DEVELOPMENT OF COCOA DRIER

By

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THESIS

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DECLARATION

I, hereby declare that the thesis entitled "DEVELOPMENT OF COCOA DRIER" 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.

Vellanikkara,
20th July, 1985.

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CERTIFICATE

Certified that the thesis entitled "DEVELOPMENT OF COCOA DRIER" is a record of research work done independently by Shri. M. Abdassalam, 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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To

Dr. Jose Samuel

Who is no more

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Symbols and Abbreviations used

a	-	Area
Agric.	-	Agricultural
b	-	Breadth
°C	-	Degree centigrade
cc	-	Cubic centimetre(s)
cm	-	Centimetre(s)
cm^2	-	Square centimetre
C.P.C.R.I.	-	Central Plantation Crops Research Institute
Cs	-	Service factor
Dept.	-	Department
d	-	Diameter
Divi	-	Division
E	-	Energy
et al.	-	And others
°F	-	Degree fahrenheat
F.A.O.	-	Food and Agriculture Organisation
f_t	-	Feet
Fig.	-	Figure
G	-	Centre of gravity
gm	-	Gram(s)
ha	-	hectare(s)
h.p.	-	Horse power
hr	-	Hour(s)
I	-	Moment of inertia, second moment of area

Ig	-	Moment of inertia about centre of gravity
I.C.A.R.	-	Indian Council for Agricultural Research
in	-	Inch(es)
I.S.A.E.	-	Indian Society of Agricultural Engineers
J	-	Journal
K	-	Radius of gyration
K.A.U.	-	Kerala Agricultural University
kg	-	Kilogram
l	-	Length, litre(s)
m	-	Metre(s), moment
m^3	-	Cubic metre
mm	-	Millimetre(s)
min.	-	Minute(s)
M.S.	-	Mild steel
N	-	Speed
No.	-	Number
O.K.	-	All right, correct
p	-	Pitch
pc	-	Circular pitch
p	-	Page
pp	-	Pages
Proc	-	Procedings
Pvt.	-	Private
Q	-	Discharge

Qty.	-	Quantity
Re.	-	Rupee
Rs.	-	Rupees
Res.	-	Research
rpm	-	Revolution per minute
Sec.	-	Second(s)
T	-	Tonnes, absolute temperature, time, torque
T/hr	-	Tonnes per hour
T/ht	-	Tonnes per hectare
T.N.A.U.	-	Tamil Nadu Agricultural University
V	-	Volume, velocity, pitch line, velocity
W	-	Work done
Wt	-	Weight
x	-	Horizontal distance
$\bar{x}$	-	Vertical distance from c.g. of area
y	-	Vertical distance
$\bar{y}$	-	Distance of centroid of area
%	-	Per cent
/	-	Per
°	-	Degree(s)
η	-	Efficiency
η_{th}	-	Thermal efficiency

Introduction

INTRODUCTION

Cocoa is one of the important beverage crops grown in Kerala. The forests of Amazon and Orinoce are believed to be the original home of cocoa. Though cocoa was introduced in India in the early thirties its large scale cultivation was started only in the seventies. Cocoa is mainly grown as a mixed crop in coconut and arecanut gardens. The annual world production of cocoa is over 1.5 million tonnes and the demand is ever increasing. India imports about 500 tonnes of beans. The present area under cultivation of cocoa in Kerala is estimated to be 25,000 hectares and the annual production is about 4,000 tonnes.

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 taste and flavour. Large scale planting of the crop was taken up in this country during the seventies. No serious attention was paid to the processing aspect. Growers are not conversant with the preliminary post harvest technology of cocoa beans. Majority of the growers sell wet beans as such to the cocoa collection centres established by private firms or societies, where the preliminary processing is carried out, which includes fermentation and drying.

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.

The basic operation of drying cocoa beans is done for reducing the moisture level in the freshly fermented beans, so as to prevent the growth of microganisms, during the period of storage.

The process of drying is governed by two important factors:

a) Transfer of heat into the beans to provide energy necessary for evaporation

b) The movement of the vapourised moisture from some point within the bean to surrounding air

The drying of beans takes place in three phases:

a) Superficial moisture removal and drying of testa

b) Removal of moisture lying between cotyledon and testa

c) Drying of cotyledon

The physical nature of the bean also changes significantly during the drying. Density falls from 700 kg/m^3 to 480 kg/m^3 which represents an effective reduction in bed depth of 24 per cent.

Where quantities are small and the climate is favourable, drying is done in the sun. For satisfactory drying and for large quantities of cocoa beans to be dried, sun drying cannot be adopted under unfavourable conditions. The problem is especially severe in regions with heavy rain, during the harvest period. In India the rainy season coincides with peak harvest and makes sun drying impossible. To overcome this, artificial methods of drying must be adopted.

Most of the existing driers utilise firewood and fuel oil as heating source, for air heating. The main drawbacks of utilising the above are the high cost of firewood and fuel oil as well as inadequacy in its availability.

The important factors governing artificial drying are

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

b) Air velocity

c) Difference in vapour pressure between the drying air and that of the product

The quality of dried bean basically depends on the temperature and low rate of drying air, bean depth and agitation of bean or a combination of all these factors.

