DEVELOPMENT OF SMALL SCALE EQUIPMENT FOR EXTRACTION OF COCOA BUTTER AND PRODUCTION OF COCOA POWDER

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled "DEVELOPMENT OF SMALL SCALE EQUIPMENT FOR EXTRACTION OF COCOA BUTTER AND PRODUCTION OF COCOA POWDER" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that the thesis entitled "DEVELOPMENT OF SMALL SCALE EQUIPMENT FOR EXTRACTION OF COCOA BUTTER AND PRODUCTION OF COCOA POWDER" is a record of research work done independently by Shri.V.Ganesan, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to him.

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We, the undersigned members of the Advisory Committee of Shri.V. Ganesan, a candidate for the degree of Master of Science in Agricultural Engineering agree that the thesis entitled "DEVELOPMENT OF SMALL SCALE EQUIPMENT FOR EXTRACTION OF COCOA BUTTER AND PRODUCTION OF COCOA POWDER" may be submitted by Shri.V. Ganesan, in partial fulfilment of the requirements for the degree.

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Dedicated

to the memory of

Late Dr. Jose Samuel.

Former Professor and Head, Department of Agricultural Engineering, Kerala Agricultural University.

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Introduction

INTRODUCTION

During the last ten years there has been an increasing interest in growing cocoa as a mixed crop in coconut and arecanut gardens. However, of late, there has been a decline in the interest among the cocoa growers owing to the sharp fall in the price of cocoa. The present area under cocoa in Kerala is estimated to be 25,000 ha and the annual production is around 3,300 tonnes. The production is expected to go up markedly in the next few years, when more plantations will attain bearing stage.

Cocoa beans deteriorate rapidly in quality after removal from the pods. Proper preliminary processing, namely fermentation and drying, of fresh beans is essential to develop and retain the characteristic chocolate flavour. Large scale planting of the crop was taken up in this country during the seventies and no serious attention was paid to the processing aspect. Growers are not conversant with the preliminary post harvest technology of cocoa beans. The majority of the growers sell the wet beans as such to the cocoa collection centres established by private firms, where the preliminary processing is carried out, which includes fermentation and drying.

Considerable work has been done with regard to various unit operations involved in the processing of cocoa beans right from harvesting to processed products. For the complete processing of beans, into products like, cocoa powder and chocolate only few industries such as Cadbury Fry (India) Private Ltd., and Kaira District Co-operative Milk Producers' Unions Ltd., (Amul) are in possession of the necessary know-how and equipment. Post harvest studies are being undertaken at various centres like C.F.T.R.I., Mysore and C.P.C.R.I., Kasaragod. But these studies too are generally aimed at large scale processing.

Some information is already available on fermentation and drying. Roasting, shelling, grinding and removal of cocoa butter are highly specialized operations on which only limited information is available. These operations are now carried out by multinationals and big firms.

Unlike in the other cocoa growing countries most of the cocoa growers in India are small farmers. Their average yield does not exceed more than 25-50 kg of fresh beans per harvest during peak seasons. There is a general feeling among the growers that they are now being exploited by the big manufacturing firms. This feeling is justifiable, to a large extent, when one considers the following facts and figures.

The present market price of wet cocoa beans is Rs.5.50 a kilogram. Three kilograms of wet beans are required to produce one kilogram of dry beans, that is the cost of wet beans required to produce 1 kg of dry beans is Rs.16.50. The loss of weight during various processes involved in the production of cocoa mass is 17.5 per cent and hence one kilogram of dry beans produces 0.825 kilogram of cocoa mass. The cost of wet beans required to produce 1 kg of cocoa mass works out to Rs.20/-.

Cocoa mass contains cocoa cake and butter in the approximate proportion 45:55. The price of cocoa powder in the market varies from Rs.100/= a kilogram to Rs.140/= a kilogram. The price of cocoa butter, which has a good export market, is much higher than that of cocoa powder. Even if the price of butter is taken same as that of cocoa powder, the price of cocoa mass will not be less than Rs.120/= a kilogram, while the cost of raw material required to produce 1 kg of cocoa mass is only Rs.20/=. There is a great disparity between the price of raw material and the finished product. The various operations involved in the production of cocoa powder are not very expensive when they are done on a large scale. This wide disparity in the prices of the raw material and the finished product is because there are only very few buyers for the raw material and a large number of sellers. It is a buyers' market where the buyers dictate the price.

Once the know how and the equipment for small scale processing of cocoa are developed, small scale entrepreneurs can take up processing of cocoa. The fermentation and drying can be carried out by the farmers and further processes of roasting, shell removal and extraction of butter can be carried out in small scale units set up at various centres in the state. The products can be sold to bakers and confectioners in the form of raw cocoa powder and butter. This will increase the number of buyers in the market which will in turn create healthy competition in the market. This will go a long way in helping the small cocoa growers of Kerala by fetching a good price for their produce. Consumers will also be benefited as the prices of the finished products are likely to come down.

This project aims at developing a viable technology and equipment system suited for small scale processing of cocoa beans into cocoa powder and cocoa butter.

Review of Literature

REVIEW OF LITERATURE

2.1. Botanical Description

The cocoa tree belongs to the genus *Theobroma*, a group of small trees whose natural home is in the Amazon basin and other evergreen tropical areas of South and Central America. The centre of origin of cocoa tree is considered to be in the Upper Amazon. There are over twenty species in the genus, but only one, *Theobroma Cacao* L. is cultivated widely (Wood 1975).

Cocoa, *Theobroma Cacao* L. is one of some twenty two species that constitute the genus Theobroma, a member of the family Sterculiaceae. Only *Theobroma Cacao* produces the cocoa of commerce, though other species are sometimes used as adulterants. The seed of cocoa is non-resting, and hence it cannot be stored within the pod for any length of time. If not harvested at maturity the seed may germinate within the pod. When taken from the ripe fruit, the seed is surrounded by a mucilaginous pulp which contains the germination inhibitor. Germination can be speeded up by removing this pulp with the testa which is thin and leathery. The testa is usually called the skin or, when dry, the shell.

The tap root of the seedling grows straight down into the ground. At a very early stage lateral roots arise in a collar just below the surface, and in the mature tree it is found that most of the secondary roots have arisen within 15 to 20 cm of the surface.

The seedling grows as an unbranched single stem to a height of one to two metres. A full grown tree grows to a height of 8 to 10 metres but to facilitate the gathering of the pods, growth is restricted to some 5 to 6 metres. The first leaves are long petioled and symmetrical. The petiole has a marked pulvinus or swelling at each end, which allows the orientation of the leaf in relation to light. The leaves on the fan branches have shorter petioles and are slightly asymmetrical. Leaves vary in colour according to the type from pale green to pink or pink red.

Cocoa is cauliflorous, that is, the flowers and fruits are borne on the old wood of the trunk and main branches. The inflorescence arise in the leaf axil and is a compressed dichasial cyme. After a compatible pollination the fruit starts to develop and normally reaches maturity in five to six months. The cocoa pod

grows near to the stem and develop into a longish oval-shaped "gourd". The average size can be anything from 18 cm to 25 cm in length and 7 cm to 11 cm in breadth. The colour of the outer shell varies and often changes from green to yellow. As the pod ripens, the outer layer of the integument of the seeds within produces a layer of prismatic cells which have a high content of sugar and mucilage. At full maturity, these cells break down and the seed separates easily, each surrounded by its layer of pulp. The high sugar content of the pulp is of importance in the fermentation process which the seeds undergo after harvesting and is essential for the proper development of chocolate flavour. The average number of beans found in the pod varies from 30 to 40. The number of pods harvested from a tree in a year ranges from 50 to 100. (Nyffeler, 1971).

2.2. Preliminary processing

2.2.1. Harvesting

This involves removing the ripe pods from the tree and opening them to extract the wet beans. Pods are removed from the tree by various forms of knives. The pods can be opened with a knife or by cracking them on a stone or on a strip of wood (Plate 2 and 3).

Plate No. 2-&-3 Opening of a cocoa pod by cracking on a [illegible] strip of wood

The process of pod opening is one that would appear suitable for mechanization, but no simple and effective machine has been developed. Some attempts at developing a pod opening machine have been reported (Jimenez, 1967, Jabogun, 1965 and Wood, 1968), but so far they do not appear to have been successful, which may be due to the difficulty of separating wet beans from pieces of broken husk. Though the task of harvesting and pod opening are separate, it has been found that a man can harvest about 1500 pods a day and similarly a man can open about 1,500 pods a day. When the beans are removed from the pods they are covered with mucilage or pulp. The pulp consists of 80 per cent water, 10 to 15 per cent glucose and fructose, upto 0.5 per cent of non-volatile acid and some amounts of sucrose, starch, volatile acids and salts (Wood, 1975).

2.2.2. Fermentation

Fermentation involves keeping a mass of cocoa beans well insulated, so that heat generated during the fermentation is retained at the optimum level. During this process, air is allowed to pass through the mass. The process lasts upto seven days, and is followed immediately by drying. Fermentation means conversion of sugars contained in the pulp to alcohol and from alcohol to acetic acid. Basic requirements for satisfactory fermentation of beans, which should commence within 24 hours after opening the pods, are maintenance of heat, drawing off sweatings and provision for adequate access to air (Chatt, 1953). The heat produced must be conserved so as to aid the chemical changes that are taking place inside the beans. Main purpose of fermentation is to develop good chocolate flavour. Wyrley (1966) reported that the most important crieterion for good fermentation is that for at least three days the temperature of the fermentation should be as close to 50°C and it should never be less than 45°C in this period. The different methods of fermentation are heap method, box method, basket method, tray method and polythene bag method.

Fermentation methods varies widely between the cocoa producing countries in the world. Proper fermentation depends on the following factors:-

1. Amount of aeration of beans,
2. Provision for drainage of sweatings,
3. Temperature control,
4. Movement of beans during fermentation,
5. Duration of fermentation.

2.2.2.1. <u>Heap fermentation</u>

In this process, the wet beans are placed on banana leaves on the ground. When the heap is complete, it is covered with more leaves and these are often held in position by small logs of wood. The heap is kept for six days, turning the beans after the 2nd and the 4th days. Generally, the leaves are kept on strips of wood above the ground level to draw off sweatings.

2.2.2.2. <u>Box fermentation</u>

Boxes of different sizes, made of wood, are used depending upon the availability of wet beans. The commonly used boxes are of sizes 60 cm x 60 cm x 60 cm and 120 cm x 120 cm x 90 cm. On the side of the boxes, 5 to 15 mm holes at a spacing of 10 to 15 cm are provided to draw off sweatings and also for proper aeration. The size of the box used varies depending on the quantity of beans to be fermented. In one of the methods developed, boxes are arranged in tiers either making use of a slope or raising initial boxes on a stand. The wet beans are covered with banana leaves or sacks in order to retain the heat. During the course of fermentation the beans are moved from one box to another to ensure uniform conditions. It also helps to revitalise the fermentation as the temperature rises immediately after mixing.

2.2.2.3. Basket fermentation

In this method baskets made of bamboo are lined with banana leaves. Beans are put inside the baskets and covered again with banana leaves. Generally some weights are kept over this. This will be kept for seven days and beans are turned on every third and fifth day.

2.2.2.4. Tray fermentation

This is relatively a new method developed by Rohan in 1958. Normally, the size of the trays will be 90 cm x 60 cm x 13 cm and is made of wood. About 10 to 12 trays are stacked one over the other. The bottom one is left empty for proper aeration. Fermentation in trays has been found to be quicker than fermentation in heaps or boxes (Wood, 1975).

2.2.2.5. Polythene bag fermentation

In this method beans are kept in polythene bags provided with holes and this though suitable for small quantity of beans, does not give very satisfactory results.

All these methods require substantial quantity of beans at a time for satisfactory results. Small scale fermentation is a problem to the majority of cocoa growers in Kerala, where the average size of most of the holdings is well below one hectare. The number of pods harvested at a time is few to go for any of the traditional methods of fermentation. Fermentation of small batches of cocoa in the range of 5 to 25 kg has always been difficult. Investigations were carried out in the Kerala Agricultural University to develop suitable methods, for small scale fermentation. Three methods, mini basket, mini box and mini trays were tested. In each of the methods, the quantities of wet beans 1.5 and 3 kg were compared. The beans were set for fermentation for varying periods, four days for mini tray method and six days for mini box and mini basket methods (Kumaran, 1980). Results revealed that the mini box and the mini basket methods, which involve keeping the beans for six days and turning them once in alternate days, were suitable for proper fermentation of small quantities of cocoa beans. Among the containers, those made of wood were better than basket as far as temperature retention and proper aeration were concerned. The quality of beans were judged by cut test. The acidity values were also found were satisfactory. Since there is sufficient information available about fermentation, no further study was undertaken in this project.

2.2.3. Drying

The objective of cocoa beans drying is to dehydrate the beans sufficiently to ensure that they will not putrify or develop unpleasant odour during the period of storage. At the end of fermentation the moisture content of beans is about 55 per cent and this must be reduced to 6 to 7 per cent for safe storage (Wood, 1975). The rate of drying varies greatly according to the method employed. If drying is too slow there is a possibility that moulds may develop on the outside and may penetrate the shell; there is a further danger that off flavours may develop.

