DESIGN AND FABRICATION OF CENTRIFUGE FOR MILK AND CREAM SEPARATION

BY

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BEING A FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) DEGREE IN AGRICULTURAL AND BIORESOURCES ENGINEERING. FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE.

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DECLARATION

I hereby declare that this project work is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished work were duly referenced in the text.

18/1/11

Ikuerowo Kehinde Leke

Date

CERTIFICATION

This is to certify that the project entitled "Design and Fabrication of Centrifuge for Milk and Cream Separation" by Ikuerowo, Kehinde Leke meets the regulations governing the award of degree of Bachelor of Engineering (B. ENG.) of the Federal University of Technology, Minna, and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This project work is dedicated to God, Almighty for making it possible for me to complete my course of study.

ACKNOWLEDGEMENTS

My profound gratitude goes to God, Almighty, for his protection, provisions, guidance and wisdom. Glory be unto your holy and powerful name.

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I sincerely acknowledge my parents, Mr. and Mrs. Ikuerowo being the best parents since I was born into this world. May God give me the power to give my best as a child to you.

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To my friends – Foluke, Toyin, Amaka, sarah, wale and Daniel- you have been a source of encouragement, fun and challenging to me; meeting you adds meaningfully to my life.

ABSTRACT

In this study, a centrifuge was designed and fabricated to separate cream from raw milk at domestic level. The fabricated machine was tested to assess its performance. The results of the performance test showed that from whole milk of $0.0079m^3$. $0.0060m^3$ of milk and $0.00058m^3$ of cream was obtained after 38 minutes of operation of the machine. This gives 84% efficiency of separation. The result showed that with further improvement, the developed machine can adequately be adopted at the house hold level instead of the spinning stick being currently used by the processors at household level.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Milk and milk products are derived normally from the raw milk produced from the cow. The raw milk from the cow contains both fat and milk and need to be separated into various components (McGee, 2004).

The process is normally tedious and requires more energy. At the household level, the process is usually carried out by spinning the bowl using some sticks. This process is time consuming and labour intensive. Processing milk at the small and medium scale level is an uncreative job, hence introducing new technologies that can reduce the energy expended can greatly enhance milk production at the household level.

Though there are many separating machine available in the market, most of these equipment are expensive and beyond the reach of traditional processors of milk product. It is therefore desirable to introduce some intermediate and affordable technologies into the system to boost the trade and hence the need for present study.

1.2 Objectives

The aims of the project are;

- To design and fabricate a centrifuge that will separate milk from cream from easily available material.
- To carry out performance test on the fabricated machine.

1.3 Justification

One basic objective of research and development is to improve standard of living of people. Milk and milk product are highly susceptible to contamination. It is therefore desirable to provide technologies that will ensure quality and safety of such product. This present work is aimed at bringing about such innovation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Milk composition

Milk is a very nutritious and versatile food. People enjoy drinking milk in its natural form and also use it to make a wide range of food products, including cream, butter, yogurt, cheese, and ice cream. Drinking milk are produced from a variety of domesticated mammals, including cows, goats, sheep, camels, reindeer, buffaloes, and llama. The major source for commercial production and consumption is from cows (Williamson and Payne, 1987).

Most milk is composed of 80 to 90 percent water. The remaining 10 percent consists of the major nutrients needed by the body for good health, including fats, carbohydrates, proteins, minerals, and vitamins. Cow milk contains approximately 87% of water, 3 to 4% protein, 4 to 4.5% fats, and approximately 4.5% milk sugar (lactose). It typically contains about 3.5 to 5 percent fat, which is dispersed throughout the milk in globules. Fat supplies taste and texture, and vitamins A, D, E, and K, as well as certain fatty acids that the body is unable to produce (McGee, 2004). The composition of milk from various sources can be seen in table 2.1

Table 2.1: Composition of milk from various sources (/100g)

Constituent	unit	Cow	Goat	Sheep	Water Buffalo
Water	g	87.8	88.9	83.0	81.1
Protein	g	3.2	3.1	5.4	4.5
Fat	g	3.9	3.5	6.0	8.0
Carbohydrate	g	4.8	4.4	5.1	4.9
Energy	Kcal	14	10	11	8
Energy	KJ	120	100	170	195
Sugar	g	2.4	2.3	3.8	4.2
Mono-unsaturated Fatty acid	g	1.1	0.8	1.5	1.7
Polyunsaturated fatty Acid	g	0.1	0.1	3.0	0.2

University of Guelph, (2009).

2.1.1 Physical properties of milk

Milk is an opaque white liquid with a complicated physical structure. Physically, it contains fat and fluid which exist in three general state of dispersion (i.e Coarse, colloidal and molecular dispersion) influenced by its particle diameter (Eckles *et al.*, 1993).

2.1.2 Chemical properties of milk

Milk is an emulsion or colloid of butterfat globules within a water-based fluid. It was found that fresh milk has an amphoteric property that turns blue litmus paper red. Therefore, it is acidic with pH of 6.5 to 6.6. The acidity of fresh milk is due to the phosphate content of the milk, the protein and slight degree of carbon dioxide and citrate (Eckles *et al.*, 1993).

2.1.3 Boiling point of milk

Eckles *et al.*, (1993), stated that milk is slightly heavier than water and boils at temperature slightly above that of water. Milk boils at temperature of 100.17°C. when milk is heated, fat globules tends to form in cluster.

2.1.4 Viscosity of milk

All liquids appear to be more viscous at low temperature than at high temperature. (Hall,1979). When milk is subjected to prolonged agitation, the viscosity is reduced. Developments of some certain types of bacteria in the milk are also responsible for an increase in viscosity. It is generally adopted that increase in the viscosity of milk is due to changes taking place in the milk (Eckles *et al.*, 1973).

2.2 Cream composition

Cream is a fat rich component and has been known from time immemorial as the fatty layer that rises to the top portion of the milk when left undisturbed. Cream may be defined as that portion of milk which is rich in milk fat or that portion of milk into which fat has been gathered and which contains a large portion of milk fat, or when milk fat is concentrated into a fraction of the original milk, that portion is known as cream. In India, cream, excluding sterilized cream is the product of cow or buffalo milk or a combination thereof, which contains not more than 25 per cent milk fat and the ratio is always 3 to 1 of milk to cream. Cream is rich in energy giving fat and fat-soluble vitamins A, D, E, and K, the contents of which depends on the fat level in cream (Ito and Bowman, 1996).

