of water initially in the ash.

Finally, a test was carried out to determine the effect of decrease in concentration of mash on the filtration rate. Here, the mash was mixed with water in different proportions and the volume of filtrate collected over a given time was recorded. These results were then plotted on a graph.

4.2 RESULTS.

4.2.0 Test One: Concentration 1:1.

Table 4.0 Results of test to determine filtration rate.

Time, t (seconds)	Volume of filtrate, V (m^3)
15	100×10^{-6}
15	90×10^{-6}
15	80×10^{-6}
45	125×10^{-6}
45	135×10^{-6}
45	130×10^{-6}

For time of 15 seconds,

$$V_1 = \left(\frac{100 + 90 + 80}{3}\right) \times 10^{-6}\ m^3$$

$$V_1 = 270/3 \times 10^{-6}\ m^3$$

$$V_1 = 90 \times 10^{-6}\ m^3$$

For time of 45 seconds, the average volume of filtrate is :

$$V_2 = 130 \times 10^{-6}\ m^3$$

From equation (1) :

$$V^2 + 2VC = Kt$$

Given $t_1 = 15s$ $t_2 = 45s$

$V_1 = 90 \times 10^{-6}\ m^3$ $V_2 = 130 \times 10^{-6}\ m^3$

Substituting into (1) :

$$(90 \times 10^{-6})^2 + 2 \times 90 \times 10^{-6} \times C = K \times 15 \text{ --------------(a)}$$

$(130 \times 10^{-6})^2 + 2 \times 130 \times 10^{-6} \times C = K \times 45$ ------------(b)

$45 \times$ (a) : $3.6 \times 10^{-7} + 0.0081C = 675K$ -----------------(c)

$15 \times$ (b) : $2.53 \times 10^{-7} + 0.0039C = 675K$ -----------------(d)

(c) - (d) : $1.11 \times 10^{-7} + 0.0042C = 0$

$$0.0042C = -1.11 \times 10^{-7}$$

$$C = -2.643 \times 10^{-5}\ m^3/m$$

Put C in (d) :

$$2.53 \times 10^{-7} - 1.03 \times 10^{-7} = 675K$$

$$1.49 \times 10^{-7} = 675K$$

$$K = 2.22 \times 10^{-10}\ m^6/m^2.s$$

The rate of filtration is calculated from equation (2) as, Rate :

$$dv/dt = K/2(V + C)$$

Using $V = V_1$ and substituting for C and K :

$$dv/dt = 2.22 \times 10^{-10}/2(90 \times 10^{-6} - 2.643 \times 10^{-5})$$

$$dv/dt = [(2.22 \times 10^{-10})/1.2714 \times 10^{-4})]\ m^3/s$$

$$= 1.746 \times 10^{-6}\ m^3/s$$

$$= 6.286 \times 10^{-3}\ m^3/hr$$

$$dv/dt = 6.286\ l/hr$$

4.2.1 TEST TWO:COMPARISON OF HAND TO MACHINE FILTRATION

A 400ml cup of soybean mash was pressed manually, then with the machine for 20 seconds and the volume of filtrate collected recorded.

	Manual	Machine
V_1	19 ml	26 ml
V_2	21 ml	24 ml
V		

For manual filtration, average volume of filtration collected in 20 seconds was :

$$V_{mav} = ((19 + 21 + 15)/3) \text{ ml}$$

$$V_{mav} = 18.3 \text{ ml}$$

For filtration using the filter press, the average volume of filtrate collected in 20 seconds was :

$$V_{pav} = ((26 + 24 + 25)/3) \text{ ml}$$

$$V_{pav} = 25 \text{ ml}$$

4.2.2 TEST THREE : Machine Production Efficiency

Results

Mass of cup, $m_1 = 81.05$ g

Mass of beaker, $m_2 = 180$ g

Mass of (cup + mash), $m_3 = 365$ g

Mass of (beaker + filtrate), $m_4 = 285$ g

Mass of mash, $m_m = m_3 - m_1$

$m_m = 283.95$ g

Mass of filtrate collected, $m_f = m_4 - m_2$

$m_f = 285 - 180$

$m_f = 105$ g

Mass of (cup + soaked grains), $m_5 = 102.8$ g

Mass of (cup + oven dried grains), $m_6 = 89.6$ g

Mass of water in grains, $m_w = m_5 - m_6$

$m_w = 13.6$ g

Initial mass of wet grains, $m_i = m_5 - m_1$

$m_i = 21.75$ g

Moisture content of grains, $w = m_w/m_i \times 100$

$w = 13.2/21.75 \times 100$

$w = 60.7\%$

Mass of water in mash before filtration, m_7 is thus :

$m_7 = w \times m_m$

$= (0.67{=}07 \times 283.95)$ g

$m_7 = 172.36$ g

Machine production efficiency, η_p is given by :

$\eta_p =$ Liquid output/liquid input $\times 100$

$= m_f/m_7 \times 100$

$= 105/172.36 \times 100$

$\eta_p = 60.9\%$

Mass of filtrate collected by manual filtration, m'_f was

$m'_f = 88$ g

Efficiency of manual pressing, η_{mp} is

$\eta_{mp} = m'_f/m_7 \times 100$

$\eta_{mp} = 88/172.36 \times 100$

$\Rightarrow \eta_{mp} = 51.06\%$

4.2.3 TEST FOUR : Effect Of Concentration On Time Of Filtration And Volume Of Filtrate

For each 400ml cup of soybean mash the corresponding volume of water was added. The mash was mixed with water and placed in the filter bag. The loaded bag was then placed in the machine, and the time taken to filter out the maximum possible fluid from the mixture, and the volume of filtrate collected were recorded as shown in table below.