Drying is done in the sun where quantities are small and climate is suitable. Artificial dryers are employed for large production or under adverse conditions. Countries where the main harvest is gathered during dry seasons, the beans are usually dried in the sun. The area required for sun drying is about 2.8 m^2 per 50 kg of dry beans. The beans are spread to a depth of about 5 cm and are raked with a wooden palette. Sun drying requires constant attention not only to ensure uniform drying but also to put the beans under cover when it rains. It is found that beans dried at ground level leads to contamination by domestic and other animals. The following are the most important factors governing the artificial drying.

(a) Difference in temperature between the drying air and that of the product.

(b) Difference in vapour pressure between the drying air and that of the product.

(c) Surface area of the product exposed to drying air.

(d) Air velocity.

The above conditions are basically dependent upon the temperature and flow rate of drying air, bean depth, and agitation of beans or a combination of all these factors.

Studies were conducted to plot cocoa beans drying curves under different conditions of air flow rate, air temperature and thickness of cocoa beans layer to determine the transfer coefficient for a drying period at constant rate and also the resistance to drying. The properties of cocoa produced by artificial and solar drying were compared in regard to pH, volatile acidity and total acidity of cotyledons, microbial contents of the whole beans, bitterness and aroma of the chocolate.

Results revealed that optimal drying condition of air temperature is 65 to 70°C and moderate air flow of 0.4 to 0.5 m/sec. (Jacquet, *et al.*, 1980) to avoid caking. Equipment for small scale drying particularly suited for Kerala condition is not readily available. Attempts are being made at the C.P.C.R.I. Kasaragod to develop a small dryer for 50 to 100 kg fermented beans.

2.3. Secondary Processing

2.3.1. Roasting

Roasting of cocoa beans, more correctly termed as treatment of cocoa beans in hot air, is one of the most important operations in the processing of cocoa and the degree of treatment required being adjusted to the degree of ripeness of the beans concerned and any other pre-treatment which they may have undergone (Riedel, 1977). The true purpose of roasting is not only restricted to loosening of the shells, but also to develop positive flavour as well as the removal of excess moisture and other undesirable volatile matters.

Different styles of roasting can be applied and they result in different end effects, some of which are more applicable to particular varieties of beans than others. The style of roasting should ensure an absolutely equal treatment of all the beans in the batch. Riedel, (1974) suggested that the main objects of roasting are (a) colour development (b) aroma and flavour development (c) modification of the structure of the shell so as to permit easier subsequent separation (d) reduction of moisture content (e) solubilisation of cocoa starch and (f) chemical changes, especially oxidation of some minor constituents of the beans.

Roasting causes some degree of loss of cocoa butter from the nib but this does not amount to a great deal. A loss of 0.2 to 0.5 per cent by weight (dry basis) has been reported (Riedel, 1974). The loss occurs as a result of migration of fat from the nib into the shell. The higher the temperature, the greater the loss. The loss of fat can be appreciably reduced if the beans are well cooled immediately after roasting. There is, in any case an overall loss in weight of 5 to 7 per cent while roasting due to reduction of moisture content. Riedel (1974) also stated that the most favoured temperature for proper roasting of cocoa beans for chocolate making lies between 120°C and 125°C. The optimum temperature is also to some extent dependent on the actual time allowed for roasting. The temperature and time have considerable influence on colour and flavour. Chemical changes take place in the nib at a temperature of about 120°C to 135°C. To obtain the final qualities of flavour, beans should usually be roasted at the lowest practical temperature. The fine beans of the criollo type should be given a lower temperature of 110°C to 115°C to prevent loss of more delicate flavouring components (Lees et al., 1975). A low temperature roast can take upto 60 minutes to complete; a medium roast upto 40 minutes and a high temperature roast from 15 to 25 minutes. The discharged beans must be rapidly cooled to prevent over roasting with attendant discolouration and spoilage of flavour. There is very little loss of volatile acids from the beans during roasting. Upto 10 per cent of acetic and propionic acids are however released from the shell (Diemer et al., 1959). They have also shown that losses of carbohydrates and amino acids also occur during roasting. Mohr et al. (1957) found this to be 0.2 per cent of the dry nib weight, while Kleinert (1957) in measurements made on a different bean variety found a loss of 0.5 per cent. Properly dried beans have a moisture content of 4 to 6 per cent. During storage there is a gradual pick up of water from the atmosphere and the moisture content can rise to 10 to 20 per cent. Well stored beans can show a weight loss during roasting of 4 to 7 per cent, the greatest part is of which accountable to the removal of moisture.

The various possible methods of heating of the beans are as follows.

(a) Direct or indirect heating

(b) Direct heating by gas

(c) Direct heating by steam pipes

(d) Heating by hot air.

One of the most economic methods of roasting is on the Lehmann Roaster. On this the air is first used for cooling the beans and the beans are then further heated for roasting.

The Buhler roaster uses heated air which blows through the beans as they pass down sloping metal plates.

The Nalder & Nalder machine is a steam heated cascard type of machine.

The Barth Sirocco machine uses only heated air for roasting.

A new style of continuous roasting machine has recently been introduced by Probat - Werke, of Emmerich. The roasting is produced by hot air which is introduced in the appropriate quantity and at the appropriate rate at each stage of the roasting process. Exact control over the moisture content can also be exercised with the help of a special apparatus (Riedel, 1974).

2.3.2. Kibbling and Winnowing.

The purpose of winnowing is to separate the shell and germ and to split the cocoa into its natural segments (cocoa nibs). Roasted cocoa beans can contain between 10% and 15% shell depending on the source and about 1% germ. The presence of significant amount of shell, in chocolate will affect both colour and flavour and in addition reduces the effectiveness of refining. The separation of shell and germ can be carried out separately or together, depending on the choice of commercial plant. Cocoa beans are first cracked by passing through rollers or rotating cones. An air current is then used to blow away the lighter shell. The velocity of this air stream is critical, it should be sufficient to remove the undesirable shell but not too high to blow off the costly nib and must be varied to suit the changing size of cocoa bean from differing sources.

Discharged cocoa shell may contain as much as 20 to 25 per cent of cocoa fat. Yields of between 80 to 86 per cent are normally achieved by winnowing. The shell butter content of commercial shell is variable and fluctuates according to the amount of fat transferred from the nibs through roasting and the efficiency of the winnowing machine in separating nibs from shell. Cocoa shell butter is a deep yellow solid, and melts to a dark brown liquid. On account of its high acid value shell butter is not acceptable as human food.

Studies were carried on husk content of cocoa beans (Marshalkin et al 1979) in relation to the fractional composition of cocoa beans and husk content. The smaller the beans the higher the proportion.

Marshalkin et al (1979) also reported that complete separation of nibs and shells are possible if the size of shell particles separated is increased. The size of shell particles can be increased by treating beans prior to cracking , with water to give a shell moisture content of 13 to 16 per cent.

2.3.3. Alkalisation

When beans are used for manufacture of cocoa powder the cocoa liquor is generally treated with alkali to improve the colour and to develop the flavour. Alkalised cocoa is known commercially as "Soluble Cocoa". The amount of alkali used for the preparation as soluble cocoa is adjusted to bring about partial rather than complete neutralisation. Saturated solutions of sodium or potassium carbonate or bicarbonates are most generally used while, ammonia, ammonium carbonate, magnessium oxide or carbonate or bi-carbonate or mixtures of certain of the above chemicals are favoured by some manufacturers. Alkali may be introduced prior to roasting or at the nib stage or at chocolate liquor stage. However, it is more economical to mix it with chocolate liquor.

The original process of alkalisation used tanks, in which the nib was soaked in warm alkali solution until complete penetration into the nib was achieved. Both the quantity of alkali and its concentration in water used had a profound effect on the colour of the final cocoa. Alkalisation temperature of 80°C to 85°C gave the best flavour . The duration of alkalisation was determined by the time taken for the alkali solution to penetrate the nib. In production experiments this was found to be about an hour which was also the adequate time required for the mixture to reach 80°C (Minifie, 1968).

Liquor alkalisation has been widely practised particularly in Britain, but suspensions or solutions of alkali are used with much less water than with nib alkalisation and as a result sandy - brown cocoa are produced. Nib alkalisation produces a darker cocoa powder than given by liquor alkalisation.

2.3.4. <u>Grinding</u>

Very fine grinding is essential for subsequent processing to chocolate. Normally cocoa is subjected to a pre-grinding stage followed by fine grinding (Bauermeister, 1978). The particle size of the finished product has pronounced effect on its suitability as an ingredient of different food products (Minifie, 1968).

The nibs or meaty part of the beans, remaining after removal of the husk and the germ are milled to liquor by grinding very finely. During this operation heat is generated by friction which melts the fat. Bywaters (1930) points out that great difficulty is encountered when dealing with low-roasted beans owing to their tendency to form a pasty mass which will not readily flow.

Normal grinding is by means of either cylinder rollers of 3 or 4 stages or a ball mill. The ball mill gives better over all performance as regards to fineness of grinding and is simple to maintain (Bauermeister, 1978).

Chatt (1953) reported the following,

In stone mills, known as tripple mill, the nibs are ground between three pairs of grooved stones. The nib falls from the hopper through the centre of the upper stone of the first pair and passes towards the outer edges during grinding. Stone mills possess certain advantages over the roll mills, in that the liquor delivered has a lower viscosity and consistent size of particle, but they suffer from the disadvantage that continuous wear necessitates frequent re-cutting of the stones. This objection can be overcome by using ceramically bounded aluminium oxide (Aloxide) stone which are more durable than the customary burr stones.

Roll grinding is effected by a series of hollow water cooled steel rolls or by a combination of steel and stone rolls operating at different speeds. The nibs are first crushed between the fluted rolls or in a disc mill. Alternately, they may pass through a series of roughing rolls before reaching the finishing rolls for finer grinding. The Buhler eight roll mill is in two sections of four rolls for coarse grinding, placed above four finishing rolls. The Lehmann eight roll mill is arranged in five-roll and three-roll sections. Stollwerck mill has two fluted crushing rolls, three roughing rolls with occassional flutes and three smooth finishing rolls. The reduction of nibs to liquor can be performed in a disc mill. The Baker Perkins model consists of two sets of gravity-fed water-cooled discs. Coarse grinding is done between the upper discs and the liquor passes to the lower set for fine grinding. The development of liquor mills has greately increased the efficiency of grinding both as regards to fineness and output. The early model developed in the 1930's had two vertical disc mills, the first a breaker, and the second a finisher which produced a fine ground liquor (Minifie, 1968). Each mill had a fixed and rotating steel disc and the gap between them was adjustable to give the required output and fineness.

Daffey (1976) reported a Bauermeister mill type referred as "Beater Blade Mill". This grinding mill is guaranteed for 600 hours which is equivalent to 600 tonnes of product. Also it has the advantage of the ease of accessibility for cleaning and adjustments.

2.3.5. Extraction of the butter from the Cocoa mass

The only practical way to remove cocoa butter from cocoa mass is with a hydraulic press. Cocoa presses have a long history. The very early presses were probably operated by a screw pushing a plunger down on a cloth bag full of cocoa mass kept inside a cylinder. Later in about the mid 18th century C.J.Vanhouten employed principles of hydraulics to get the required plunger pressures (Carver, et al., 1970).

Changes in presses began in the early 1920's Cocoa presses remained Vertical for about 150 years. They did not change much until early 1920's when metal filters were developed and patented by Fred.S.Carver (Carver, 1970). These metal filter plates with their woven metal screens did away with canvas and felt pads, which were messy, expendable and contributed foreign fibers to the cocoa cake. Important improvements in vertical presses were developed and put into use during that decade by Carver. These included spring closing of the pots (instead of individually screwing them closed) hydraulic cake ejection, multiple pot filling (instead of using buckets and hoses). He also put into use the self contained pot presses employing all these features.

In the 1930's Carver developed the large horizontal pressure - filled cocoa press and some of the first ones built are still running on a round the clock basis. At present there are four manufacturers in the world offering cocoa-presses. All the four makers employ the horizontal feature, spring closing of the pots, metal filters, hydraulic ejector of cakes and simultaneous liquor feed to the pots. Two makers, Carver & Bauermeister, employ pressure filling to pre filter much of the butter out, using the energy of a liquor pump for this purpose. This allows a larger load or charge for a given size of press. It also permits more rapid ram advance in the initial stages of the hydraulic cycle. Some makers exert as much as 865 kg/cm^2. This helps to reach lower residual cake fat in a given time. However excellent results, have been and are being obtained at less than half this pressure. One of the plants made a study on the effect of pressure on the individual cocoa particles and found a definite flattening effect at 400 kg/cm^2.

Horizontal pump-filled presses seems to work best when liquor is fed at temperature of about 93^{o}C. Some of the installation go as high as 104^{o}C to 113^{o}C. Holding the liquor at these temperature for a long time can affect the flavour and perhaps the colour of the final powder. Welch (1975) has also reported that liquor for pressing is normally heated just prior to pressing from 98^{o}C to 110^{o}C, and for fast pressing will ideally contain 1-1½ per cent moisture. Addition of water can be done a short time before pressing for purpose of thickening the liquor and for easier pressing to a lower 10 to 12 per cent fat content.