2.3 Methods of separation

Sedimentation and centrifugation are used to separate immiscible liquids and solids from liquids. The separation is carried out by the application of either natural gravity or centrifugal forces (Leung, 1997).

Centrifugation is typically used in the dairy industry in the clarification of milk, the skimming of milk and the concentration of cream (Svarovsky, 1999).

Centrifugation is used to separate mixtures of two or more phases, one of which is a continuous phase. The driving force behind the separation is the difference in density between the phases. By using centrifugal forces the separation process is accelerated by rotating the materials. The force generated depends on the speed and radius of rotation. In raw milk for example, the skimmed milk is the continuous phase, the fat phase is a discontinuous phase formed of fat globules with diameters of some microns, and a third phase consists of solid particles, hairs, udder cells, straw etc. When the differences in density are large and time is not a limiting factor, separation can take place by gravity (Zhang and Weng, 2006).

2.3.1 Traditional method of milk separation.

From the information gathered through an interview with our local farmers, there are two methods used in milk separation which include the shallow pan and the deep-setting methods. These methods are still practiced where small quantities of milk are produced. Eckles *et el.*, (1993), refers to these methods as gravity creaming.

The milk is poured into the pans. When still warm, the pans are placed in a moderate temperature environment where the separation is accomplished by gravity. After 24 to 36 hours, the cream will rise to the top and then skimming is done. The milk which is below the cream is coagulated and the cream is removed with a tin skimmer. The cream collected is also shaken vigorously due to some little percentage of skim milk and the two contents are totally separated.

2.3.2 Water dilution method of milk separation

When water is added to whole milk, the viscosity of the milk is lowered and this allows cream to rise more rapidly. A tank is fitted to the bottom with a drain faucet, above which is a strip of glass giving a view of content of the tank. Separation is accomplished after twelve hours, the milk-water mixture is drained out through the faucet. The cream which is on top will be caught into a separate container. Eckles *et al.*, (1993) said that using this method, the fat cannot be separated completely from the milk.

2.3.3 Separation by gravity

- Batch-wise: this occurs in a vessel containing a dispersion of solid particles with a higher density than the liquid. In time these heavier particles fall to the bottom of the vessel. If the height of the vessel is shortened and the surface increased, the sedimentation time can be reduced (Kopf, 2009).
- Continuous: the liquid containing the slurred particles is introduced at one end of the process and flows towards an overflow. The sedimentation capacity of the vessel can be increased by adding baffle plates (horizontal or inclined).

2.3.4 Milk Separation by centrifugal force

Centrifuges are classified into three groups:

- tubular/disc bowl centrifuges for separating of immiscible liquids
- solid bowl/nozzle valve discharge centrifuges, for clarifying liquids by the removal of small amounts of solids
- Conveyors bowl/reciprocating conveyor centrifuges, for dewatering sludge (with high solids content).

2.3.4.1 Tubular/disc bowl centrifuge

A tubular bowl centrifuge consists of a vertical cylinder, which rotates between 15000 – 50000 rpm, inside a stationary casing. It is used to separate immiscible liquids, e.g. vegetable oil and water or solids from liquid. The two components are separated into annular layers, with the denser liquid or the solid setting nearer to the bowl wall. The two layers are then discharged separately (Othmer, 1999).

Typically, the disc bowl centrifuge is more widely used in the food industry as it can achieve a better separation due to the thinner layers of liquid formed. With the disc bowl centrifuge, the cylindrical bowl contains inverted cones or discs. The liquids only have to travel a short distance to achieve separation. These centrifuges operate at 2000 – 7000 rpm and have capacities of up to 150000 l/h (Kopf, 2009).

2.3.4.2 Solid bowl nozzle or valve type centrifuges

A solid bowl centrifuge is the simplest solids/liquid centrifuge and is useful when small amounts of solids must be removed from large volumes of liquid. It consists of a rotating cylindrical bowl. Liquor is fed into the bowl; the solids settle out against the bowl wall while the liquid spills over the top of the bowl. Periodically the centrifuge has to be stopped to enable the cake to be removed. Liquors containing higher levels of solids, i.e. >3% w/w, can be separated using nozzle or valve discharge centrifuges. These centrifuges are a modified disc bowl centrifuge with a double conical bowl and enable the discharge of solids automatically. These types of centrifuges are used to treat oils, juices, beer and starches to recover yeast cells. They have capacities of up to 300000 l/h. A special type is the "*bactofuge*", which is specially designed to separate micro-organisms from milk. Bacteria, and particularly spores, have a higher density than milk and the solids are called *bactofugate* (Costa, 2009).

2.3.4.3 Conveyor bowl/reciprocating conveyor/basket centrifuges

These centrifuges are used when the feed contains high levels of solids (sludge). They are used, for example, to recover animal and vegetable proteins (i.e. precipitated casein from skimmed milk), to separate coffee, cocoa and tea slurries and to dislodge oils. In the conveyor bowl centrifuge (decanter), the solid bowl rotates at 25 rpm faster than the screw conveyor. This causes the solids to be conveyed to one end of the centrifuge whereas the liquid fraction moves to the other larger diameter end (Costa, 2009).

The reciprocating conveyor centrifuge is used to separate fragile solids (e.g. crystals from liquor). The feed enters a rotating basket through a funnel, which rotates at the same speed. This gradually accelerates the liquid to the bowl speed and thus minimises shear forces. Liquid passes through perforations in the bowl wall. When the layer of cake has built up it is pushed forward by a reciprocating arm.

The basket centrifuge has a perforated basket lined with a filtering medium, which rotates at 2000 rpm. Separation occurs in cycles, which last from 5 – 30 minutes. In the three stages of the cycle the feed liquor first enters the slowly rotating bowl, the speed is then increased and separation takes place, finally the speed of the bowl is reduced and the cake is discharged through the base. Capacities for this group of centrifuges are up to 90000 l/h. (Costa, 2009).