Sun drying is the most popular method followed in Kerala, though the peak harvest period coincides with the rainy season. This causes improper drying and deterioration in the quality of the cocoa product to a great extent. Artificial driers are not readily available in the market. The driers available in the market are mostly grain driers, which are not suitable for drying cocoa. Attempts were made in K.A.U. and C.P.C.R.I., for developing suitable driers for cocoa. K.A.U. developed a bulb heated drier, which has a capacity of 30 kg/loading. The C.P.C.R.I. developed an electric coil heated drier with a capacity of 50 kg/loading. Both these driers are suitable only for small scale processing.

The land holdings of most of the cocoa cultivators in Kerala are very small and these farmers sell their cocoa pods to the nearest cocoa collecting firms or societies. The preliminary processing of cocoa namely fermentation and drying are done in these collecting centres. During the peak harvesting season they collect up to two tonnes at a time and since it coincides with the rain, drying of the beans becomes difficult for them. With this in view, a project "Development of Cocoa Drier" is taken up. The main objective is to develop a low cost medium size cocoa drier for drying of cocoa without impairing its qualities. Other objectives are

a) To compare the performance of the existing types of artificial cocoa driers

b) To conduct basic studies on the drying characteristics of cocoa including moisture, temperature, rate of air flow, depth of beans etc.

c) To evolve suitable design of drying equipment for cocoa

d) To test the cocoa drier thus evolved and compare its performance with the existing type of cocoa driers

This project aims at developing a viable technology and equipment system suitable for large scale drying of fermented cocoa beans.

Review of Literature

REVIEW OF LITERATURE

2.1 Botanical description

Cocoa the "Food of Gods" is derived from the seeds of "Theobroma cacao", indigenous to Central and South America. The increasing popularity of cocoa caused its introduction for cultivation into various other tropical countries. Cocoa grows as an inter crop with coconut and arecanut.

The cocoa tree belongs to the genus Theobroma a group of small trees whose natural home is in the Amazon basin and other ever green tropical areas of South and Central America. There are over twenty species in the genus, but only one Theobroma cacao is cultivated widely (Wood, 1975).

Cocoa is cauliflourous. The inflorescence arises 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 develops 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 dia/width. 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 development of chocolate flavour (Wood, 1975).

2.2 Fermentation

The characteristic flavour and aroma of cocoa develop only on proper fermentation/curing of cocoa beans. Fermentation of cocoa beans involves keeping the mass of cocoa beans with the mucilage well insulated so as to retain the heat, at the same time allowing air to pass through the beans for a stipulated period of time (normally lasting up to seven days).

Fermentation methods vary widely between the cocoa producing countries in the world. Of the various methods, tray and sweat box fermentation methods are most commonly used.

According to Wood (1975), fermentation trays have been used more than other methods. Each normal tray takes about 20 kg of wet beans and the bigger tray over 40 kg beans. The bottom of the tray is either slatted or drilled with half inch holes on a two inch square pattern for drainage of sweatings. Ten or more trays could be stacked one above the other with the first or bottom tray resting on a raised platform and the top tray covered with banana leaves or sacks. Fermentation is completed in 4-6 days.

Sweat box fermentation is an improved method of fermentation, of cocoa. Bridgland (1959) and Salz (1971) reported on a modified design using boxes of two different sizes instead of using boxes of one size throughout. The shallow boxes which are normally used for the first three days of fermentation are 30 to 50 cm in depth, while the deep boxes used for remaining fermentation period, are approximately 75-90 cm deep.

Rohan (1958) found that quantities of 70 kg wet beans could be properly fermented using heap method. Wood (1975) described the methodology of heap fermentation. In this method, the wet beans heaped on banana leaves are covered with the leaves themselves. The fermentation process lasts for six days during which time the beans are turned twice at intervals of two days. Investigations were carried out in the Kerala Agricultural University to develop suitable methods for small scale fermentation. Three methods, mini box, mini tray and mini basket were tested. In each of the methods, the quantities of wet bean of 1.5 kg 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 et al., 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.

2.2.1 Efficiency of different methods of fermentation

Many scientists have compared the efficiency of different methods of fermentation and their variation.

Knapp (1934) compared six methods of fermentation of cocoa beans (Heap, pin, wooden mini box, basket, plantain stem frame and bamboo frame) under Ghana conditions. He concluded that the best type of container was the wooden box, in spite of the fact that it lacked sufficient protection against cooling.

Lay Cock (1936) reported that the heap method of fermentation was superior to the pit method.

Rohan (1958) tried heap, sweat box and tray methods. From the observations made on the physio chemical changes at different stages in the cocoa mass, he reported that when heap fermentation was used, the temperature on the surface 10 cm layer rose more rapidle than in the centre, causing rapid killing of the beans. Kumaran et al. (1980) fermented cocoa beans using wooden mini box, bamboo mini basket and wooden mini tray charged with two quantities of beans 1.5 kg and 3.0 kg each . In the case of mini tray method the beans were fermented for four days and in the other methods, six days. They found that for the proper fermentation of small quantities, turning the beans once in alternate days is necessary. The variation in temperature followed the same trend in all the methods, as in the conventional methods using large quantity of beans. However, among the various containers tried, wooden container was found to be better than the basket, because of better temperature retention and aeration. The quality of the beans, as judged by the cut test and pH of cured beans was satisfactory in the wooden mini box and bamboo mini basket methods.

2.2.2 Changes during fermentation

Saposhnikova (1952) suggests that a final pulp - pH less than 5.00 indicates defective fermentation.

Acetic acid bacteria appear earlier in the superficial zones of fermenting mass (Roelofsen, 1958). It might be expected, therefore, that the change in pH of the pulp would occur more rapidly at the surface.