Van Brederodo (1974) explains an automated system in which the roasted nibs are ground and during the process temperature develops upto 100°C. Fat in the nib (55%) melts and the resultant liquid is pumped into a battery of horizontal pot presses, which are hydraulically operated at a pressure of 390 kg/cm^2. The press cake that is obtained will have a fat content of 10 to 24 per cent according to pressure and time. Carver *et al*., (1970) describes various treatments of cocoa beans to produce good quality cocoa butter and recommends that removal of butter is best achieved by using a hydraulic press.

The other methods of separating cocoa solids and butter are now rarely used, because they affect the quality of the powder or the butter or often both.

Screw presses have been employed on nibs but not too successfully. The extreme heat of friction involved in this process usually burns the cake spoiling its flavour. Screw presses are usually used to recover butter from shells and scrap cocoa. Years ago, this operation was more popular when cocoa solids were used for extraction of theobromine. Much of this type of butter goes into cosmetics and pharmaceuticals (Carver, 1970).

Another method of fat removal is solvent extraction. The powder and butter that is obtained by solvent extraction will contain solvents which may cause undesirable flavour changes as in the case of screw pressing.

Roselius et al (1975) Germany has suggested a method for extraction by use of Co_2 under specific conditions for the production of cocoa butter from cocoa nibs or cocoa mass. In principle, it is immaterial whether or not the cocoa nibs are roasted or whether or not the material has been alkalised. The method is based on the observation that various food acceptable gases which are super critical in respect to pressure and temperature constitute excellent solvents for cocoa fat. The cocoa fat can be thereafter separated from the solution.

Centrifugal type of separation of liquid from cocoa mass is rarely used. Very little literature is available on the use of centrifuges.

The physical characteristics of Cocoa powder are as follows:- (Fincke's, H. 1965)

1. Bulk weight:-

Natural process cocoa powder: from 350 g/l with 10 per cent fat to 450 g/l with 22 per cent fat.

Alkalized cocoa powder: from 400 g/l with 10 per cent fat to 500 g/l with 22 per cent fat.

2. Density:-

Fat-free dry cocoa particles=1.45

Cocoa powder with 10 percent fat = 140

Cocoa powder with 22 per cent fat = 1.35

3. Specific Heat:-

Cocoa powder with 10 per cent fat : 0.41 cal/g

Cocoa powder with 22 per cent fat : 0.42 cal/g

4. Ignition temperature:-

Spontaneous combustion hazard arises at approx. 165 deg. C Dust explosion hazard arises at approx.40 grams of cocoa powder per cubic metre of air.

The physical characteristics of Cocoa butter are as follows:- (Kaufmann, 1958)

1. Specific heat(liquid) - 0.5 cal/g deg.C.

2. Melting heat: Average melting heat of the crystalline form 36 cal/g.

3. Heat transfer coefficient : At 80 deg.C the heat transfer coefficient between stainless steel and cocoa butter, whilst being stirred, amounts to 370 K cal/deg.C/m^2/h.

A glossory of terms used in Cocoa industry is given in Appendix I

Materials and Methods

MATERIALS AND METHODS

3.1. Objectives

The over-all objective of this project is to select or design various items of equipment which are required for small scale processing of cocoa beans into cocoa powder and cocoa butter.

The specific objectives are:-

(1) To study the existing technology of processing of cocoa and to select suitable methods for processing of cocoa beans on a small scale.

(2) To identify a set of unit operations to be performed for production of cocoa powder and butter.

(3) To assess the performance of the selected or newly evolved machines in relation to the quality of the products obtained.

(4) To standardise the conditions and equipment for the above operations.

The unit operations to be performed in the processing of cocoa beans are fermentation, drying, roasting, kibbling and winnowing, grinding and extraction of butter from the ground cocoa. Though studies were conducted on most of the above unit operations, more emphasis was given to the extraction of butter in this project.

3.2. Preliminary processing

3.2.1. Fermentation

From the literature reviewed, it was seen that mini-box method of fermentation was more suitable than the other methods for fermenting small quantities of beans. Therefore the box method fermentation was selected. The fermentation boxes were made of wood. The capacities of the boxes were 2 kg, 5 kg and 11 kg (Plate 4). The beans were kept for fermentation for 144 hours. The temperature variations were noted at 9am and 5pm throughout the fermentation period.

3.2.2. Drying

A dryer for drying small quantities of beans was fabricated (Fig.I),& (Plate 5). The dryer mainly consisted of a wooden box with shutters, of internal dimensions 60 cm x 60 cm x 90 cm, with three wooden racks, placed one over the other at a spacing of 15 cm between them. The wooden racks were fitted with wire

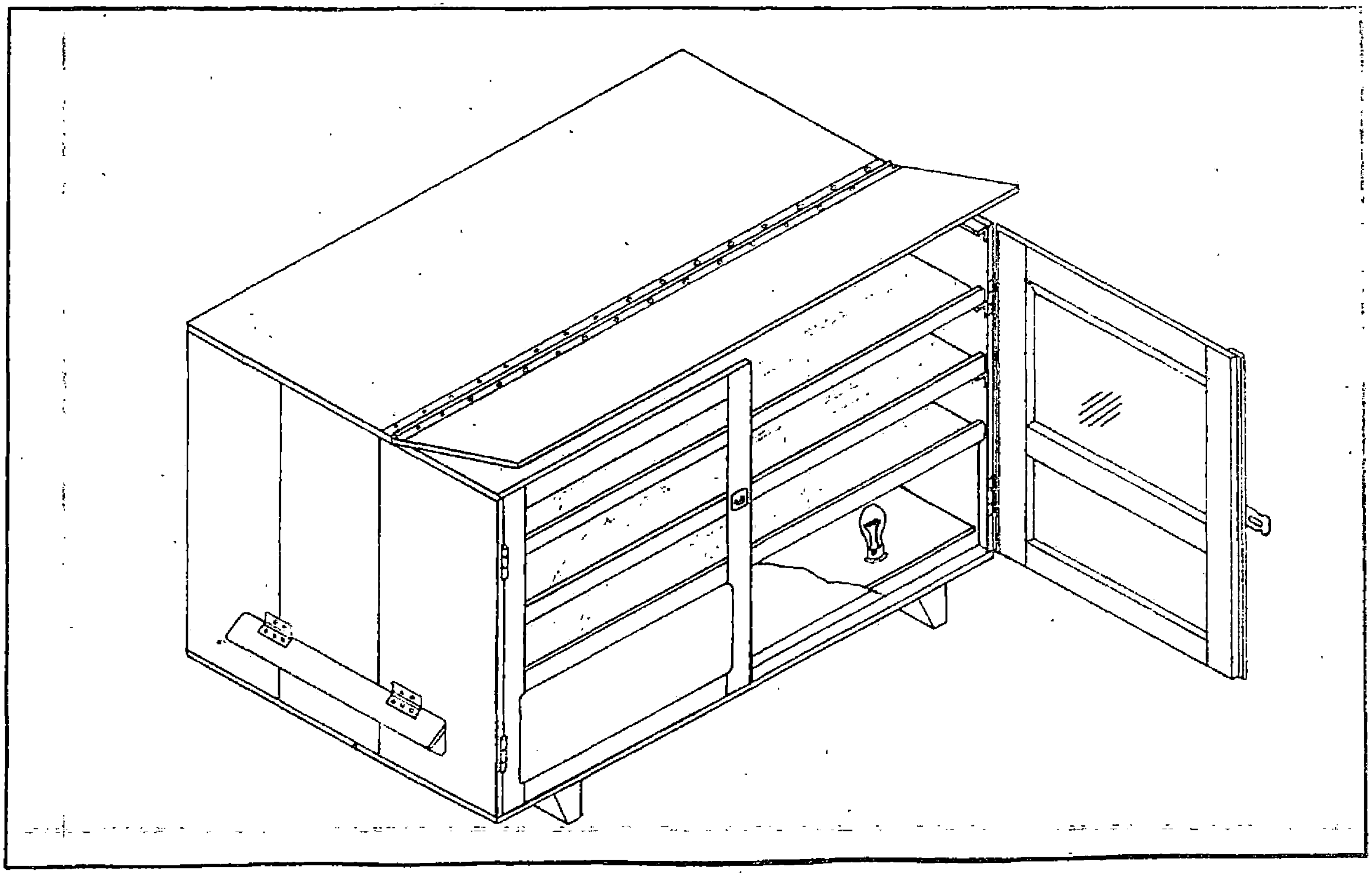


FIG: 1. BULB HEATED DRYER.

Plate No. 4 - Different sizes of fermentation boxes

Plate No. 4 - Different sizes of fermentation boxes

mesh at the bottom. Six electric bulbs fitted at the bottom of the dryer were used for heating the air. Ventilations were provided at the bottom on the sides and the back of the dryer for entry of air. There was provision for escape of heated air at the top.

Initially 6 numbers of 60 watts bulbs were used for determining the average inside temperature without loading the material. The quantity of air flow was controlled by adjusting the openings of the ventilators. The steady state temperature of 55°C was reached after 2½ hours. But this temperature was not sufficient to dry the beans, when the dryer was fully loaded with beans. Therefore six bulbs of 100 watts each were used for obtaining higher temperature. In this case, about 70°C steady state temperature with sufficient air flow was reached at no load condition after 2½ hours. This was sufficient for drying the beans. About 30 kg of fermented beans were used for drying. Each tray was loaded with 10 kg of wet beans. Beans were agitated at one hour interval and the trays were interchanged after every two hours. For the first 20 hours the average temperature was 45°C and from the second day onwards the temperature rose upto 50°C under loaded condition. The beans were dried to the required extent after 36 hours of drying.

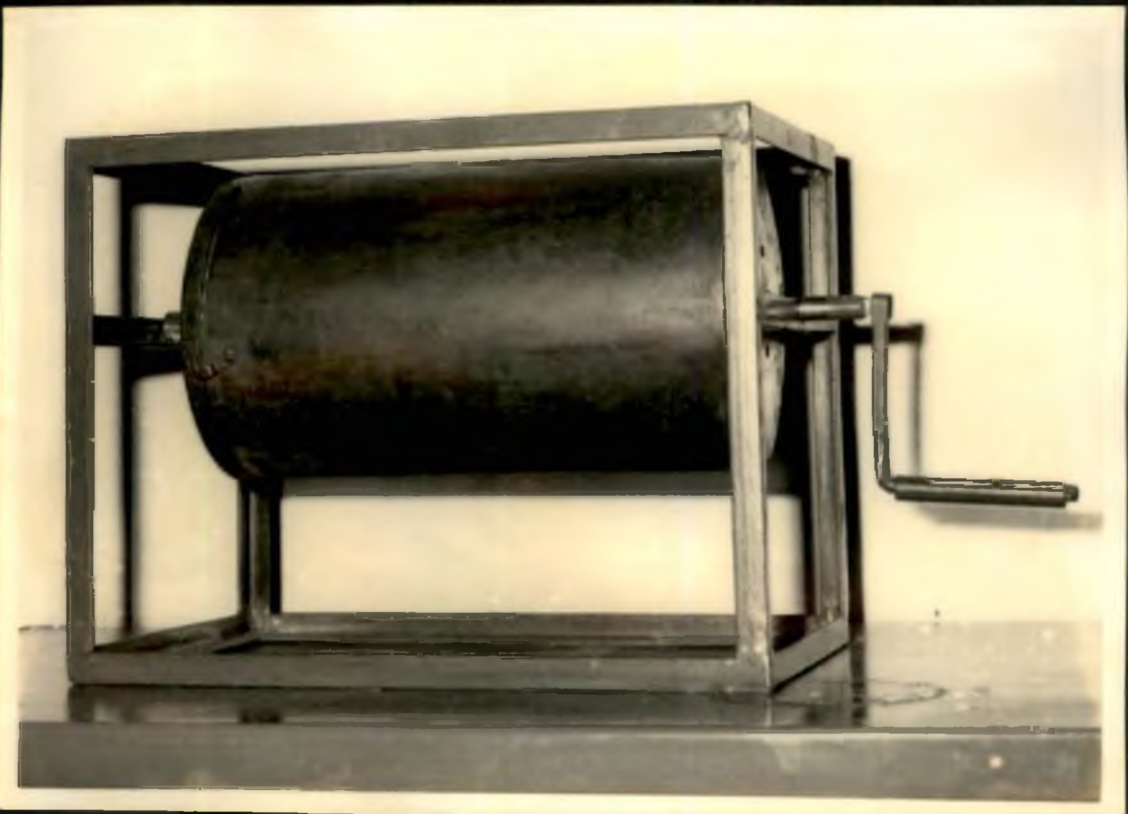
3.3. Secondary processing

3.3.1. Roasting

The roasting of the beans was carried out in an open pan, heated by an electric heater (Plate 6). The temperature of roasting was maintained at 115°C. The time taken for roasting was 40 - 50 minutes.

A roaster as shown in Plate 7 was fabricated. This consisted of a cylindrical drum of diameter 200 mm and length 350 mm made of mild steel sheet. Both ends of the drum were closed and a door with a hinged shutter was provided at one end for feeding the beans. The drum was supported on a central shaft which was mounted on a suitable frame. Four number of curved blades of 50 mm width and 350 mm length, made of mild steel sheet, were fitted inside the drum longitudinally to function as agitators, when the drum was rotated. The roaster was tested by keeping an ordinary heater beneath it. The performance was satisfactory. A curved electrical heating unit, which would follow the curve of the

Plate No. 6 Roasting of dried cocoa beans in an open pan.



cylinder, might further improve the efficiency of the system.