From the methods described above, this study is in conformity with the operation of the disc bowl centrifuge (Othmer, 1967) except that the inner cylinder is fixed in a stationary position while the shaft rotates with the paddles attached to it for thorough stirring of the milk.

2.4 Early development of centrifugal separation machine

It all started when the military engineer Benjamin Robins (1707-1751) invented a whirling arm apparatus to determine drag. A dairy centrifuge was then invented to separate milk from cream.

In 1984, the first continuous centrifugal separation was demonstrated making its commercial application feasible for human use. The centrifuge can also work using sedimentation principle, where the centripetal acceleration causes heavier particles to move out along the radial direction and lighter object will move to the top.

Centrifugation mostly used in food industry for treatment of milk, principally for standardization of milk and milk products and in production of cream. During the operation, fat globules separate from the rest of the milk suspension and the original milk feed is separated into a cream portion and scheme milk portion. The milk should be at the temperature around 40°C before entering the centrifuge.

Cream, thick, light yellow portion of the milk from which butter is made contains the same constituent as milk but rich in fat, varying from 10 to 70 percent butter fat by weight. Cream used for household comes in different grades. The light cream forms an airy form when beaten. Because cream is lighter than skim milk, the component of the whole milk cream will slowly rise to the surface and can be separated by skimming (McGee, 2004).

Since the fat in raw milk is lighter in weight than the rest of the milk, it will naturally rise to form a layer of cream if allowed to stand. Spinning the milk in a large machine, called a centrifuge, accelerates the formation of a cream layer, or the separation of fat, from raw milk. Varying amounts of fat are removed from the raw milk, resulting in different kinds of fresh milk. If the fat content is lowered to 3.25 percent, the milk is sold as whole milk. Low-fat milk typically has 1 percent or 2 percent fat. Skim milk, or non-fat milk, is the liquid that remains after removing all the cream; it contains about half a percent milk fat (Zhang and Weng, 2006).

Once the fat level has been reduced to the desired level, most fresh milk is homogenized to prevent the further separation of a cream layer. Homogenization is accomplished by forcing hot milk under high pressure through small nozzles. The fat globules become so small that they remain evenly dispersed throughout the milk. In order to insure its safety for human use, almost all milk undergoes pasteurization, in which milk is heated to a high temperature for a specified length of time to destroy pathogenic bacteria.

Milk in its natural form, directly from a cow, is called raw milk. It is an extremely versatile product from which a myriad of commercial products are derived.

Refrigeration is the single most important factor in maintaining the quality of milk. By law, Grade A milk must be maintained at a temperature below 4.4^0C. It is critical that these temperatures be maintained through warehousing, distribution, delivery and storage. Remember temperature is the most important factor. Check the expiration dates on milk before you purchase. Harmful bacteria can grow rapidly in milk above 40F (Zhang and Weng, 2006).

2.5 Construction of centrifuge

A centrifugal separator has a housing with a generally cylindrical inner surface defining an inner chamber. A hollow rotor is disposed within the chamber for rotation therein. At least one inlet is provided for introducing a liquid mixture into the annular volume between the rotor and the housing, where it is then directed into the rotor. An upper rotor assembly separates the liquid mixture by phase densities with the disparate components directed to respective outlets. In one embodiment of the invention, the upper rotor assembly includes an easily removable weir ring to facilitate "tuning" of the separation process. The rotor of the separator is mounted on a unitary rotor shaft that extends axially through the separation chamber to the upper and lower bearing assemblies in the separator housing. The bottom surface of the housing, where the liquid mixture is directed from the annular mixing volume into the rotor, preferably includes a plurality of radial vanes that are curved in the direction of rotation of the rotor to assist in directing the liquid mixture with minimal turbulence. Collector rings for the separated components provided from the upper rotor assembly are preferably formed integrally in the wall of the housing with a smoothly contoured peripheral surface to reduce turbulence of the output streams (Eckles *et al*., 1993)

Comparing the construction described above to the aim of the study, the principle of operation is similar except that this study is based mainly on the rotation of the paddle with the aid of the shaft and also on the conduction of heat through the inner cylindrical wall to the product compartment.

2.6 Efficiency of the centrifuge

Eckles *et al.*, (1993) indicated that, a good separator properly operated, leaves practically no fat in the skim milk. A fat content of more than 0.03% is said to mean that the machine is either mechanically imperfect or incorrectly operated. Culpin (1992), explained that with a separator that is properly adjusted, it is possible to reduce the loss of fat to 0.02%.

2.7 Dairy hygiene

Milk is an excellent medium for the multiplication of bacteria of many kinds and the warmer the milk, the more rapidly the bacteria multiply. Therefore, strictly, dairy hygiene most be observed (Barret and Larkin, 1979).

2.7.1Pasteurization of milk

Pasteurization is a relatively mild heat treatment, (usually performed below 100°C) which is used to extend the shelf-life of milk for several days. It preserves the milk by the inactivation of enzymes and destruction of heat-sensitive micro-organisms, but causes minimal changes to the nutritive value or sensory characteristics of a food. Some heat-resistant bacteria survive to spoil the milk after a few days, but these bacteria do not cause food poisoning (Longree, 1972).

The time and temperature combination needed to destroy 'target' micro organisms will vary according to a number of complex inter-related factors. For milk, the heating time and temperature is either 63°C for 30 minutes or alternatively 72°C for 15 seconds. Only the former combination is possible on a small scale and for this the simplest equipment required is an open boiling pan. Better control is achieved using a steam jacketed pan, and this can be fitted with a stirrer to improve the efficiency of heating. Both of these are batch processes which are suited to small-scale operation. A higher production rate may be possible using a tubular-coil pasteurizer. This equipment has been tested and has been successful for some fruit products but it is presently still at a developmental stage (Longree, 1972).

2.7.2 Sterilization of milk

Sterilization is a more severe heat treatment designed to destroy all contaminating bacteria. The milk is sterilized at a temperature of 121°C maintained for 15-20 minutes. This can be achieved using a retort or pressure cooker. Unlike pasteurization, this process causes substantial changes to the nutritional and sensory quality of the milk. In some countries, flavoured milk has become a very popular product (Scott, 1989).