Wesiberger *et al*. (1971) and Hopez and Quesnel (1973) observed the presence of a range of both volatile and non-volatile organic acids during fermentation.

Wood (1975) reported the pH of fresh pulp as 3.5 and that of the cotyledon as 6.6

According to Liew (1979), Malaysian wet beans possessed more pulp and sugar and these were assumed to be the major reasons for the acidity of Malaysian beans. Greater aeration at the end of fermentation reduced the acidity considerably. Turning the beans three times a day during the last three days of fermentation promoted aeration leading to the reduction of acidity considerably.

2.2.3 Judging the end point

According to Wood (1975) the appearance of beans undergoing fermentation both external and internal, temperature changes, smell etc. provides clues in judging the end point of fermentation. In box fermentation, temperature falls during fermentation but rises after mixing till the seventh day. After 6-7 days fermentation is completed, temperature falls and over fermentation sets in as indicated by the smell of ammonia gas.

The internal appearance of the beans is another guide to judge proper fermentation and end point. Well fermented beans contain a reddish brown liquid, the cotyledons become pale (originally bright and violet) in the centre with a brownish ring outside. Cotyledons, when cut open, turn brown rapidly. If 50 per cent or more of the beans of a sample show this condition the ferment is ready for drying (Quesnel, 1958).

2.3 Drying

The basic operation of drying cocoa, the most difficult part of processing is the reduction of moisture in the freshly fermented beans to such a level that micro-organisms cannot grow, so that the beans can be stored safely for a longer period. During drying a considerable reduction in weight and volume of the materials takes place, along with certain chemical changes inside the bean which give rise to the typical taste, aroma or flavour associated with good chocolate. The freshly fermented beans with a loose surface coating of mucilage, have a maximum initial moisture of approximately 55 per cent (w/w) and are dried down to an average seven to eight per cent to ensure good keeping qualities during storage (Ghosh, 1970). The Indian Standards Institution has specified that the moisture content of cocoa beans shall not exceed 7.5 per cent i.e. 8865. The physical nature of the beans also changes significantly during drying. The density falls from

700 kg/m^3 to 480 kg/m^3 which represents an effective reduction in bed depth of 24 per cent (Wood, 1975).

Slaz (1971) suggested that the cocoa bean loses its moisture in two phases.

a) Through constant drying rate of surface moisture

b) Falling drying rate of internal moisture migrating from the cotyledon tissue to the bean surface

According the Howat et al. (1957), it is usually a matter of good judgement to dry at a rate which permits the necessary changes to take place, and yet inhibit the growth of putrefying organisms. Their findings showed a higher volatile acid content with rapid drying and extremely slow drying resulted in development of foul flavour in the bean.

Moisture content of the bean is a deciding factor during drying. Knapp (1957) reported that activity of the cocoa oxidase, an enzyme, falls off rapidly below a moisture content of 20 per cent. He suggested that rapid drying must either interfere with oxygen intake by the bean in the early stage of drying or the enzymes must be inactivated by dehydration before sufficient oxidation has taken place or a combination of these factors.

De Vos (1956) named the following conditions as most important in 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 mixing of beans.

Brid Gland (1959) recommended that the temperature of the beans should never exceed 50°C (122°F) during drying.

Roelofsen (1957) stated that the temperature of the beans could be tolerated upto 60°C (140°F) but not above 60°C.

De Vos (1956) used temperature upto 90°C (194°F) in the converted Gordon drier for 1-3 hours and followed by tunnel drying at a lower temperature.

Wood (1957) employed a high temperature of 80°C in his experiment and reported that the beans would not reach that temperature until they were nearly dry. Wood gave the high latent heat and specific heat of water being the possible explanation.

Howat *et al.* (1957) have provided evidence that air temperature upto 80°C and drying time as short as 14 hours are not detrimental to cocoa quality. In fact they found that a drying temperature of 80°C was most economical as regard to fuel consumption and drying time.

Powel (1958) reported that cocoa beans rapidly dried contained more acetic acid than sun dried, beans and these beans gave rise to chocolate with fruity flavour. However, rapid drying within limits specified had no other adverse effect on flavour.

Slaz (1971) stated that if low air volume and high temperature were employed for initial stage of drying, the beans would heat up just as fast as the surface moisture was lost.

With the loss of surface moisture from nib, the bean will shrink and the skin will collapse about the nib, resulting in unattractive and shrunken beans.

2.3.1 Existing system for drying cocoa beans

2.3.1.1. Drying is done in the sun where quantities are small and the climate is favourable. The length of sun drying depends upon the weather. Countries where the main harvesting is done during dry season, the beans are dried in the sun (Wood, 1975).

According to Micheal (1979) demerits of sun drying are

a) Drying is nonuniform

b) Sun drying needs vast open space and sufficient manpower at appropriate time

c) Dust, dirt and foreign materials get mixed with the cocoa bean during drying on open space

d) Involves extra labour for collecting and re-exposing during the day

According to Allison et al. (1979), advantage of artificial drying methods are

a) Drying can be done in foul or fair weather

b) Farmers can plan their harvest season for efficient use of available labour

c) Permits the farmers to sell a better quality product which will be worth more to him and to those who use it

d) Drying operation can be controlled more accurately and thus moisture content of bean can be reduced more closely to the levels necessary

e) Shattering loss and losses due to rodents and birds are reduced

f) The rate of drying can be controlled by adjusting the temperature of hot air ventilating through the bean mass

g) Beans can be dried irrespective of weather conditions, day or night, as the process does not depend on any natural source like sun energy

h) The process is automatic and requires only unskilled labourers except a trained person to operate the drier

i) There are practically no losses due to insects, birds and rodents in this process

j) Mechanical drying requires much less space (Ongkhenghol, 1977)

k) In India, the heavy rainy season coincides with peak harvest and makes sun drying impossible. To overcome this artificial methods of drying have to be adopted (Patil, 1982).