3.3.2. Kibbling and Winnowing

The roasted beans were craked or kibbled and shells and germs were removed manually. As the shells and germs were removed manually, very clean nibs were obtained. However this operation consumed a lot of human labour — one woman was required to clean 5 kg of roasted beans. No attempt was made to mechanize this operation during this project.

3.3.3. Alkalisation

To improve the quality of the cocoa liquor, the beans were treated with alkali. The alkali used was potassium-bi-carbonate and the concentration of the alkali in the solution was maintained at 0.1%. The beans were soaked in the solution and the solution was heated to 85°C. The beans were kept in the solution at that temperature for one hour.

Another method tried was neutralisation of the acid by soaking the beans in water for 24 hours. The results obtained were somewhat satisfactory.

3.3.4. Grinding

An ordinary wet grinder of 2 litre capacity was used for grinding the nib (Plate 8). The material was ground for one and a half hours.

3.3.5. Extraction of butter

The separation of the cocoa butter from the ground cocoa mass is achieved in the conventional methods by using screw presses, horizontal presses, vertical presses and by solvant extraction. These methods are suitable only for processing large quantities of beans. Equipment suitable for extraction of butter on a small scale is not available.

The main objective of the present study was to develop a system for separating cocoa butter from ground cocoa mass by mechanical process and further to pulverise the cocoa cake into cocoa powder. The basic technique used in this process was to subject the cocoa mass to a high pressure for separation of cocoa butter. The pressure requirement for the extraction varied from 10 - 800 kg/cm^2 depending upon the quantity of butter to be extracted.

Plate No. 8 .- A wet grinder used for grinding cocoa nibs

A 4.2 cm diameter pipe with one end closed was used to fabricate a cylinder. A mild steel rod of 5 cm diameter was machined to make a suitable piston. 32 numbers of 2 mm holes were drilled on the bottom plate of the cylinder. A small quantity of cocoa mass wrapped in cloth bag was kept inside the cylinder. Load was applied at the top of piston, using a 1½ ton bull-press. An yellowish liquid came out through the bottom of the cylinder and the solid matter was left inside the cotton bag. The quantity of butter extracted was less than 10 per cent. This gave an indication that much higher pressure was required to extract more butter.

An automobile wet liner made of cast iron with internal diameter 81 mm, length 200 mm and thickness 9 mm was used to fabricate an extraction unit for testing under high pressure (Fig.2). A 7 mm plate made of mild steel, with 20 numbers of 3 mm holes, was used as filter (Fig.3). A suitable adapter was made to seat the filter at the bottom of the cylinder. A round solid shaft of 85 mm diameter was used to make a piston of 80 mm diameter (Fig.4) & (Plate 9).

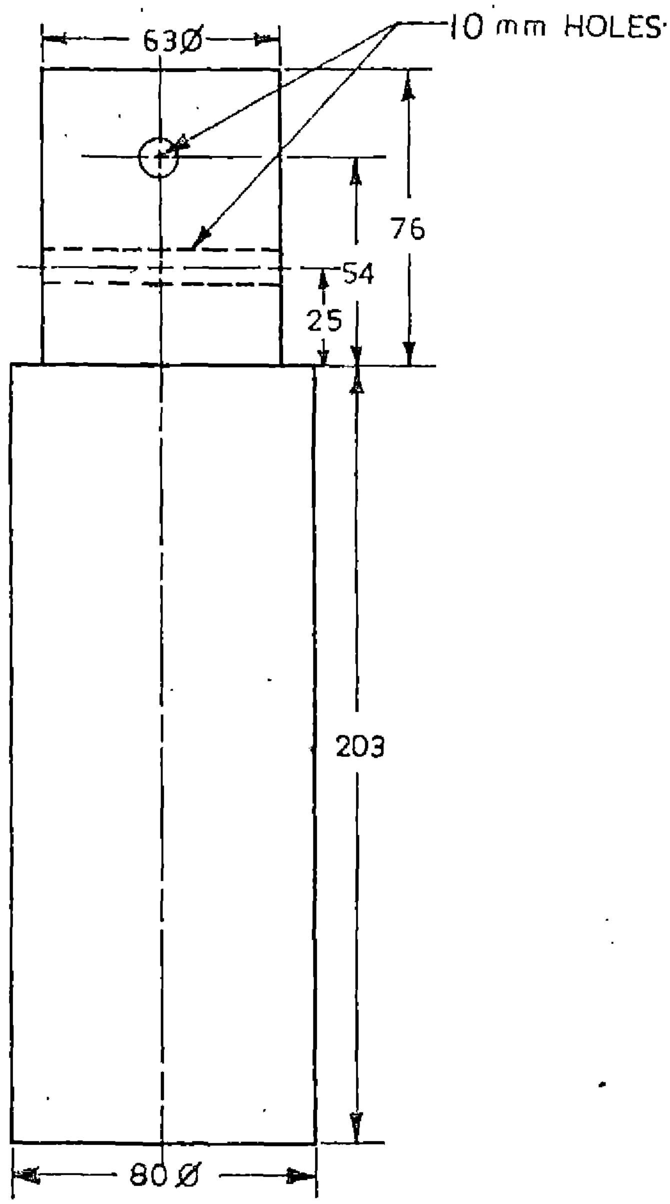


FIG: 4 PISTON

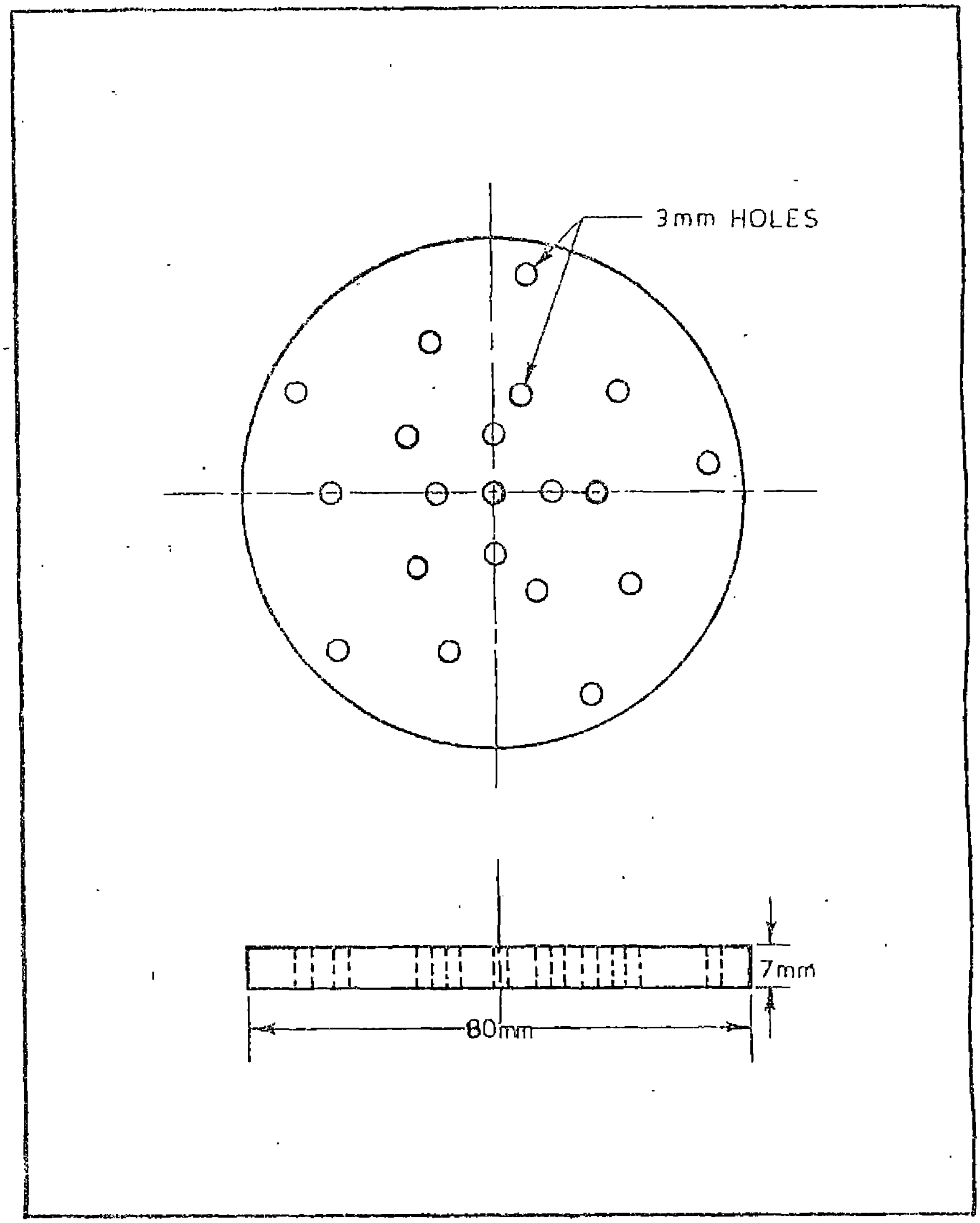


FIG: 3· FILTER·

Plate No. 9 – An automobile wet liner used as extraction unit, filter plate and the piston

A frame was fabricated with a stand at the bottom and a strong cross member at the top. The frame was made with 6 mm thick box and channel sections so as to make it very strong (Fig.5). The cylinder was placed on the bottom stand. Cocoa mass wrapped in filter cloth bag was placed inside the cylinder. The piston was placed inside the cylinder over the cocoa mass. On the top of the piston a three ton hydraulic jack was placed. In this condition the cross member on the top of the frame was barely touching the top of the jack. When the jack was operated, the stem of the jack moved up. The upward movement of the jack was stopped by the cross member. On further operating the jack, as it could not go up, it pressed the piston which in turn pressed the cocoa mass placed inside the cylinder. As the pressure increased the butter was forced out of the cocoa mass which was collected in a container placed below the stand. A pressure of about 60 kg/cm^2 could be applied using this jack. With this system about 25 per cent of the butter could be extracted at ambient temperature.

The main defect noticed in the working of this system was that substantial quantity of butter came out

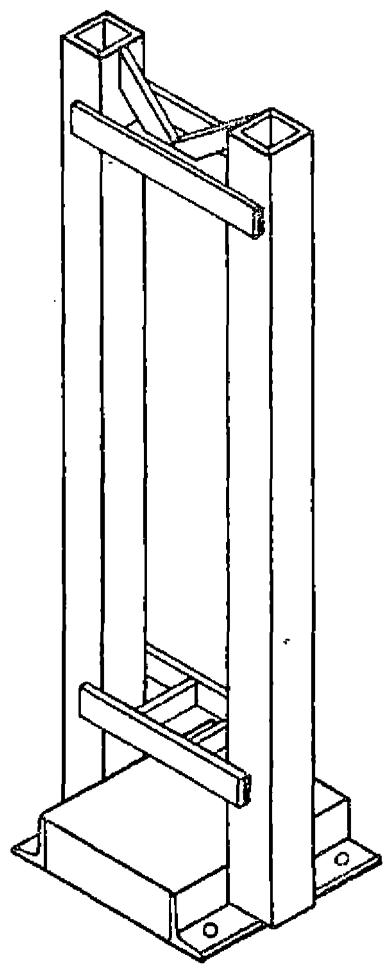


FIG: 5. PRESSING FRAME.

through the interspace between the cylinder and piston. The butter spilled over the sides and oozed out in all directions making the collection of butter very difficult. To prevent the leakage of butter through the interspace, a tight fitting leather washer was used at the bottom of the piston. This, to a large extent, prevented the leakage of the butter. But another serious drawback was noticed. The removal of the butter from the cocoa mass was not uniform. Very little butter was removed from the top half of the cylinder eventhough, considerable quantity of butter was removed from the lower half. During the pressing operation, the butter that entered into the interspace between piston and cylinder provided an air seal which prevented the entry of air from outside into the cylinder. This made the removal of piston from the cylinder very difficult because of the vacuum effect it produced. To overcome this difficulty various modifications were tried, but none of them were successful and they were discarded. All these trials however indicated that for uniform extraction of butter from cocoa mass, there should be some provision on the sides of the cylinder for the butter to flow out.

With this in view, another wet liner of the same dimensions was taken and 12 numbers of longitudinal slots of 10 mm width and 2 mm depth were made around the outside pheriphery. 2 mm diameter holes at a spacing of 10 mm were drilled on the centre line of the slots. At the bottom, a ring slot around the pheriphery was made to collect the butter oozing out through the holes in the rectangular slots (Fig.6) & (Plate 10). Four slanting holes were provided to convey the butter collected in the ring slot to the bottom of the cylinder from where the butter would flow into the collecting device provided at the bottom of the cylinder.

The collecting device was made with 12 mm thick mild steel plate and was made of a slightly larger diameter than the cylinder bottom. It was provided with a hole in the centre and a sloping top surface towards the hole. Any butter that spilled over the collecting ring was also collected in the collecting device. Four slots were provided on the surface of the device, which conveyed the spilled butter to the centre (Fig.7).