TABLE 4.1: RESULTS OF TEST OF EFFECT OF CONCENTRATION ON TIME AND VOLUME OF FILTRATE.

Concentration Soybean mash :water	Volume of filtrate (ml)	Time taken, t(seconds)
1 : 0.5	265	120
1 : 1	450	129
1 : 1.5	680	100
1 : 2	890	80
1 : 2.5	1050	67
1 : 3	1200	55

4.3 DISCUSSION OF RESULTS

The test to determine the rate of filtration gave the throughput of the machine, at a concentration of one soybean mash to one water, as 6.286 l/hr. This value is low because of the concentration of the mixture used. It will be higher if the recommended concentration of one to six [Reference 11] is used.

The test to compare hand with machine filtration gave the volume of filtrate collected after 20 seconds from hand pressing as V_{mav} = 18.3 ml, and from machine pressing as V_{pav} = 25 ml. Thus, the output per unit time is higher for the machine, than pressing with hand. It is thus more economical to use the machine.

While the test to determine the production efficiency gave us the efficiency of manual filtration as 51.06% and of machine filtration as 60.9%. Thus, the filtration process is more efficient when the machine designed is used compared to using the hands.

The final test results shows that as the proportion of water added to the mash increases,

1. The time of filtration decreases. That is to say filtration is faster, thus the filtration is higher.
2. The volume of filtrate collected increases. Thus the quantity of milk obtained is greater.

It is therefore advisable to add water to the mash in a proportion of 1:6 [Reference 11] and carry out filtration on a given mash at least twice before discarding the cake. This will give a higher output of the required quantity.

4.4 DESIGN LIMITATIONS

The major limitation of this design was finance, thus its small size, as the cost of the machine depended on the quantity of material used. Due to the high cost of stainless steel, aluminium paint was used to coat the mild steel used. However, stainless steel is the best material for this design.

Also, due to the fact that the power screw is not static (moves longitudinally), and that a heavier weight increases the power requirement for operating the machine, the power screw-press plate assembly could not balance easily.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

From the design and test carried out it was observed that,

i) The soymilk filter press is portable, aesthetically attractive and simple to operate.

ii) The machine is easy to disassemble as most joints in it were bolted and not welded. It is easy to maintain.

iii) The efficiency of the machine to filter soybean milk was higher compared to filtering with hands.

iv) The quality of milk obtained using the machine can be guaranteed.

v) The power requirement for operating the machine is quite low (0.043 hp), and thus imposes very little fatigue on the operator.

vi) The cost of the machine is low (material cost of ₦ 4385.0) It is thus economically available to the rural dwellers.

5.1 RECOMMENDATIONS

Having tested the machine and observed some problems in operation, I will recommend that,

i) The frame of the machine be slanted. This will prevent loss of milk through the open end of the cylinder.

ii) The outlet should be welded to the sealed edge of the drum and holes drilled to that end to prevent accumulation of milk within the drum.

iii) An additional iron sheet should be used to bolt the cylinder to the frame, as the open end tends to lift during pressing.

iv) The clearance between the press plate and the drum should be minimal, as low as 1 mm, so as to prevent the bag from being trapped between the cylinder and the plate edges.

v) The muslin cloth should be sown double to prevent damage during operation. Also the mouth should be firmly tied.

vi) The pressing compartment should be made larger and completely sealed, or the inlet chute should be at the second end of the cylinder, away from the outlet chute.

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APPENDIX

TABLE 5.0 MATERIAL COSTING

S/No	Item Description	Quantity	Unit Cost (Naira)	Cost (Naira)
1	Angle Iron ($1_{1/2}$" × $1_{1/2}$")	1	540	540
2	Mild Steel Sheet: (a) Gauge 16 (b) Gauge 8	 1/2 1/18	 2400 5400	 1200 300
3	Bearing (6202)	1	120	120
4	Steel Rod (ϕ10 mm)	1/2	500	250
5	Brass Nut	1	400	400
6	Screw Shaft (ϕ25 mm)	1/2	1400	700
7	Electrodes (G 12)	30pieces	5	150
8	Bolts (m13 × 1)	11	15	165
9	Bearing Housing	1	100	100
10	Aluminium Paint (450 ml)	2	150	300
11	Thinner (Gallon)	1/3	480	160
	TOTAL COST			₦ 4385.00

A: Graph of Concentration Against Volume of filtrate

B: Graph of Concentration Against Time (t-seconds)