2.3.1.2 Samoan drier

This dries the beans by means of a convection current. This drier consists of a simple flue in a plenum chamber and a permeable drying platform above. Air inlet must be provided in order to allow the convection current to flow and the flue must be properly sealed to prevent the escape of smoke. Platform of 3.5 x 3 m size will have a capacity of 225 to 272 kg of dry beans per batch and the drying period would be one and a half to two days, but this varies considerably according to the fire and temperature. The most of fuel consumed has been estimated to be one and a half tonnes of fire wood/tonne of dry beans (Cadbury Brothers, 1963).

2.3.1.3 Martin drier

It has a drying platform 13.5 m long and 7.5 m wide and is filled with a 'U' shaped flue. The roof runs on rails so that sun drying can also be done. The capacity is three tonnes of dry beans and the drying period is twenty hours (Urquhart, 1955).

2.3.1.4 Banda drier

This has a raised drying mat protected from the rain, with a wood fire on the ground below. The smoke from the fire passing through the beans give the dried product an objectionable flavour (Rohan, 1979).

2.3.1.5 Secader

This is used in Brazil and Bahia estates and it mainly consists of a simple drying floor. A convection current of hot air is generated by a flue (Wood, 1975).

2.3.1.6 Estufa

This is another type of drier used in Brazil. Hot air current is passed through the layers of wet cocoa. Eight to ten trays with mesh bottom filled with wet cocoa beans are arranged one over the other. The air temperature is controlled by regulating the admission of cold air through the bottom. Heat is normally supplied from wood fire (Wood, 1975).

2.3.1.7 Platform driers

This combines sun drying with artificial drying. This has a platform 12 m x 6 m with a wire mesh floor raised about 0.5 m from the ground. The platform is covered by a sliding roof running on rails (Allison et al., 1964). For artificial drying, the unit is provided with an oil fired heat exchanger and a fan driven by a diesel engine. The capacity of the unit is 2.5 tonnes of dry cocoa per batch which could be dried in less than two days (Wood, 1974).

Driers of this type make use of machinery designed for many purposes and hence a variety of sizes and capacities are available.

2.3.1.8 Bin driers

The drying platform has been replaced by a drying bin of similar dimensions as that of platform driers but holding beans upto a depth of 45 cm. Some of these bins are sealed or covered and arranged in such a way that the air flow can be reversed. This helps to overcome the lack of uniformity that will occur in a deep layer but the cocoa must still be stirred and this cannot be done easily (Salz, 1972).

2.3.1.9 Rotary drier

It is generally considered that rotary drum driers are not suitable for the complete drying of cocoa beans, though they can be used for the last stage of drying. There are two main reasons for this, first the sticky remains of the mucilage on the beans tend to clog the holes in the drum, second the mass of beans shrinks during the course of drying to about two-thirds its original volume. The wet beans should move and mix and it is essential that some free space be left when the drier is filled. As the beans dry and shrink the drum will become about half full and this will lead to considerable heat loss. Rotary driers are used for the later stages of drying, after the beans are externally dry. The drum should revolve slowly at about 0.25 to 0.5 per minute in order to prevent breakage of shell and bean. The holes in the drum should be eight to ten mm in diameter (Newton, 1966).

2.3.1.10 Tunnel driers

The beans are spread in a thin layer on trays and the trays are loaded on to a trolly, which is placed in the tunnel. Hot air is blown through the tunnel and arrangements are usually made for recirculation (Wood, 1975).

2.3.1.11 Buttner drier

This is the only continuous drier that has been used for cocoa beans. It consists of an endless belt of small trays, each holding about 40 kg wet beans. The trays pass down a drying tower through which hot air is blown. The beans are dried in sixteen hours and the machine can handle nine tonnes of wet beans when fully charged (Wood, 1975).

2.3.1.12 Ner Barico drier

The simplicity of this large capacity drier is that it achieves high thermal efficiency and produce low acidity cocoa without mechanical stirring of the beans.

The Barico drier at full capacity, requires about half a tonne of firewood to dry one tonne of cocoa, where as the average oil fired heater uses 27 to 30 gallons of diesel fuel per tonne of cocoa produced (Anselmi, 1979).

2.3.1.13 Drying of cocoa beans by gas

The commercially available gas for house-hold cooking is used in the gas system for drying cocoa beans, the heat being applied by infrared heaters from the bottom of a drying platform in the same way as in other types on non-mechanical driers. The equipment is fairly simple and there are no moving parts like fans or electric motors, as natural convention forces set up by cold air entering at the bottom of the plenum chamber forces the heated air to rise through the layer of drying beans (Ghosh, 1973).

2.3.1.14 K.A.U. Cocoa drier

Kerala Agricultural University fabricated a small cocoa drier of capacity 25 kg of fermented cocoa beans with ordinary electric bulbs. Drying could be completed in 24 to 72 hours depending upon the season. The cost of the drier is about Rs.300/- and the cost of drying is about 50 paise per kg of dry beans (Kumaran et al. 1980).