There was an increase in the percentage of butter removed, and the loss of butter was substantially reduced

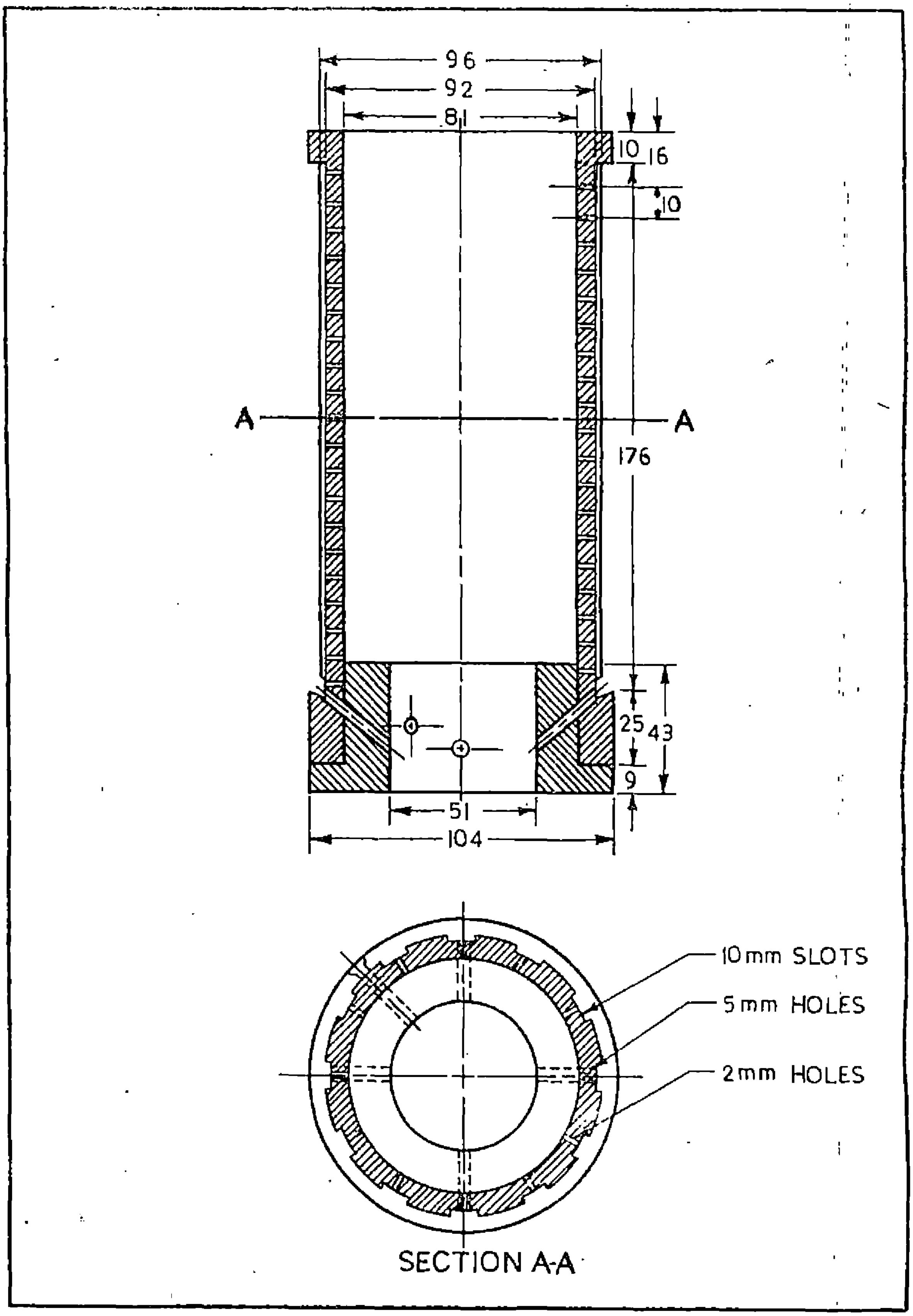


FIG: 6 BUTTER EXTRACTION UNIT

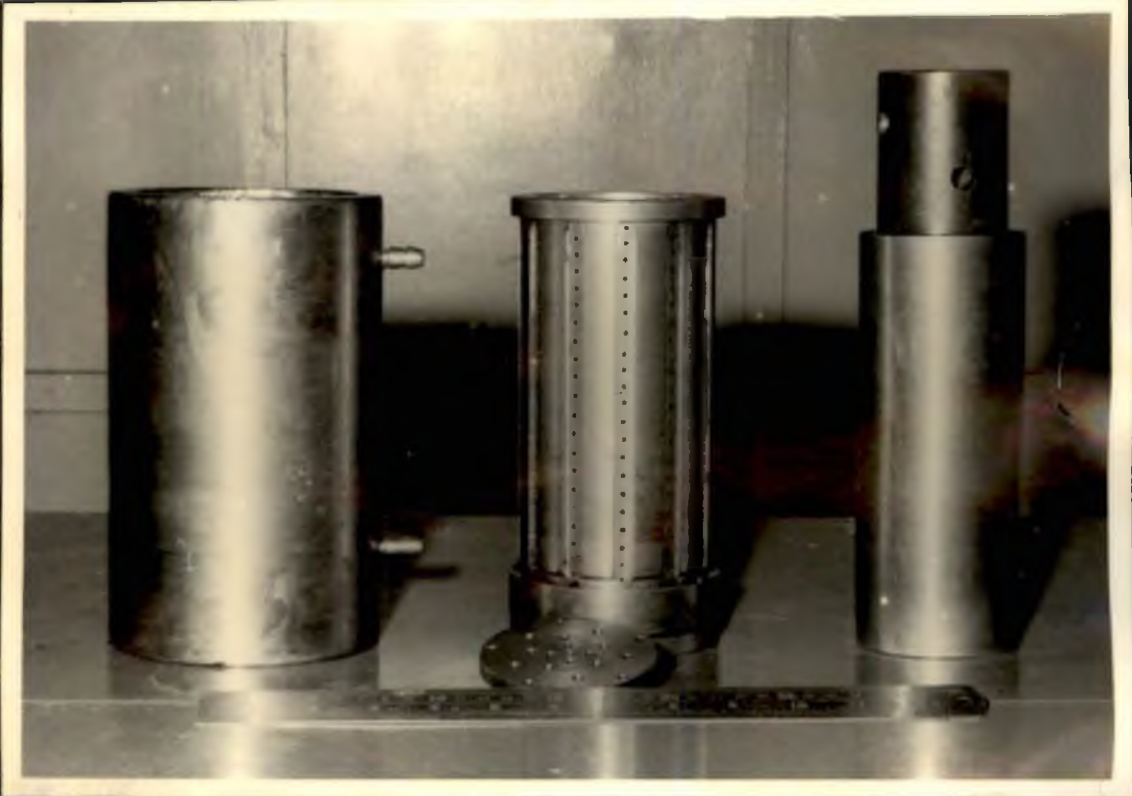


Plate No. 10 . Cocoa butter extraction unit - water jacket, extraction cylinder, filter and the piston

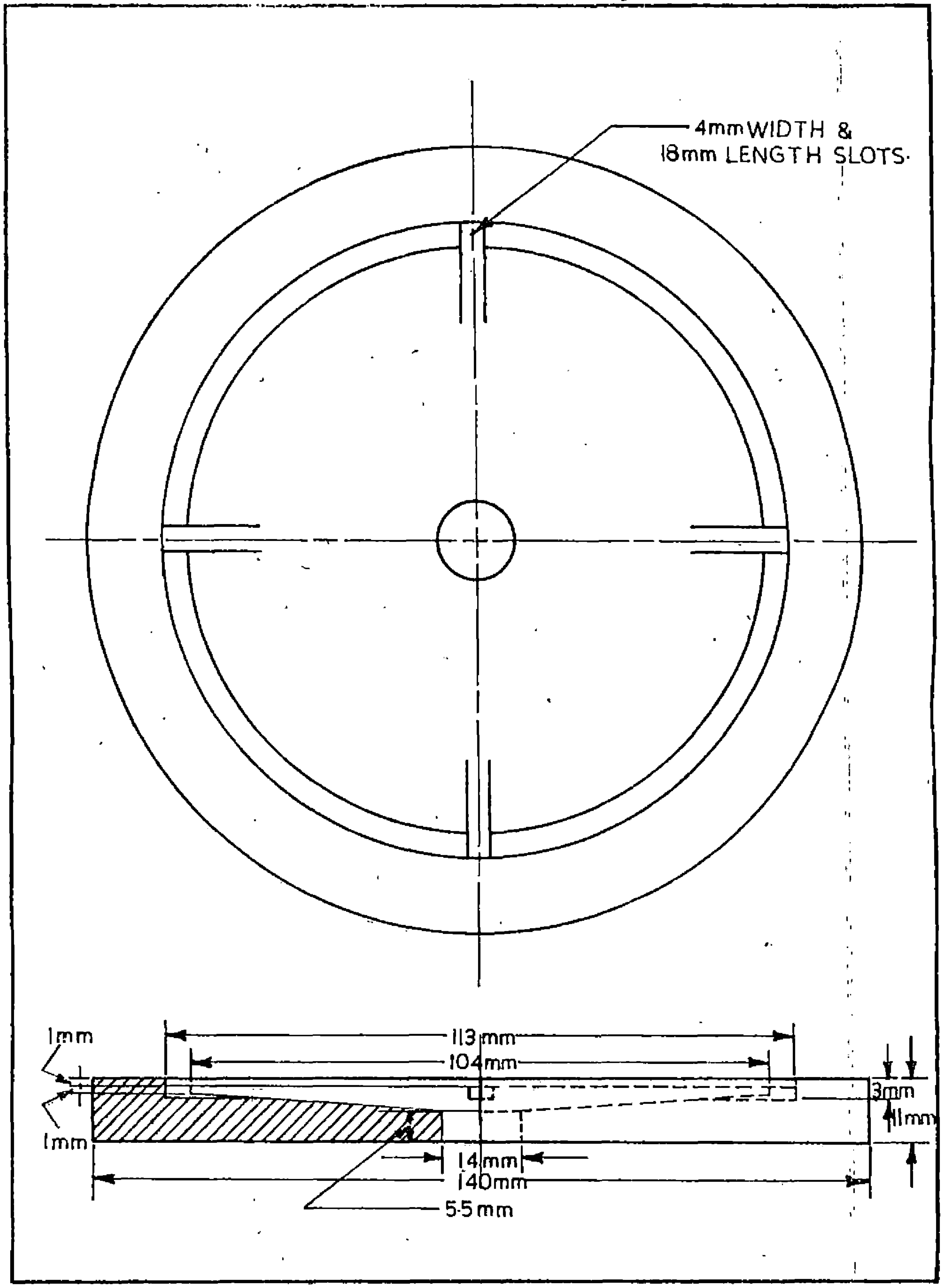


FIG: 7· COLLECTING DEVICE·

when collecting device was used. The piston could also be taken out without difficulty from the cylinder because the side holes allowed free entry of air from atmosphere.

Temperature of the cocoa mass has a pronounced effect on the quantity of butter removed at a particular pressure, and the range of optimum temperature lies between 40°C – 70°C. To maintain the temperature during the experiment a suitable water jacket was fabricated with mild steel sheet (Fig.8).

The overall performance of the equipment fabricated was satisfactory and tests were conducted to determine the optimum temperature and pressure for various levels of extraction of butter. The temperatures tested were 35°C, 40°C, 50°C, 60°C and 70°C and the loads tested were 2.5 tonnes, 5 tonnes, 7.5 tonnes, 10 tonnes and 12.5 tonnes. The area of the piston used was 50.26 cm^2 making the loads equivalent to 49.74 kg/cm^2, 99.47 kg/cm^2, 149.20 kg/cm^2, 198.94 kg/cm^2, 248.67 kg/cm^2 respectively. A hydraulic press with a load guage attached to it was used to apply the load.