However, sterilization is not recommended for small-scale production for the following reasons:

· The cost of a retort and ancillary equipment is high for the small-scale processor.

It is essential that the correct heating conditions are carefully established and maintained for every batch of milk that is processed. If the milk is overheated, the quality is reduced, and it may have a rather burnt taste and aroma.

If the milk is not heated sufficiently, there is a risk that micro-organisms will survive and grow inside the bottle. In low-acid foods such as milk, many types of bacteria including *Clostridium botulinum* can grow and cause severe food poisoning (Scott,1989).

Due to the potential dangers from food poisoning, the skills of a qualified food technologist/microbiologist are required in order to routinely examine samples of sterilized milk that have been subjected to accelerated storage conditions. This requires a supply of microbiological media and equipment.

In summary, the process of sterilization requires a considerable capital investment, the need for trained and experienced staff, regular maintenance of sophisticated equipment, and a comparatively high operating expenditure (Scott,1989).

2.7.3 Cooling of milk

Pasteurization does not destroy all of the micro-organisms, therefore the milk has to be cooled rapidly to prevent the growth of surviving bacteria. Cooling can be achieved on a small scale by using a bottle-cooling system (Culpin, 1992).

2.7.4 Storage of milk

Pasteurized milk has a shelf-life of 2-3 days if kept at 4°C. Maintaining this low temperature causes a substantial increase to the cost of transportation and distribution and is therefore a major disadvantage to the development of a small-scale pasteurized milk business. If packaged in sealed bottles and stored at room temperature, sterilized milk should have a shelf-life in excess of six months (Culpin, 1992).

In summary, although many milk separators are in use, the process at the household level still need more improvement through the introduction of small to medium scale technologies that are affordable and effective, hence the need for this kind of study.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The centrifuge designed is made up of the following components;

i. An outer and inner cylindrical bowl made of aluminium

ii. A shaft.

iii. Paddles attached to the shaft for stiring of the milk.

iv. A heater.

v. An electric motor to rotate the shaft.

vi. Plastic pipes for steam outlet for milk and water

vii. A plastic tap for outlet of the processed products

3.1 Design considerations

i. To increase the surface area of the paddle in contact with the product.

ii. To improve the efficiency of the milk separation with the use of heater.

iii. To perform the operation under hygienic condition.

iv. To use proper materials that would not react with the product.

3.2 Description of the machine

The machine is made of two cylindrical containers, one of which is fixed inside the other. The outer cylinder has a 0.3m diameter, inner cylinder of diameter 0.2m and a height of 0.3m. The outer cylinder has a capacity of $0.0118m^3$ while the inner has the capacity of $0.0094m^3$.

The machine has a casing at the top covering the inner cylinder where the shaft attached the electric motor are bolted. The shaft has six paddles welded to it each machined at an angle to be able to slice through the whole milk during operation.

At the top of the outer cylinder, a hole is bored and a plastic pipe is fitted to the bored hole which serves as an outlet for the steam that comes from the raw milk. Also another hole is bored at the same distance from the first hole through to the inner cylinder and a pipe is passed through leading to the inner cylinder as a steam outlet.

At the bottom of the outer cylinder, holes are bored leading to each of the cylinders. A pipe is passed through to the one leading to the inner cylinder and on the outside of each of the bored holes, a valve is fixed for the discharged of water and separated products respectively.

3.3 Machine component design calculation

3.3.1 Shape and dimension of the cylindrical container

Cylindrical shape was used because it tends to conform with the centrifugal principle which rotates substances in a circular motion.

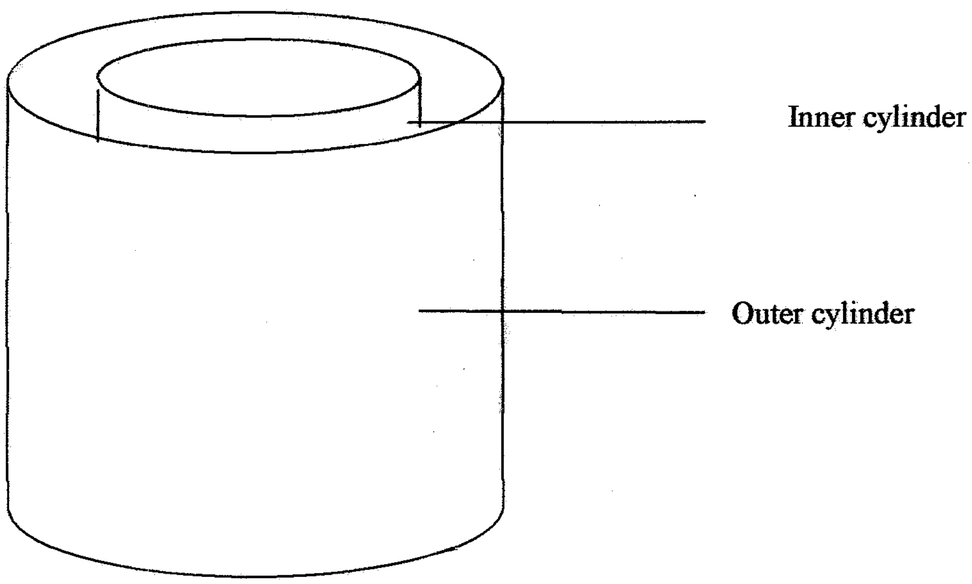

Fig 3.1 showing the centrifugal cylinder.

Volume of cylinder = $\pi r^2 h$

Where;

Π = 3.142

R = radius of the cylinder

h = height of the cylinder

V = volume of the cylinder

To calculate for the volume of the outer cylinder

Diameter of 0.3 m outer cylinder and 0.2 m inner cylinder was chosen to ease portability.

Where the diameter D = 0.3 m

Radius = $D/2$

= 0.15 m

Volume = $3.142 \times 0.15^2 \times 0.3$

= $0.0212\ m^3$

For inner cylinder

Where the diameter, d = 0.2 m

Radius = $d/2$

= 0.1m

Volume = $3.142 \times 0.1 \times 0.3$

= $0.0094\ m^3$

To calculate for water compactment

Volume of outer cylinder – volume of the inner cylinder = volume occupied by water.