2.3.1.14 C.P.C.R.I. Drier

The drier consisted mainly of a heat source, plenum chamber, drying chamber and exhaust air chamber. Materials used for construction are hard wood, G.I. Sheet, Aluminium angle and a 500W industrial air heater/kerosene wich stove/biogas burner.

At a time, up to 40 kg. of fermented beans can be handled in this drier. The beans can be loaded in all the six trays in approximately equal quantities. After loading the beans, the trays are placed in the drying chamber to facilitate uniform drying.

30 kg beans can be dried in about 48 hours and 40 kg in about 65 hours (Patil, 1980).

2.3.2 Multistage drying

Deep bed brying is essentially a two-stage process and many attempts have been made to design driers to benefit from this behaviour. These design have had the following objectives and design feature.

a) Increased drier throughput and efficiency by pre-drying in shallow beds and later passing to a deep bed unit; or by reducing temperature and air flow rate at some point in the process, or by re-circulation of the unspect drying air.

b) Improved handling properties by drying initially on a mechanically agitated unit and later, when the beans become prone to breakage, removing to a static bed.

c) Improved product appearance by removing the cocoa to a mechanical polisher/drier for some part of the drying period.

Increased capital and handling cost are to be expected from a system of multi-stage drying and the resultant benefits must obviously exceed these if the method is to be cost effective (Wood, 1972).

2.3.3 Interrupted drying

Several workers have taken advantage of a multi-stage drying system to introduce interruption or rest periods which claimed to increase end product quality and or system efficiency. The argument in favour of rest periods, where drying efficiency is concerned, are that the tempering period allows the moisture inside the beans to move towards the outside and helps in preventing hardening of the outer casing of the bean. Case hardening of the bean tests has often been discussed, but has never been experimentally studied and would not normally be a problem at the temperatures, used for cocoa drying.

Resting also increases the capital cost because of the lower drier throughput and would increase handling costs if the beans are in fact removed from the drier for the purpose (Wood, 1975).

2.3.4 Stirring or agitation

Stirring is necessary during the process of drying in order to achieve uniformity in drying as well as for speeding up the rate of drying (Ongkhenghol, 1977).

Hynes (1958) reported that there was a very marked difference in the rate of drying if the beans were thoroughly mixed at hourly intervals. It was found difficult to mix the beans if the bed depth exceeds 125 cm. Allison and Kenten (1964) recommended three rakings at an interval of about two hours to give unformity in drying with low percentage of breaking of beans at a bean depth of ten cm. More frequent and careful raking would be necessary with deeper beds of cocoa.

Whymper (1921) has reported the use of a mechanical agitator in Trinidad with apparent success. The mechanical agitator used for coffee drying has been used for cocoa also for 15 to 18 cm bed depth with slight damages to beans. It is further reported that in mechanical agitation of high speed is undesirable as it will result in high percentage of bean breakage, and two slow speed will be ineffective in agitating the beans properly. According to Salz (1971) tests with agitator using aluminium ploughs travelling at five meter per minute had been successful for bean depth upto 45 cm. The only disadvantage reported with these agitations is that the bean mass tend to build up, in front of the agitator ploughs thus requiring high power input to drive them and also causing uneven hot air distribution.

Bridgland (1959) mentioned that the speed of the rotary drier in the first few hours should be approximately two revolution per minute, and after that it is desirable to reduce it to the range of ¼ to one revolution per minute. Slaz had slightly different recommendation of ¼ revolution every 15 minutes for the first four to six hours and then continuously at the speed of ¼ revolution per minute.

2.3.5 Acidity

The effect of the drying process upon the cotyledon acidity (as defined by pH was investigated by Howat et al. (1951) who during a sequence of 11 tests, on a through flow tray or cabinet type drier at 80°C, showed that the average post fermentation pH of 4.8 did not change during artificial drying. Sun drying control samples showed a higher pH of 5.2.

2.3.6 Drying temperature and end product quality

Wilbaux (1938) found that that drying attwo tempeture levels gave better results. Using acidity as his quality criteria he proposed 20 hour drying in ten cm beds at an air temperature of 90°C with continuous mixing, followed by finishing at 45 to 50°C in beds of 15 to 20 cm.

Haynes (1958) working in Malaysia with a small platform drier (of 0.19 m^2) operating at 65.6°C, produced cocoa which gave chocolate of acceptable flavour. Neither the cocoa loading nor the drying air flow were specified, though the latter must have been high (i.e. of the order of 0.2 m/sec) in order to dry the mass in the specified period of 12 hours.

Jacquet *et al.* (1980) in a well controlled sequence of 12 tests on a laboratory scale, investigated the through flow drying of cocoa in beds of depth between 10 to 28 cm. Drying air temperature of 65 to 111°C were used and kept constant during any run. High air flows were applied (0.37 to 0.94 m^3/sec) and the bean temperature was assumed to have approximated closely to that of drying air for some time before the end of the process, which took between 13 and 19 hours. Cocoa dried at temperatures above 65 to 70°C developed an unacceptable flavour. Bravo *et al.* used a single bean layer and showed that after 16 hours of drying at an air temperature of 60°C the bean had a temperature at the centre of the cotyledon, of about 59°C, for an air flow of 0.49 m^3/second but only 56°C for an air flow of 0.047 m/second. Thus beans dried on a through flow drier will require regular mixing at a frequency determined by the air flow rate adopted. The lower the air flow the more frequent should be the mixing. Mixing not only prevents the beans sticking together but also effectively distributes sensible heat through the bed, thus reducing the risk of condensation.