The ground cocoa beans, the cylinder and the filter cloth bag were kept in an oven and temperature was

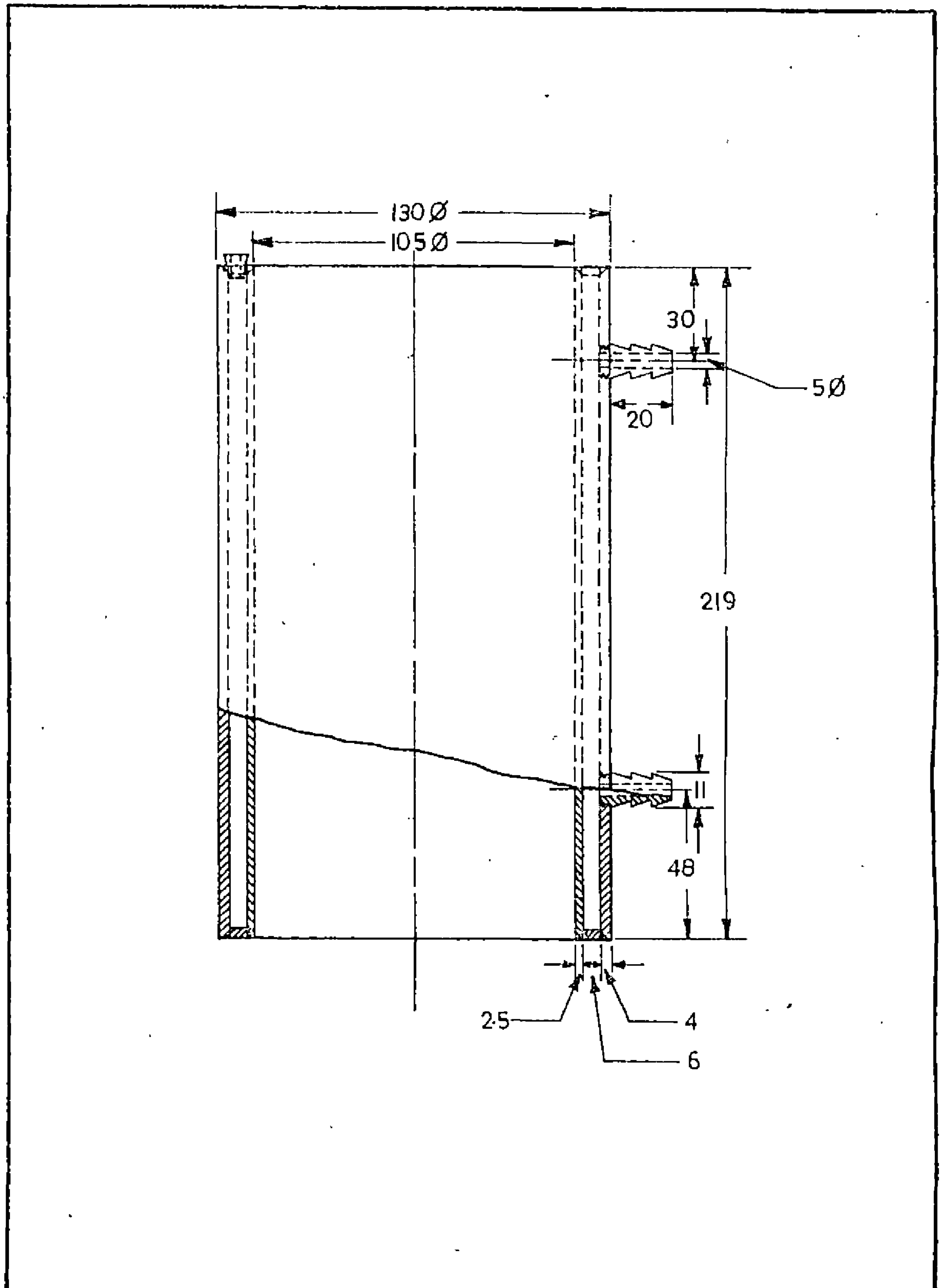


FIG:8· WATER JACKET·

maintained at 35°C. After 15 minutes when the material kept inside the oven attained steady state temperature of 35°C, the cylinder was taken out and placed over the bottom stand. Water jacket was put around the cylinder with arrangements for hot water circulation and the temperature of the circulating water was maintained at the same temperature as that of the material. 250 gm of cocoa mass was taken and put inside the filter cloth bag. This was kept inside the cylinder. A load of 2.5 tonnes was applied to the mass by operating the hydraulic press (Plate 11). As the butter was forced out, the pressure dropped. The hydraulic press was operated to maintain the steady state load of 2.5 tonnes. Initially the pressure dropped at a faster rate. As more and more butter was expelled the rate of pressure drop became slower. Finally after about 20 minutes, there was no further reduction in pressure. This gave an indication that under the given state of temperature and pressure no further expulsion of butter could take place. The butter obtained was weighed separately.

For the second test, the load was increased to 5 tonnes and this was maintained through out the test. When the load attained a constant reading for five minutes, the butter obtained was weighed. The experiment was repeated for 7.5, 10 and 12.5 tonnes.

Plate No. 11   Experiment set up using an hydraulic press

The temperature of the oven was raised to 40°C. The cocoa mass, cylinder and filter cloth bag were also kept inside the oven till they attained the same temperature. The experiment was repeated for different loads viz. 2.5, 5, 7.5, 10 and 12 tonnes. Similar tests were conducted at temperature of 50°C, 60°C and 70°C.

The cocoa cake and butter obtained were used for making drinking chocolate and milk chocolate. The standard recipes given in text books were followed for the preparation of the above products.

A typical design for the cylinder and filter plate of the butter extraction unit is given in Appendix II. Thin cylinder theory has been used for the design of the cylinder, beam theory has been adopted for filter plate design.

Results and Discussion

RESULTS AND DISCUSSION

4.1. Preliminary processing

During the conduct of this project the following results were obtained at each stage of operation.

4.1.1. Fermentation

The results of the experiments conducted on fermentation using mini-box method are given in Table No.(1).

The mean weight loss during the fermentation was 30.39 per cent. The quality of the beans after fermentation was judged by cut test and it was satisfactory.

The temperature variations noted at 9 am and 5 pm during the fermentation period are given in Table (2). A graph showing the temperature variations is given in Fig.(9). The mean maximum temperature attained during fermentation was 46°C.

The results showed that the pattern of the temperature curve agreed well with the curves given in the standard published data, even though the maximum temperature attained in the experiment was lower than that given in the published data which was around 50°C.

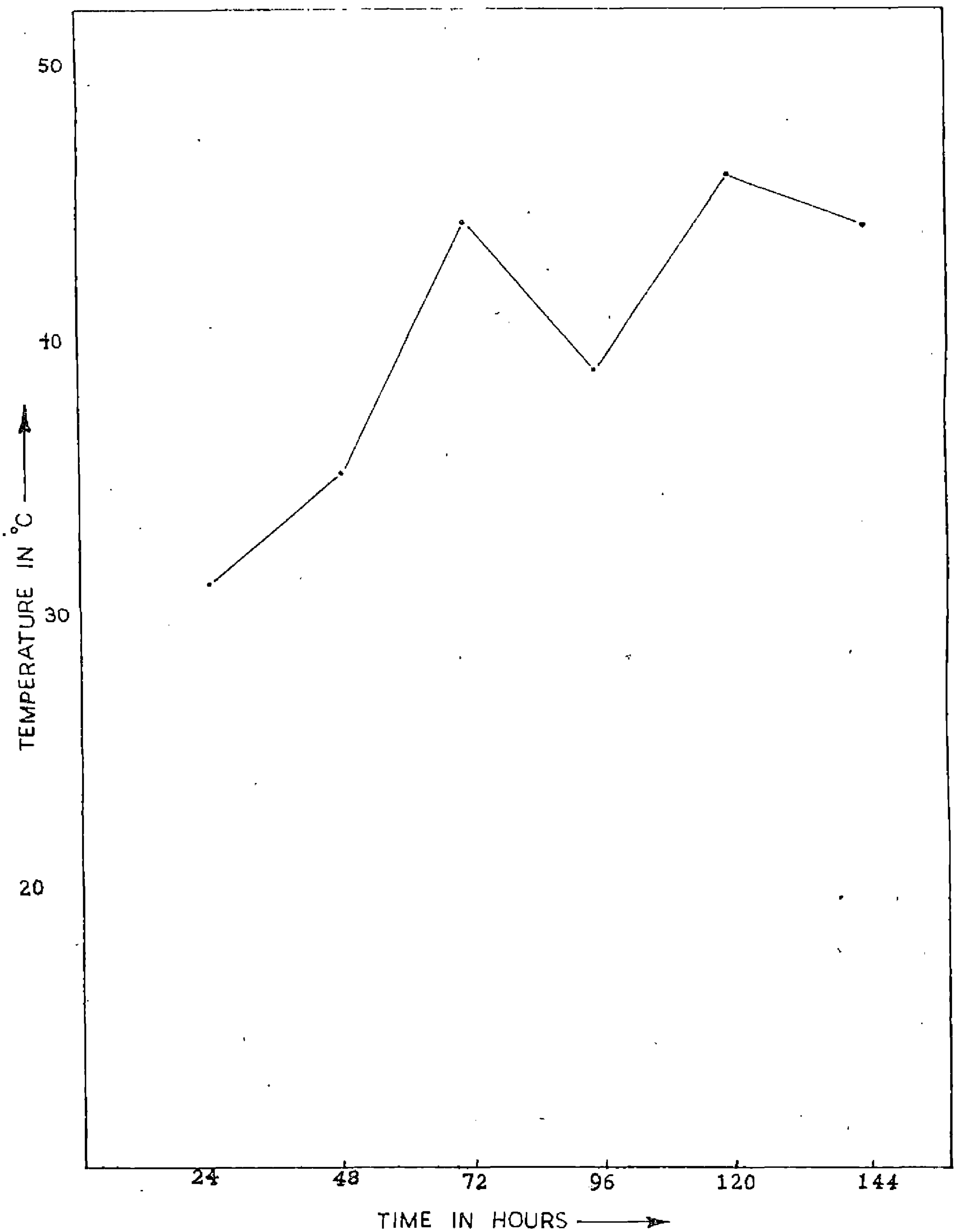


FIG: 9. TEMPERATURE VARIATION CURVE DURING FERMENTATION

Table No. 1. Weight loss during fermentation

Weight of wet beans (kg)	Weight of fermented beans (kg).	Weight loss in %
11	7.7	30.00
11	7.5	31.18
5	3.5	30.00
	Average	30.39

Table No.2. Temperature variations during fermentation

Time (hrs)	(Temperature °C)			
	Box (1)	Box (2)	Box (3)	Average
0	30	30	30	30
16	30	30	30	30
24	33	30	31	31.33
40	37	34	35	35.33
48	30	34	34	35.33
64	45	45	40	43.33
72	47	44	42	44.33
88	40	40	38	39.33
96	38	40	39	39.00
112	42	43	42	42.33
120	45	47	46	46.00
136	43	44	44	43.63
144	44	44	45	44.33

Box No.1 - Capacity, 2 kg.
Box No.2 - Capacity, 5 kg.
Box No.3 - Capacity, 11 kg.

The temperatures given against each box in the table are mean values of three sets of experiments.

This could be due to the smaller size of the boxes for fermentation. The lower temperature achieved in the mini-box method of fermentation apparently did not have any adverse effect on the quality of the beans.

4.1.2. Drying

The temperature attained, when 6 bulbs of 60 watts each were used, was 50°C after 2½ hours of heating. When the dryer was tested after loading with fermented beans, the temperature came down to about 40°C. It was observed that this temperature was not sufficient to dry the beans. After replacing the 60 watts bulbs with 100 watts bulbs, the no load temperature of the dryer rose to 70°C after 2½ hours. This temperature was sufficient to dry the beans to the desired moisture content in 36 hours. A table showing the weight losses during drying are given in Table No.(3). A moisture loss of 52.54 per cent was observed during drying and the moisture content of the dried beans was about 10-12 per cent.

The capacity of the dryer was 30 kg of fermented beans. This dryer could be used for drying during rainy season to produce about 15 kg of dry beans per loading.

4.2. Secondary processing

4.2.1. Roasting

The roasting was carried out in an open pan and

Table No.3. Moisture loss during drying

Weight of fermented beans (kg.)	Weight of dried beans (kg)	Moisture loss in %
11	7.05	53.00
19	9.00	52.64
30	14.40	52.00
	Average	52.54

Table No.4. Moisture loss during roasting

Weight of dried beans (kg)	Weight of beans after roasting (kg)	Moisture loss in %
1.000	0.952	4.80
1.000	0.946	5.40
1.000	0.940	6.00
	Average	5.40

and the weight loss noted during roasting is given in Table No.(4). A weight loss of 4 to 6 per cent was noticed during this process.

The cylindrical roaster fabricated when tested with an ordinary electric heater, as the heating unit, gave satisfactory results. The agitators provided inside the cylindrical drum gave good agitation to the beans, when the drum was rotated, as evidenced by the uniform roasting of the beans. A curved heating unit is likely to improve the heating efficiency of the system.

4.2.2. Kibbling and Winnowing

Shells and germs were removed manually. As it was done manually, very clean nibs were obtained, but it was a labour consuming operation. One woman could only clean 5 kg of roasted beans in a day. A weight loss of 12 to 15 per cent was noted during this process. One draw back noticed during this operation was that complete removal of the germs from the nibs was not possible. If a simple, cheap and efficient equipment could be devised to mechanise kibbling and winnowing, it would considerably reduce the cost of this operation.

4.2.3. Alkalisation

The beans that were alkalised with potassium bi-carbonate were used to make drinking chocolate.

Drinking chocolate was also made with beans that were treated with water, for neutralisation of acids. Out of these, drinking chocolate made with alkalised beans tasted better, did not have any sour or bitter taste and was comparable with the standard products. However, the drinking chocolate made with water treated beans, tasted better than the drinking chocolate made with untreated beans.

4.2.4. Grinding

The particle size of the material ground in the wet grinder was not of the desired fineness. Further improvements in this operation are desirable to improve the quality of the final product.

4.2.5. Extraction of butter

The quantities of butter that could be extracted with the equipment, that was designed and developed as a part of this project, at various pressures and temperatures are given in Table No.(5). These values are plotted in Fig.10 .