$0.0212 - 0.0094 = 0.0118\ m^3$

3.4 Flow rate

To calculate the amount of the whole milk:

$$\rho_m = \frac{M_m}{V_m}$$

Note that allowance should be left to avoid spillage. Therefore, milk will only occupy 85% Of the total volume of the cylinder.

Assuming time = 60 mins

85% of the total volume of the cylinder = the volume occupied by the milk.

Where;

ρ	=	the density of milk.
M_m	=	the mass of milk
V_m	=	Volume of milk
M_m	=	$\rho_m \; x \; V_m$
M_m	=	1031 x 0.0079
M_m	=	8.14 Kg

Mass flow rate $= {}^{Mass}/_{Time}$

$= {}^{8.14}/_{60}$

= 0.14 kg/min

Flow rate, Q = velocity x area

$$= \text{distance}/_{\text{time}} \text{ x area}$$

$$= \text{volume of milk}/_{\text{time}}$$

$$Q = \ 0.0079/_{60}$$

$$= 0.0013\ m^3/min$$

3.5 Calculation of centrifugal force and speed of rotation

According to McGraw (1982),

Centrifugal force, $Fc = \ mr\omega^2$

$$m = \rho v$$

$$\omega = {}^{v}/_{r}$$

$$\omega = {}^{2\pi N}/_{60}$$

Centrifugal force can also be written as

$$Fc = \ m \text{ x } r \ x \ ({}^{2\pi N}/_{60})^2$$

$$Fc = 0.0109 \ x \ \rho \text{ x } v \text{ x } r \text{ x } N^2$$

Where,

m = mass of milk

ω = angular velocity

r = radius of rotation, 0.02 m

v = linear velocity

ρ = density of milk, 1031 kg/m^3

v = volume of milk, 0.0079 m^3

N = number of revolution per minute

$$Fc = 0.0109 \times 0.0079 \times 1031 \times 0.02 \times N^2$$

$$Fc = 0.00047 \times N^2$$

According to Rajput (2006),

$$N = \frac{60000P}{2\pi fr}$$

Where,

P = power of the electric motor, 1.5 kw.

f = centrifugal force, $0.00047 \times N^2$

r = 0.02 m

$$N = \frac{60000 \times 1.5}{2\pi \times 0.00047 \times N^2 \times 0.02}$$

$$N^3 = \frac{90000}{0.000059}$$

$$N = \sqrt[3]{1523823923}$$

N = 1150.74 rpm

Centrifugal force,

$$Fc = 0.00047x\,1150.74^2$$

$$Fc = 622\ N$$

3.6 Determination of the wall pressure

Static pressure (ps) exerted by the milk on the separator bowl

$$P_s = {force}/{Area}$$

$$= {\rho V g}/{A}$$

Where;

P_s = static pressure

A = area of the inner cylinder

F = force, N

ρ = Density of milk

V = volume of milk

g = 9.81 m/s²

Area of inner cylinder bottom = πr^2

$= \quad 3.142 \times 0.1^2$

$= \quad 0.0314\ m^2$

Area of the cylinder $= \quad 2\pi rh$

$= \quad 2 \times 3.142 \times 0.1 \times 0.3$

$= \quad 0.118\ m^3$

Total area $= \quad \pi r^2 + 2\pi rh$

$= \quad 0.314 + 0.188$

$= \quad 0.219\ m^2$

$$p_s = 1031 \times 0.0079 \times 9.81 / 0.219$$

$= \quad 364.85\ N/m^2$

3.7 Pressure exerted on inner wall due to centrifugal force

Centrifugal acceleration G is measured in multiples of earth gravity.

According to Leung (1997) G is giving by;

$$G/g = 0.00059\Omega^2 D$$

Ω = speed of centrifuge

D = diameter of the bowl

G = 0.00059 x 1150 x 0.2 x g

$$= 135.7 \times g$$

Pressure on the inner wall due to centrifugal acceleration is given;

$$Pc = {}^{Fc}/_{A}$$

$$= {}^{MG}/_{A}$$

Where;

Pc = wall pressure due to centrifugal force N/m^2

Fc = centrifugal force

M = mass of whole milk per batch.

$$Pc = 8.14 \times 135.7 \times {}^{9.81}/_{0.188}$$

$$= 57.63\ N/m^2$$

Total wall pressure = Ps + Pc

$$= 121.50 + 57.63$$

$$= 179.63\ N/m^2$$

3.8 Calculation of the component weight

To calculate the axial load

Mass of the milk per batch = 8.14 kg

Weight of milk per batch = 79 N

Weight of the bowl = area x thickness x ρ x g

Area of the bowl = 2πrh

= 2 x 3.142 x 0.15 x 0.3

= 0.283 m^2

Weight of the bowl = 0.283 x 0.001 x 2700 x 9.81

= 7. 49 N

3.9 calculation of the shape of the paddle

The larger the surface area of the paddle in contact with the mixture, the more efficient the operation. Therefore, the area covered by the paddle has to be put into consideration.

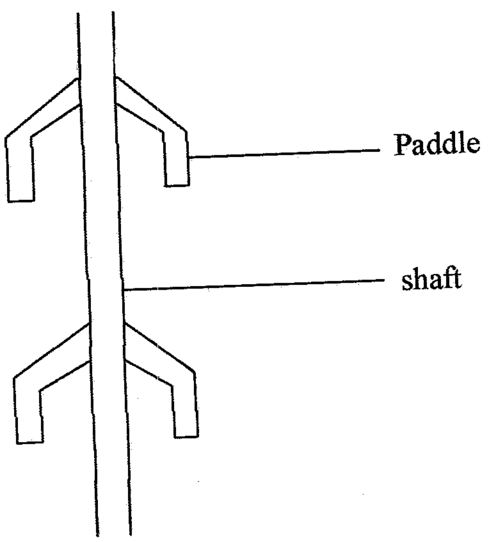

Fig. 3.2 Showing shape of the paddle welded to the shaft.

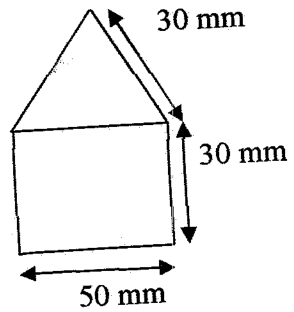

Fig 3.3 showing the shape of the area covered by the paddle derived from fig 3.2 above.