Materials and Methods

MATERIALS AND METHODS

The present studies were undertaken in the Department of Agricultural Engineering, College of Horticulture, Vellanikkara during the period 1981-'83. Studies on fermentation, sun drying of fermented cocoa beans and artificial drying in the existing type of bulb drier and newly fabricated driers were conducted utilising the following materials and methodology.

3.1 Fermentation

Four wooden boxes having capacities 2 kg, 5 kg, 11 kg and 16 kg were used, for the fermentation studies. The pods were broken by hitting against hard surface, the wet beans were taken out from the placenta and transferred to the boxes up to their brim. It was then covered with a gunny bag and a weight was placed over it. All the boxes were then placed over bricks to facilitate the drainage of sweating. By the second day, the beans were taken out and thoroughly mixed. It was again covered with gunny bags. Weight was placed over the gunny bags for fermentation again. The beans were mixed in alternate days, and were kept for fermentation for 144 hours. The temperature inside the boxes was noted at 9 am and 5 pm daily. The mean weight loss during fermentation was also calculated. The quality of the beans was tested by cut test. The bleached appearance of the cut cotyledons in the centre with a brownish ring towards the periphery showed that the beans were well fermented.

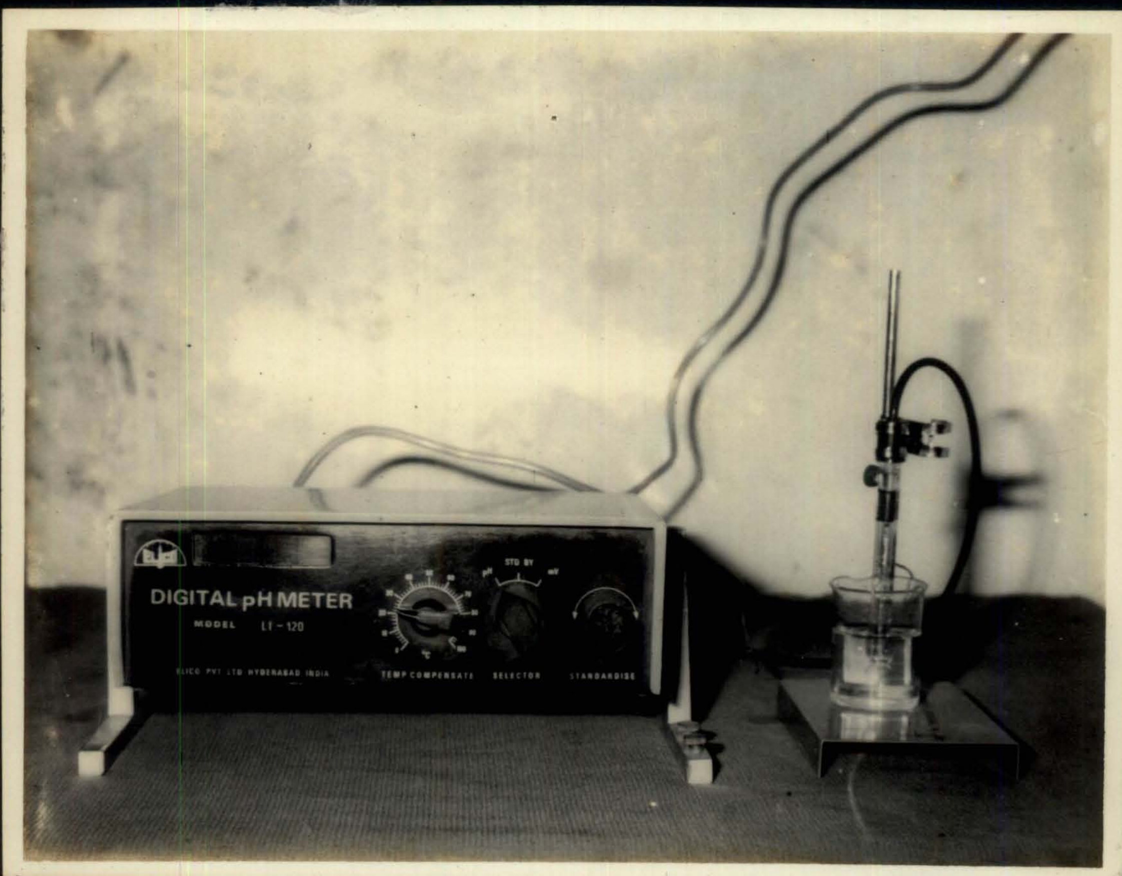
3.2 Drying

Preliminary investigations on sun drying of fermented beans and artificial drying in the existing type of bulb drier were conducted. Tests were also carried out in the modified bulb heated drier, modified C.P.C.R.I. model electric heated drier, modified C.P.C.R.I. model cocoa drier with 0.5 hp electric motor and blower and agitation type multistage drier.

3.2.1 Sun drying

Seventeen kilogram of well fermented cocoa beans were taken and spread in a mat and were kept for sun drying. The process of drying was continued up to seven days for complete drying. Temperatures at regular intervals were noted. The weight of the beans was recorded daily. For finding the pH of the beans, ten grams of cocoa beans were ground to powder and 100 ml of boiling water was added to it. After cooling to room temperature, the pH was noted using a digital pH

Plate 1. Digi al pH meter



meter (Plate 1). Moisture content was tested using an infra red moisture meter (Plate 2).