From the results it was seen that the temperature had a pronounced effect on the quantity of butter that could be extracted at various pressures. For example,

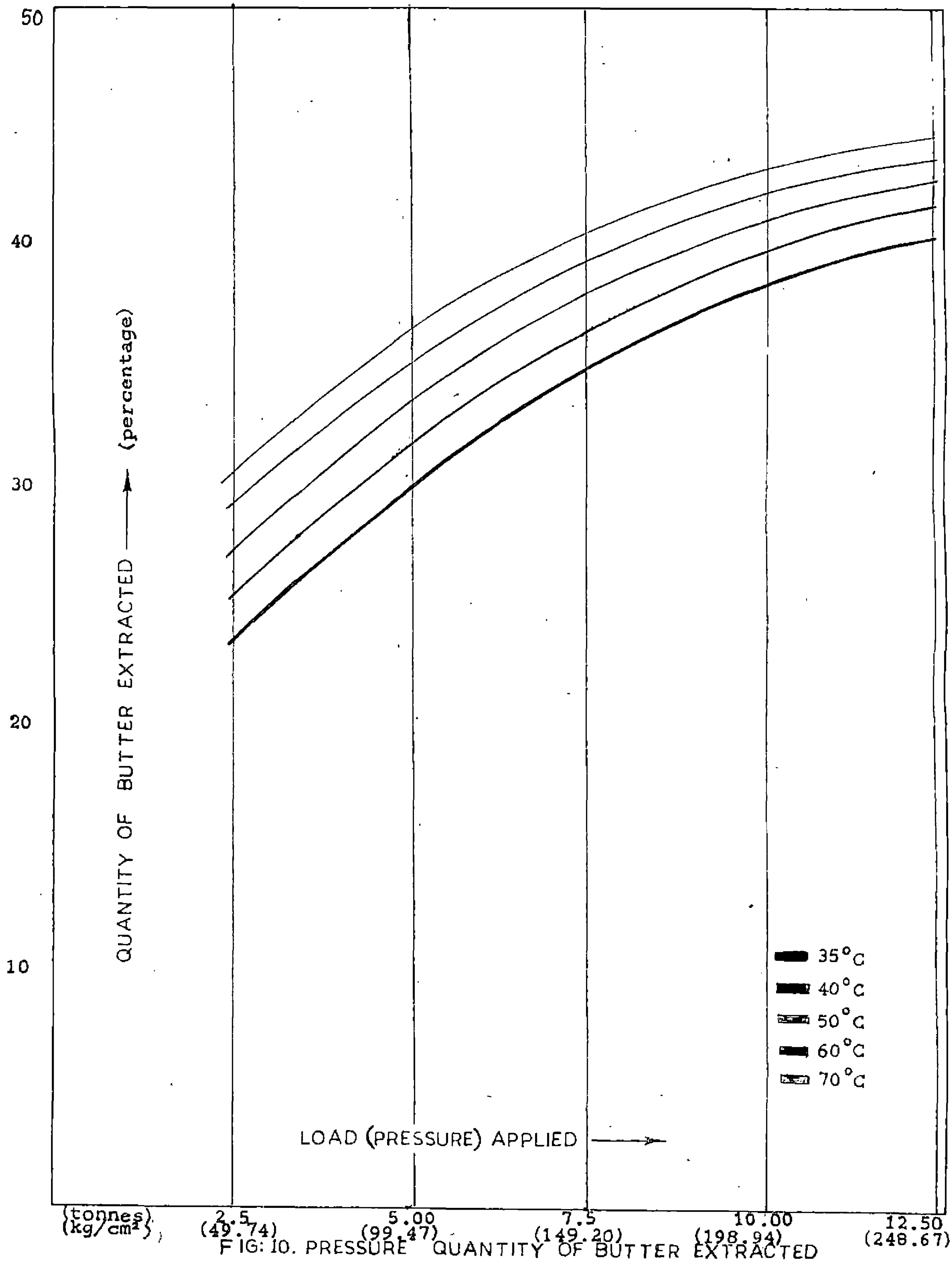


FIG: 10. PRESSURE QUANTITY OF BUTTER EXTRACTED

Table 5(a) Quantity of butter extracted at a constant temperature of 35°C at various pressures

Sl. No.	Weight of cocoa mass (g)	Load applied (Tonnes)	Equivalent pressure (Kg/cm^2)	Quantity of butter removed (g)	Average weight of butter removed (g)	Percentage of butter extracted
1	250	2.5	49.73	62.17 57.50	59.84	23.94
2	"	5.0	99.47	79.15 74.50	76.83	30.73
3	"	7.5	149.20	82.17 85.50	83.84	33.54
4	"	10	198.94	89.15 89.05	89.33	35.73
5	"	12.5	248.67	103.17 103.00	103.09	41.23

Table 5(b) Quantity of butter extracted at a constant temperature of 40°C at various pressures

Sl. No.	Weight of cocoa mass (g)	Load applied (Tonnes)	Equivalent pressure (Kg/cm^2)	Quantity of butter removed (g)	Average weight of butter removed (g)	Percentage of butter extracted
1	250	2.5	49.74	63.90 65.50	64.70	25.8
2	"	5.0	99.47	84.40 78.50	81.50	32.6
3	"	7.5	149.20	93.90 89.00	91.45	36.58
4	"	10	198.94	104.60 97.90	101.25	40.50
5	"	12.5	248.67	106.00 106.00	106.00	42.40

Table 5(c) Quantity of butter extracted at a constant temperature of 50°C at various pressures

Sl. No.	Weight of cocoa mass (g)	Load applied (Tonnes)	Equivalent pressure (Kg/cm^2)	Quantity of butter removed (g)	Average weight of butter removed (g)	Percentage of butter extracted
1	250	2.5	49.74	66.00 68.25	67.13	26.85
2	"	5.0	99.47	86.00 82.91	84.46	33.78
3	"	7.5	149.20	92.98 93.75	93.37	37.35
4	"	10	198.94	101.80 103.50	102.65	41.06
5	"	12.5	248.67	106.00 109.00	107.50	43.00

Table 5(d) Quantity of butter extracted at a constant temperature of 60°C at various pressures

Sl. No.	Weight of cocoa mass(g)	Load applied (Tonnes)	Equivalent pressure (Kg/cm^2)	Quantity of butter removed(g)	Average weight of butter removed(g)	Percentage of butter extracted
1	250	2.5	49.74	71.00 75.00	73.00	29.20
2	"	5.0	99.47	87.50 89.10	88.30	35.32
3	"	7.5	149.20	95.00 98.00	96.50	38.60
4	"	10	198.94	103.80 105.00	104.40	41.76
5	"	12.5	248.67	108.00 110.00	109.00	43.60

Table 5 (e) Quantity of butter extracted at a constant temperature of 70°C at various pressures

Sl. No.	Weight of cocoa mass (g)	Load applied (Tonnes)	Equivalent pressure (Kg/cm^2)	Quantity of butter removed (g)	Average weight of butter removed (g)	Percentage of butter extracted
1	250	2.5	49.74	74.50 72.50	73.50	29.40
2	"	5.0	99.47	91.50 89.20	90.35	36.14
3	"	7.5	149.20	102.50 98.15	100.32	40.13
4	"	10	198.94	108.50 107.10	107.00	43.12
5	"	12.5	248.67	111.00 113.00	112.00	44.80

Table 5(f) Quantity of butter extracted at various temperature and pressure

Pressure (kg/cm^2)	49.74	99.47	149.20	198.24	248.67
Temper-ature(^{o}C)					
35	23.94	30.73	33.54	35.73	41.23
40	25.80	32.60	36.58	40.50	42.40
50	26.85	33.78	37.35	41.06	43.00
60	29.20	35.32	38.60	41.76	43.60
70	29.40	36.14	40.13	43.12	44.80

the butter that could be extracted at a pressure of 49.74 kg/cm^2, at ambient temperature (35°C) was only 23.94 per cent, while at 60°C, it was 29.2 per cent.

The normal fat content of cocoa mass is around 55 per cent. The quantity of butter to be left in the cocoa mass is determined by the end product required. High fat cocoa powder (break fast cocoa) contains about 20 per cent butter and in low fat cocoa it is about 10 per cent. From the results it was seen that at 70°C and 248.67 kg/cm^2 pressure, the butter that could be extracted was 44.8 per cent, leaving about 10 per cent in the cocoa powder. Under the ordinary circumstances, the maximum quantity of butter that is extracted from cocoa mass is 45 per cent and as this level was achieved at 70°C and at 248.67 kg/cm^2 pressure extraction at higher temperatures and pressures was not tried.

The equipment developed for extraction of butter using the pressure developed by a 12 ton hydraulic jack would not cost more than Rs.1,100/=. This has a capacity to process about 15 kg of cocoa mass per day. Small scale processing units could profibtably use such an equipment for production of cocoa butter and cocoa powder Plate (12).

Plate No. 12 Working of the cocoa butter extractor, operated by an hydraulic jack

Drinking chocolate and milk chocolate were made following the standard recipes given in text books. They were palatable and somewhat comparable with the products manufactured by reputed firms.

4.3. Economic analysis

The cost of processing of 1 kg of cocoa powder and butter, using the different equipment suggested for small scale processing of cocoa, is worked out and given in appendix (II). The cost of production comes to Rs.10.29 per kg of cocoa powder and butter excluding the cost of raw material. The cost of raw material (cocoa beans) required to produce 1 kg of butter and powder is Rs.20/=.

The technology of fat removal, which was one of the main stumbling blocks in the processing of small quantities of beans, could be standardised.

Summary

SUMMARY

Cocoa is cultivated as a mixed crop in coconut and arecanut gardens. Large-scale planting of the crop was taken up in this state during the seventies and no serious attention was paid to the processing aspect. The production of cocoa beans is expected to go up markedly in the next few years when more plantations will attain bearing stage.

At present the cultivators sell the cocoa beans as such to the cocoa collection centre where the preliminary processing of fermentation and drying are carried out. The secondary processing namely roasting, kibbling and winnowing, alkalisation, grinding and extraction of butter are undertaken by the big manufacturing firms.

There are only few such firms in the country and they have a monopoly in the cocoa products. The important cocoa products are cocoa powder, cocoa butter, milk chocolate and drinking chocolate. At present there are no small scale processing units taking up secondary processing of cocoa in the state. The main impediment for starting such units is the lack of know-how and equipment for small scale processing.

The primary aim of this project was to evolve a viable technology and equipment system for small scale processing of cocoa beans into cocoa powder and cocoa butter. Though studies were conducted on most of the unit operations required for the production of cocoa powder and butter, more emphasis was given for the development of an extraction unit for the separation of butter.

The mini-box method of fermentation, developed earlier in the Kerala Agricultural University, was selected for fermenting small quantities of beans. The results obtained were satisfactory. A weight loss of 30.39 per cent was observed during fermentation.

A bulb heated dryer was fabricated and tested. The capacity of the dryer was 30 kg of fermented beans. Beans could be dried, to the desired moisture content in 36 hours. The loss of weight due to drying was 52.54 per cent.

Beans were roasted in an open pan. An ordinary electric heater was used for heating. There was a reduction of 4 to 6 per cent in moisture content of the beans during roasting. A rotating drum type roaster with provision for agitation during roasting was fabricated and tested. Uniform roasting of beans could be achieved with this roaster.

Kibbling and winnowing were done manually and was a labour consuming operation. A weight loss of 12 to 15 per cent was noted during this operation.

Alkalisation was done by soaking the beans in potassium bi carbonate solution of 0.1 per cent concentration at a temperature of 85^{o}C for one hour.

An ordinary wet grinder of 2 litre capacity was used for grinding the cocoa mass. Particle size of the desired fineness could not be achieved with this grinder. Further improvements in this operation are necessary.

The study mainly concentrated on the extraction of butter from cocoa mass and production of cocoa cake. Initially a hydraulic jack was used to extract butter. A hydraulic press with a pressure guage was used to conduct the experiment at various pressures and temperatures and the butter that could be extracted at various pressures and temperatures was determined. The temperature at the desired level was maintained by controlling the temperature of circulating water passing through a water jacket which surrounded the extraction unit. The data obtained could be used to decide the pressure to be applied and temperature to be maintained for various levels of extraction of butter from cocoa mass. The extraction unit designed and fabricated during this project and operated by a 12 tonne hydraulic jack could be recommended to the small scale entreprenures, for processing of cocoa. The cost of this extraction unit would not exceed Rs.1,100/=.

Drinking chocolate and milk chocolate were made using standard recipes.

Equipment already available and suitable for various unit operations in the processing of cocoa beans were identified and tested. They were the mini-fermentation box for fermentation of small quantities of beans and the wet grinder for grinding the cocoa mass. The equipment that were designed, fabricated and tested during the course of this project were the dryer, cylindrical roaster and the butter extraction unit.

The technology of fat removal, which was one of the main problems encountered in the processing of small quantities of cocoa beans, could be standardised.

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* Original not seen

Appendices

APPENDIX I

1. Cocoa beams:-

The seeds of the cacao-tree (Theobroma cacao L.) fermented and dried.

2. Cocoa nib:-

Cocoa beans, roasted or unroasted, when cleaned, shelled and having undergone germ separation, containing, a maximum residue of 5% shell or germ and a maximum ofcontent of 10% ash-these percentages to be based on the weight of dry defatted matter.

3. Cocoa mass:-

Cocoa nib reduced to a paste by a mechanical process without losing any of its natural fat content.

4. Cocoa press cake:-

Cocoa nib or cocoa mass converted into a cake by a mechanical process, containing, cocoa butter at least 20% - this percentage to be based on the weight of the dry matter-and a maximum of 9% of water.