To determine the area covered by the paddle from the figure above;

Total area covered = Area of rectangle + Area of triangle.

Area of triangle = $2\left(\frac{1}{2} \text{x base x height}\right)$

Area of rectangle = length x breadth

Total area covered = $2\left(\frac{1}{2} x\, 25\, x\, 30\right) + (50\, x\, 30)$

= 900 + 1500 = 2400 mm^2

To determine the total surface area of the paddle;

From the fig 3.2, the shape of the paddle is cuboid's.

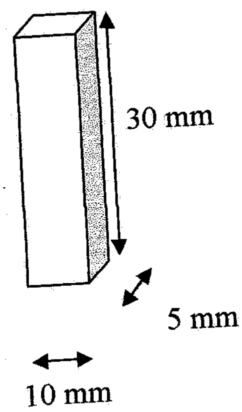

Fig 3.4 showing the dimension of the paddle

Total surface area of a cuboid = 2(length x width + width x height + height x length)

$= 2(10\, x\, 5\ + 5\, x\, 30\ + 10\, x\, 30)$

$= 2 \; x \, 500$

$= 1000 \; mm^2$

3.10 Calculation of torsional moment

Mt = $KW \times 9550/_{N}$

Where;

KW = power required from electric motor, 1.5 kw

N = number of revolution per minute, 1150.74 rpm

Mt = $1.5 \times 9550/_{1150.74}$

= 12.4 N/m

3.11 Power required to operate the machine

Power = 2πNT

The machine is expected to work at a speed of 1460rpm

To rev/secs, it becomes

$= 1150.74/_{60}$

= 19.2 rev/secs

Where;

T = torsional moment

N = shaft revolution per secs

$P = 2 \times \pi \times 19.2 \times 12.4$

$= 1495$ watts

≈ 1.5 Kw

3.12 Centrifugal shaft design

Power of elctric motor = 1.5 kw

Speed of electric motor = 1150 rpm

Mass of the bowl = 2.20 kg

Mass of milk per batch = 8.14 kg

Density of aluminium, ρ = 2700 kg/m³

Weight of the driving motor = 5.2 N

3.12.1 Determination of shaft diameter

According to hall (1980)

$$d^3 = \frac{16}{\pi Ss}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

where;

d = Shaft diameter

Ss = Allowable stress (for shaft without keyway) = 55 MN/m²

Kb = Combined shock and fatigue factor for bending moment for gradually applied load = 1.5

Mb = Bending moment

Kt = Combined shock and fatigue factor for torsional moment for gradually applied load = 1.0

Mt = Torsional moment

$$d^3 = \frac{16}{\pi(55x\ 10^{-6})}\sqrt{(1.5 \times 0)^2 + (1 \times 12.4)^2}$$

$$d^3 = 9.2 \times 10^{-8}\sqrt{153.76}$$

$$d^3 = 9.2 \times 10^{-8} \times 12.4$$

$$d^3 = 114.08 \times 10^{-8}$$

$$d = \sqrt[3]{114.08 \times 10^{-8}}$$

$$d = 0.0094 \text{ m}$$

3.13 Heat insulation load

Ambient operating temperature = 30°C

Required whole milk temperature = 35°C

Thermal conductivity of aluminium = 240 $Jm^{-1}s^{-1}°c^{-1}$

Thermal conductivity of whole milk = 0.56 $Jm^{-1}s^{-1}°c^{-1}$

Circumference of the cylinder = 2пr

= 2 x 3.412 x 0.1

= 0.628 m

Heat conducted away from the milk to the sorrounding atmosphere

= 240 x 0.628 x 0.36 x (35 - 30)

= 271.13 KJ

Heat released by the whole milk

= 0.56 x 0.628 x 0.36 x (35 – 30)

= 24.373 KJ

3.14 Calculation of ratio of milk to cream.

According to Ito *et al.*,(1996), the fat content most not be more than 25%.

Volume of whole milk, V = 0.0079 m^3

25% of the whole milk is;

$$\frac{25}{100} \times 0.0079$$

= 0.0019 m^3

Therefore, the volume of milk is = Whole milk – the fat content.

$$= 0.0079 - 0.0019$$

$$= 0.006 \text{ m}^3$$

The ratio of milk to cream $= \dfrac{0.006}{0.0019}$

$$= 3:1$$

3.15 Performance test procedure

After the design machine was fabricated, performance test was carried out to actually assess its performance. The assembled machine was first ran empty. 0.0079m^3 quantity of raw milk was obtained and poured into the machine and the machine was operated for 20 minutes. A reasonable separation was not achieved at that time, so the machine was then operated for another 18 minutes taking the total time of operation to 38 minutes before the separation was achieved. The product was then left to settle for total separation to occur after which the separated products were collected and weighed.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

From the experiment conducted, the results are as shown in table 4.1 below.

Table 4.1: The results obtained from separation of milk from cream

Measured Parameters	Values
Volume of the whole milk (m^3)	0.0079
Expected time of separation (mins)	20
Time of separation occurs (mins)	38
Mass of whole milk (kg)	8.10
Mass of milk (kg)	6.22
Mass of cream (kg)	0.60

From the table above;

ration of milk to cream = $^{6.22}/_{0.6}$

= 10 : 1

4.2 Discussion of result

The results of the performance test carried out on the designed machine are as recorded in the table 4.1. From a raw milk of $0.0079m^3$ or 8.1kg, the cream obtained after 38 minutes was $0.00058m^3$ or 0.60kg while the milk obtained was $0.006m^3$ or 6.22kg. This result showed that the ratio of milk to cream obtained was 10:1. This result differ slightly from that in literature (Ito *et al.*, 1996) which gave a ratio of 3:1.

Though the time designed for was 20 minutes, it took 38 minutes to achieve the above separation. It was observed during the test that the paddle did not cover enough area inside the inner cylinder hence the stirring of the raw milk was not effective.

$$\text{The efficiency of the machine} = \frac{\text{sum of mass of separated product after operation}}{\text{mass of the whole product before separation}} \times 100$$

$$= \frac{6.82}{8.1} \times 100$$

$$= 84\%$$

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A portable centrifuge has been designed and fabricated using available material which could be employed at household level to process raw milk. From the performance test, it can be concluded that with little modification the machine can form part of the drive to establish small to medium scale processing industries at the rural communities in the country.