3.2.2 Bulb heated drier

Artificial drying of cocoa beans was done in the existing K.A.U. bulb heated drier.

This drier 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 wiremesh at the bottom. Six electric bulbs fitted at the bottom of the drier were used for heating the air. Ventilations were provided at the bottom, on the sides and at the back of the drier for the entry of air and there was provision for escape of heated air at the top.

At no load condition by switching on all the six 100 watt bulbs, a steady state temperature of 70°C was obtained with sufficient air flow, in 2.5 hours. 30 kg of fermented beans were taken for drying. Each tray was loaded with 10 kg of wet beans. The beans were mixed 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 up to 50°C under loaded

Plate 2. Infra red moisture meter

conditions. The beans were dried to the required moisture content after 38 hours of drying. The readings were tabulated and a graph was drawn. Energy required for drying each kg of fermented cocoa beans was calculated. Final pH of the beans was also noted.

3.2.3 Modification of bulb heated drier

Modification in bulb heated drier was done by using a 500 watt electric heating coil instead of bulbs. This was fixed at a distance of 15 cm, below the bottom-most wiremesh (Plate 3).

The drier was loaded with 30 kg of fermented beans, distributed equally in three trays. Then the heater was put on. The beans were mixed, at an hourly interval and the trays were interchanged after every two hours. For the first 12 hours, the average temperature was 50°C and thereafter the temperature increased to 55°C, under the loaded condition. The beans were dried to the required moisture level in 34 hours of heating. The moisture content of the beans was recorded at an interval of two hours and the pH of the dried beans was also noted.

3.2.4 Modified C.P.C.R.I. model electric heated drier

The drier fabricated consisted of the following:

Plate 3. Modified bulb heated drier

a) Plenum chamber with an electric heating coil

b) Drying chamber

c) Exhaust air chamber

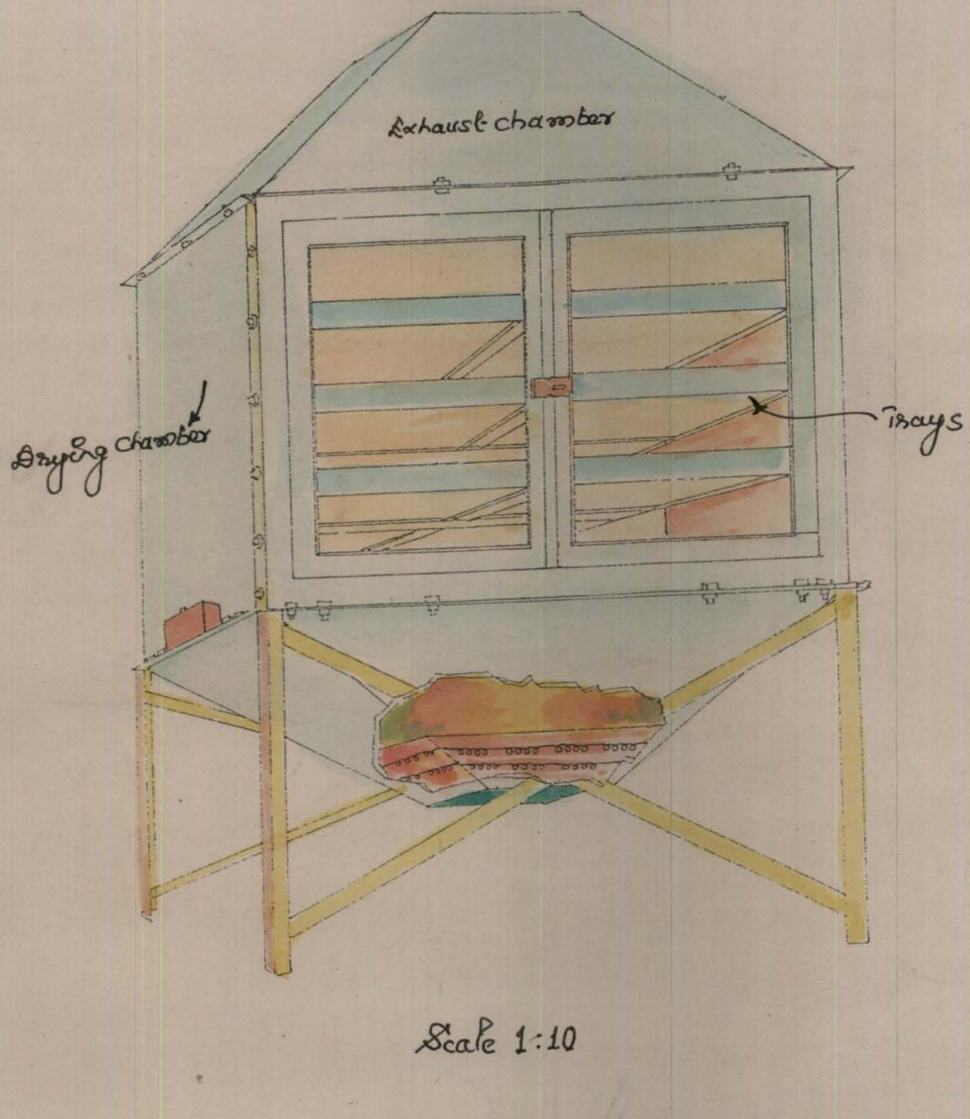
The materials used for construction were asbestos sheet, wood, wiremesh and plain glass. The drier consisted of four trays made of wiremesh and wood. The trays were fixed at a distance of 10 cm. The inlet and outlet openings for air circulation were provided at the bottom and the top of the drier. A 500 watt single phase electric heater of size 60 x 72 cm was used as the heating source and was fixed below the bottommost tray (Fig. 1).