5. Fat-reduced cocoa press cake:-

Cocoa press cake containing a minimum of 8%

of cocoa butter, based on the weight of the dry matter.

6. Sweetened cocoa, sweetened cocoa powder:-

The product obtained by mixing cocoa powder and sucrose so that 100 g of the mixture contains at least 32 g of cocoa powder.

7. Drinking chocolate:-

The product obtained by mixing cocoa powder and sucrose so that 100 g of the mixture contains at least 25 g of cocoa powder.

8. Cocoa butter:-

The fat obtained by pressure from one or more of the following materials:- Cocoa nib, cocoa mass, cocoa press cake, fat-reduced cocoa press cake.

9. Chocolate:-

The product obtained from cocoa nib, cocoa mass, cocoa powder or fat-reduced cocoa powder and sucrose with or without added cocoa butter, having a minimum total dry cocoa solids content of 35%-at least 14% of dry non-fat cocoa solids and 18% of cocoa butter.

10. Plain chocolate:-

The product obtained from cocoa nib, cocoa mass, cocoa powder or fat-reduced cocoa powder and sucrose with or without added cocoa butter, having a minimum total dry cocoa solids content of 30% - at least 12% of dry non-fat cocoa solids and 18% of cocoa butter.

11. <u>Vermicelli chocolate, chocolate flakes</u>:-

Chocolate in the form of granules or flakes having a minimum total dry cocoa solids content of 32% including 12% of cocoa butter.

12. <u>Milk chocolate</u>:-

The product obtained from cocoa nib, cocoa mass, cocoa powder or fat-reduced cocoa powder and sucrose, from milk or milk solids obtained by evaporation, with or without added cocoa butter, and containing, a minimum total dry cocoa solids content of 25% including at least 25% of dry non-fat cocoa solids, at least 14% of milk solids obtained by evaporation, including at least 3.5% of butter fat. not more than 55% of sucrose, and at least 25% of fat.

APPENDIX II

Design of the pressing Vessel:- Extraction ... unit

Pressure vessels can be classified into thin cylinders and thick cylinders. The ratio of the wall thickness(t) of the shell to its diameter(d) is a deciding factor. If the ratio $\frac{t}{d}$ is less than 0.1 it is called thin cylinder and if the ratio is greater than 0.1, then it is a thick cylinder. For the design of the pressing vessel, thin cylinder theory has been used here.

Stresses in a thin cylinder due to interval pressure

When a thin cylinder is subjected to an internal pressure it is likely to fail either by splitting up into two cylinderical shells (ie. circumferentially) or by splitting it up into through (ie. longitudinally). Thus the wall of a cylindrical shell subjected to internal pressure has to withstand tensile stresses of the following two types.

1. Circumferential or hoop stress

A tensile stress acting in a direction tangential to the circumference is called circumferential a hoop stress or is referred as tensile stress on longitudinal section.

2. Longitudinal stress

In a closed vessel; a tensile stress acting in the direction of the axis is called longitudinal stress.

Calculation of circumferential stress:-

Let d = Intensity of pressure kg/cm^2

d = diameter of the cylinder (cm)

l = length of the cylinder (cm)

t = thickness of the cylinder (cm)

f_t = circumferential or hoop stress in the cylinderical material. kg/cm^2.

Total force acting on a longitudinal section (A section cut from a cylinder by a plane that contains the axis is called longitudinal section) is = Intensity of pressure & projected area

$= p \times d \times l$ (1)

Total resisting force acting on the cylinder wall $= f_t \times 2t \times l$ (2). f_t = tensile stress of the material. Equating (1) & (2) $t = \frac{pd}{2f_t}$ - (3)

Calculation of longitudinal stress

Total force acting on the transverse section (A section from a cylinder by a plane at right angles to the axis of the cylinder is called transverse section) is = Intensity of pressure x cross sectional area

$= p \times \frac{\pi d^2}{4}$ (4)

Total resisting force = $f_t l \times \pi \times d \times t$ (5)

Equating (4) & (5) $t = \frac{pd}{4 f_t l}$ (6)

f_t = longitudinal stress (Khurmi, et al, 1979)

Design of thickness (tc) of thin cylinder

p = pressure = $\frac{\text{Load}}{\text{Area}}$

$= \frac{12500}{50.25} = 248.72$ kg/cm^2

$f_t = \frac{pd}{2\ tc}$

d = diameter of the cylinder

= 8.1 cm

tc = Minimum thickness of the cylinder

If we assume that the material to be pressed is purely a fluid, the pressure (p) will exert equally on all sides of the cylinder. In actual practice, it is found that, it is not a complete fluid, but solid containing oil (cocoa cake). And so the side thrust, due to the pressing operation is a dependant factor of the Poisson's ratio of the material (cocoa cake). Poisson's ratio of the material is assumed as 0.3

$$\text{Side thrust} = \text{Pressure} \times 0.3 = 248.72 \times 0.3 = \underline{\underline{74.62\ kg/cm^2}}$$

$$ft = \frac{p \times d}{2 \times tc \times b}$$ Where b = Unit length = $\underline{\underline{1\ cm}}$.

Since there are 2mm holes provided at the side walls at an interval of 10mm, the effective area to resist the side thrust is reduced.

ie. 1-0.2 = 0.8 x (be) where be = (b-d)

(d = dia. of holes provided at the side wall) = 2mm

$$\therefore tc = \frac{p \times d}{2 \times f_t \times be} = \frac{74.62 \times 8.1}{2 \times 600 \times 0.8} = \underline{\underline{0.63\ cm}}$$

Therefore the thickness of the cylinder wall = $\underline{\underline{0.63\ cm}}$

<u>Design of the filter plate</u>

For the design of the filter plate the beam theory has been used. Here, for the analysis, an element (strip) of the plate having unit width, with uniformly distributed load (w kg/unit length) throughout its length (l) is considered. The beam is assumed to be partly fixed at both ends. That is a case between simply supported and fixed. Maximum bending moment in such a case is taken as $\frac{Wl^2}{16}$, where W is the load per unit length and l is the effective span of the support.

Design of filter plate thickness (beam theory)

From the beam theory $\frac{BM\ max}{Zxx} = f_t$ (7)

Where

(1) BM max = Maximum bending moment

$= \frac{Wl^2}{16}$

(2) Zxx = Section modulus about xx $= \frac{b \times t_p^2}{6}$

b = width of the beam (plate) - taken as 1 cm

t_p = thickness of the filter plate

(3) f_t = Design bending stress.

$BM\ max = \frac{wl^2}{16} =$ 404.41 kg/cm^2

Where

w = load per unit length

l = length of span

Since the filter plate is provided with 3mm diameter holes, the effect of these holes are considered in the section modulus, Zxx

ie. $Zxx = \frac{(1 - 0.3) \times t^2}{6}$

t = thickness of plate

(Assumed that along the width the number of holes = 1 No. per centimeter)

Design tensile stress for the filter plates material (mild steel) is taken as 1200 kg/cm^2 (Ref I.S.Code)

Substituting the above values in Eqn. (7)

$$\frac{BM_{max}}{Z_{xx}} = f_t$$

$$\frac{404.41}{\frac{1-0.3 \times t^2}{6}} = 1200$$

$$\therefore \quad t_p = \underline{\underline{1.69 cm}}$$

The thickness of the plate designed (using beam theory) is 1.69cm. Since the plate used is a circular plate with holes, the actual thickness necessary for the pressing operation may still be lesser. It is found from lab experiments that 0.7 cm thickness for the plate is sufficient enough for the filter plate. This thickness is checked for the safe shear stress.

<u>Check for shear stress</u>

The shear may occure at a diameter of 5.1 cm

Load acting on this area $= 12{,}500 \times \frac{(5.1^2)}{(8.1^2)} =$

$= \underline{\underline{4955.41 \text{ kgf}}}$

The above load will act on an area of $\pi \times d \times t_p$

$$\text{Shear stress} = \frac{\text{Load acting on this area}}{\text{Area resisting the shear load}}$$

$$\pi \times d \times t_p = 4955.41 \text{ kgf}$$

Since there are holes provided it may weaken the plate. Therefore an 80% efficiency is considered, for the plate.

$$\pi \times d \times t \times 0.80\ f_t = 4955.41 \qquad t = 0.7 \text{ cm}$$

$$\therefore\ f_t = \underline{\underline{552.29 \text{ kg}}}$$

This is within the limit of safe shear stress for the material. Safe shear stress for mild steel = 350 - 650 kg/cm^2 (Ref I.S. code)

APPENDIX - III

Economic analysis

The cost of production of one kilogram of cocoa powder and butter is worked out on the basis of the following assumptions.

(1) Capacity of the small scale unit is 15 kg of processed material per day - (cocoa powder and cocoa butter).

(2) The unit will work atleast 100 days in a year.

(3) Total annual production of the unit is 1500 kg.

(4) Artificial drying need be resorted to only when sun drying is not possible. However, the cost is calculated on the basis that the entire quantity is dried artificially.

(5) The fermentation boxes made of wood will last only for one year and they have to be replaced every year. Hence the cost of fermentation box is taken in the operating cost and not in the fixed cost.

APPENDIX - III

Economic analysis

The cost of production of one kilogram of cocoa powder and butter is worked out on the basis of the following assumptions.

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Calculation

Annual fixed cost:		Rs. P.
(a) Cost of dryer	-	500 00
(b) Cost of Roaster with heating element	-	300 00
(c) Cost of wet grinder	-	2500 00
(d) Cost of pressing cylinder with water jacket	-	300.00
(e) Cost of hydraulic jack	-	500 00
(f) Cost of stand	-	300 00
Total capital cost	-	4,400 00
Interest on capital cost at the rate of 16%	-	704 00
Depreciation at 10%	-	440 00
Repairs and maintenance at 10%	-	440.00
Total fixed cost	-	1,584 00
Fixed cost per kilogram of finished product	-	$\frac{1584}{1500}$ = 1056/kg.

Operation cost

			Rs.P.
(a)	Fermentation (one woman at Rs.15 per day)	-	15 00
(b)	Drying (1/3 woman)	-	5 00
(c)	Kibbling and winnowing (3 woman)	-	45 00
(d)	Roasting (1/2 woman)	-	7 50
(e)	Butter extraction (2 woman)	-	30 00
(f)	Packing and storing material (1/3 woman)	-	5 00
(g)	*Cost of fermentation boxes - $\frac{75 \times 8}{100}$	-	6 00
(h)	Cost of packing material	-	15 00
(i)	+Cost of electricity	-	9 98
			138 48

Operating cost per kg of finished product - $\frac{138.48}{15}$ = 9.23

∴ Total cost of production excluding the cost of raw material (Fixed cost + operating cost) - 1.056 + 9.23

= 10.29/kg

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*The cost of one fermentation box of the required size is about Rs.75/=. The duration of fermentation being six days, a minimum of six such boxes are required to keep beans for fermentation to consecutive days and if two boxes are to be kept as spares, total number of boxes required are eight. The cost of eight boxes will come to Rs.600/=. These boxes can be used only for 100 days and hence the cost per day (that is to produce 15 kg of finished product) is $\frac{600}{100}$ = Rs.6/=.

+Cost of Electricity:

Electrical energy consumed by different equipment for producing 15 kg of finished product are as follows:

	Load (Watts)	No.of hours of working	Energy (Units)
1. Dryer (bulb heated)	600 (6 x 100W)	35	21.00
2. Roaster	1000	4	4.00
3. Grinder (1/2 H.P.motor)	375	4	1.50
4. Hot water bath	500	4	2.00
Total energy required (kilowatt hour)			28.5

At present 35 paise is the rate for one unit of energy.

∴ Total cost of electrical energy required to produce 15 kg of finished product - Rs.9.98/=

DEVELOPMENT OF SMALL SCALE EQUIPMENT FOR EXTRACTION OF COCOA BUTTER AND PRODUCTION OF COCOA POWDER

By

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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
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ABSTRACT

The primary objective of this project was to evolve a viable technology and equipment system for small scale processing of cocoa beans. The study mainly concentrated on the development of an extraction unit for the separation of butter from cocoa mass. Various equipment required for small scale processing of cocoa beans were either identified or designed.

The mini-box was selected for fermentation of beans. A bulb heated dryer was designed and fabricated. This dryer could dry about 30 kg of fermented beans in 36 hours. A rotating drum type roaster, which was designed and fabricated, roasted the cocoa beans uniformly. Winnowing and kibbling was done manually. Alkalisation was done to reduce the acidity of the beans by soaking them for one hour in a solution of 0.1 per cent potassium bi-carbonate. A wet grinder of two litre capacity was selected for grinding the cocoa nibs.

A cocoa butter extractor, which utilised the pressure developed by a hydraulic jack for extraction of butter, was fabricated and tested. The butter that could be extracted at various temperatures and pressures

was determined. A maximum of 44.8 per cent of butter could be extracted applying a pressure of 248.72 kg/cm^2 at a temperature of 70°C. Drinking chocolate and milk chocolate were made and they were palatable.

The cost of production, including the cost of raw materials of 450 g of cocoa powder and 550 g of cocoa butter (yield from one kg cocoa mass) would come to Rs.30.29.

The technology of fat removal, which was one of the main problem encountered in the processing of small quantities of cocoa beans, could be standardised.