From the experiment conducted, the fabricated centrifuge was able to separate $0.0079m^3$ of raw milk into $0.00058m^3$ of cream and $0.006m^3$ of milk giving a ratio of milk to cream to be 10 : 1 and separation efficiency of 84%.

5.2 Recommendations

The following recommendations were made;

1. A better way of reducing the sticky nature of the cream should be investigated.
2. A larger paddle design should be taken into consideration to improve the efficiency of the machine.
3. Stainless steel should be used for the part that comes in contact with the milk.

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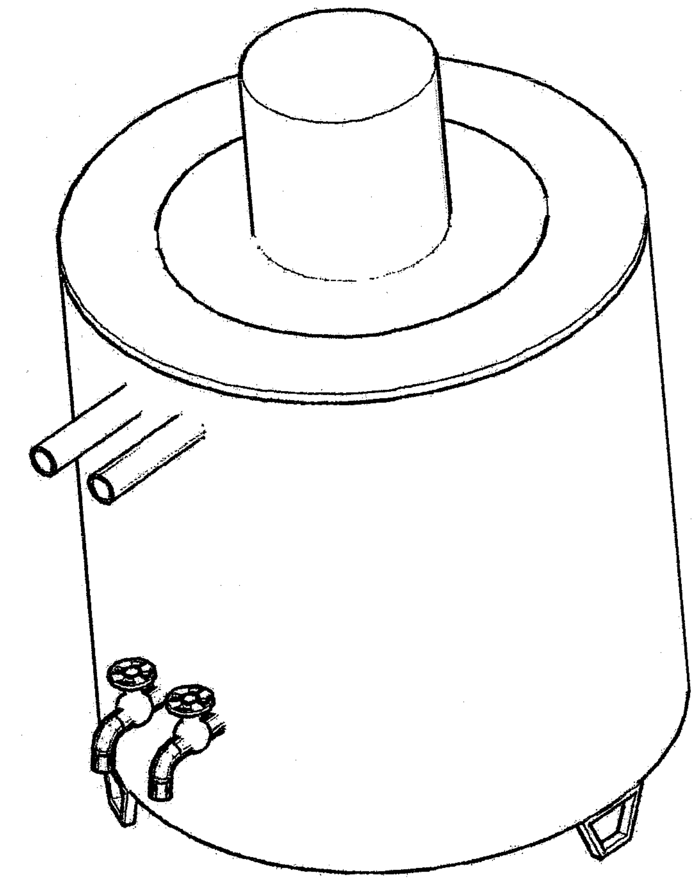
APPENDIX

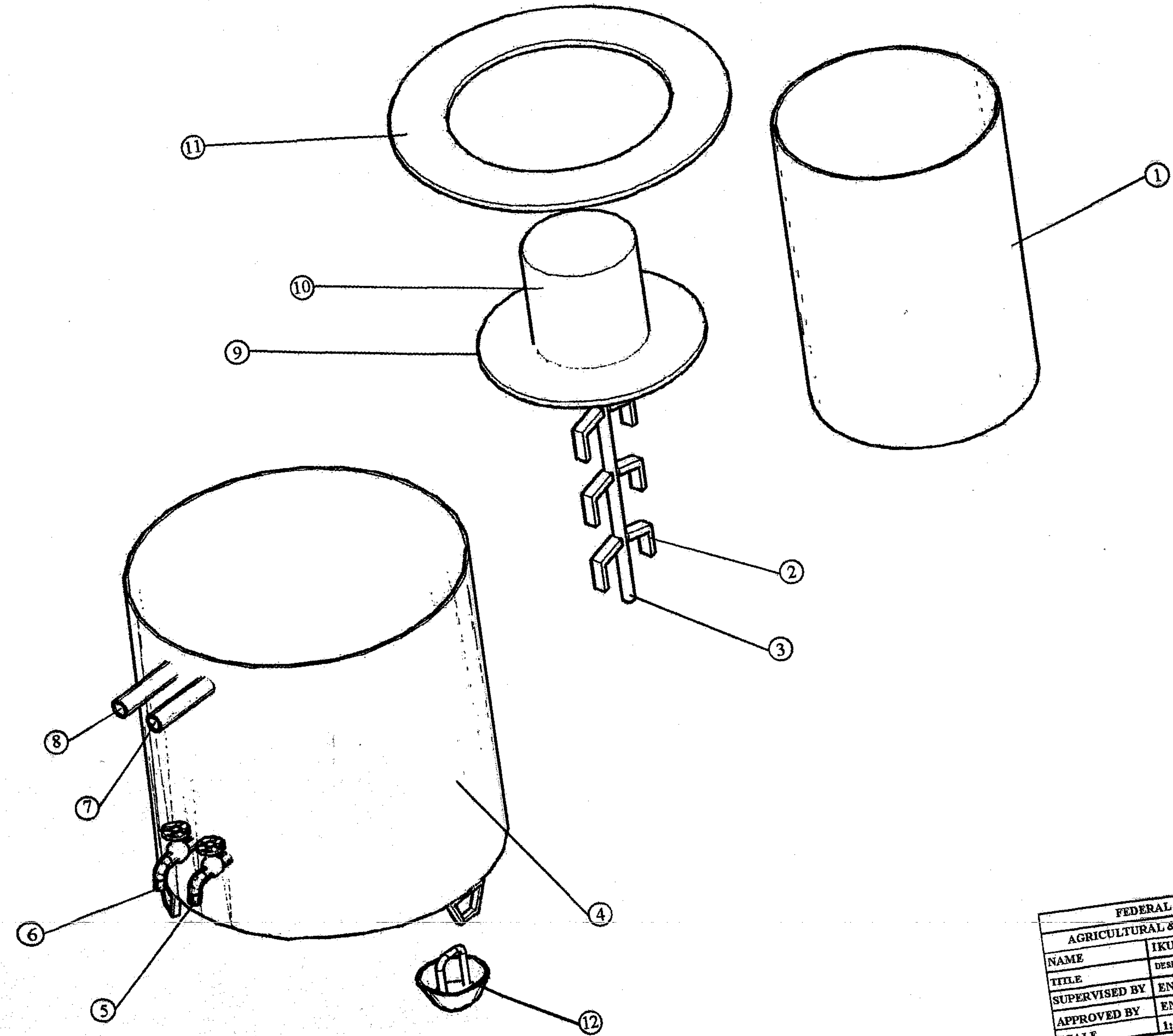
Table 4.2: Material Cost

S/N	Material	Specification	Quantity	Amount (₦)	Price (₦)
1	Aluminium sheets	Two square meters	Two	600	1200
2	Taps	Plastic	Three	600	1800
3	Bolt and nuts	Ten and eight millimeter diameter	Six	200	1200
4	Shaft	0.0094 diameter Rod	One	500	500
5	Electric motor	1.5kw	One	1500	1500
6	Electric cable	2mm thickness	Two yards	350	700
7	Boiling ring		One	1500	1500
8	Raw milk	Cow milk	$0.0079m^3$	1200	1200
9	Wire gauze	0.5 square meter	One	500	500
10	Gum		Two	500	1000
11	Welding			1000	1000
12	Labour cost			2000	2000
	Total cost				14100



ISOMETRIC VIEW

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA			
AGRICULTURAL & BIORESOURCES ENGINEERING DEPARTMENT			
NAME	IKUEROWO KEHINDE LEKE	2005/21614EA	
TITLE	DESIGN AND FABRICATION OF CENTRIFUGE FOR MILK AND CREAM SEPARATION		
SUPERVISED BY	ENGR. DR. P.A. IDAH	SIGN:	
APPROVED BY	ENGR. DR. P.A. IDAH	SIGN:	
SCALE	1:5	DATE:	NOVEMBER 2010



ITEM	DESCRIPTION	MATERIAL
12	WATER HEATER	ALUMINIUM
11	OUTER CYLINDRICAL COVER	
10	MOTOR	ALUMINIUM
9	INNER CYLINDRICAL COVER	RUBBER
8	STEAM OUTLET FOR PRODUCT	RUBBER
7	STEAM OUTLET FOR WATER	RUBBER
6	PRODUCT OUTLET	RUBBER
5	WATER OUTLET	ALUMINIUM
4	OUTER CYLINDER	MILD STEEL
3	SHAFT (9Ax280mm)	MILD STEEL
2	PADDLE	ALUMINIUM
1	INNER CYLINDER	

PARTS LIST

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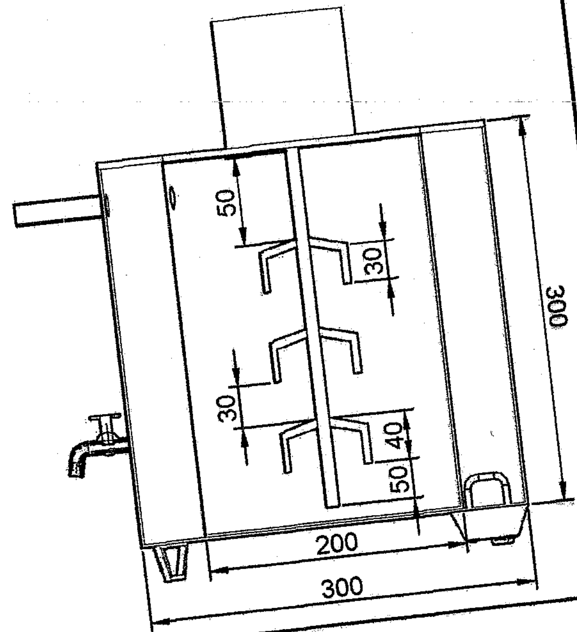

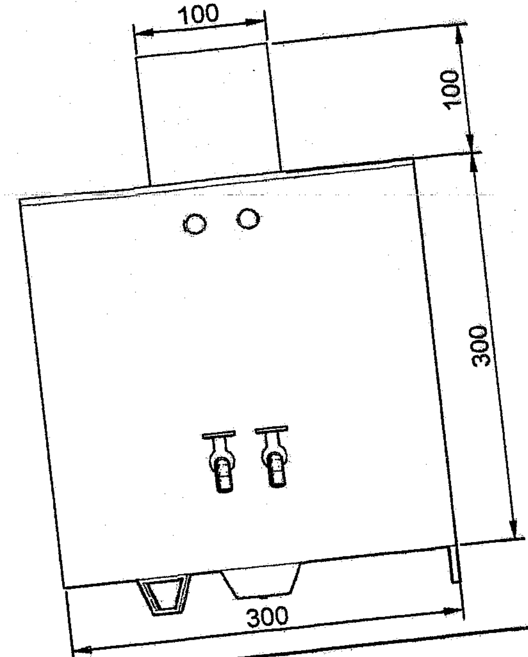

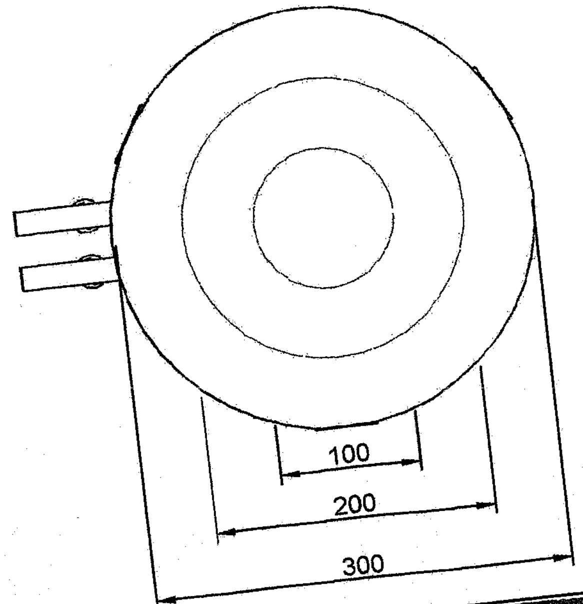

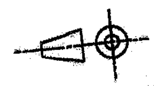

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