3.2.4.1 Testing of modified C.P.C.R.I. model electric heated cocoa drier

Sixty kilogram of fermented beans were loaded into the trays at the rate of 15 kg/tray. Then the doors were closed and the heater was switched on. After four hours the heater was switched off for about 15 minutes and the positions of the trays were interchanged. The beans in each tray were mixed to avoid sticking to each other while changing the tray position. The weight of the beans and their moisture content were recorded. After interchanging the position of trays the doors were again closed and the heater was put on.

FIG. No. 1

MODIFIED C.P.C.R.I MODEL DRIER



Scale 1:10

Sixty kilogram of beans were dried in about 64 hours at 55 °C. The drier was tested with 50 kg and 40 kg of cocoa beans. The pH and moisture content of the dried beans were noted.

3.2.5 Modified C.P.C.R.I. model cocoa drier with 0.5 hp electric motor and blower

The tray type through flow electric drier was modified by incorporating a blower as shown in Plate 4 and Fig. 2 . The prime mover of the blower was a 0.5 hp electric motor. The capacity of the blower was 0.2 m^3/sec.

The air drawn from the atmosphere by the blower was transmitted to the heater through the duct provided. The air was heated by the electric heating element and was passed to the tray in which the beans were kept for drying.

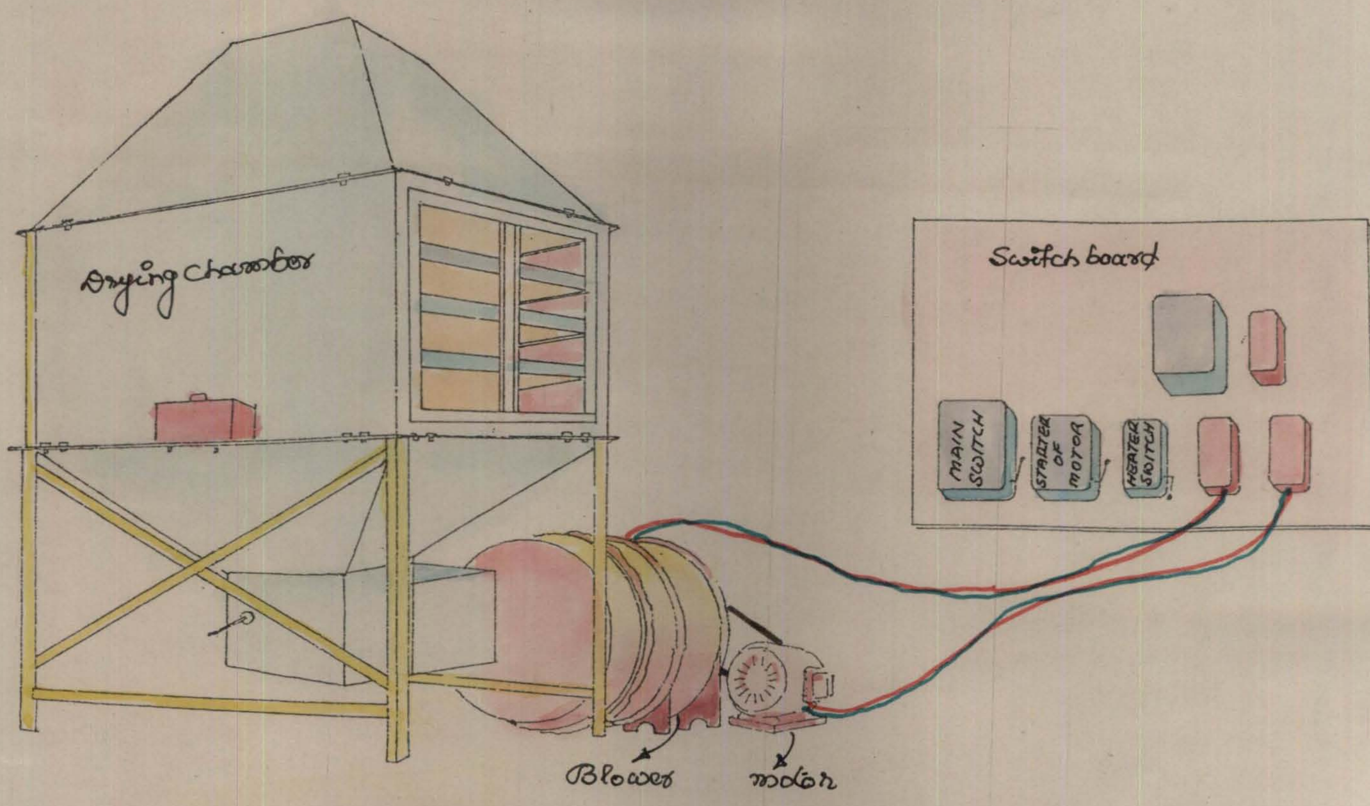
The moisture content of the beans was recorded at an interval of three hours.

3.2.6 Agitation type multistage cocoa drier

Agitation type multistage cocoa drier of 90 kg/ loading capacity was designed, fabricated, tested and the economics was worked out. Also a large model of the same type of drier of capacity 2000 kg was designed and its economics worked out.

FIG. No. 2.

MODIFIED C P C R I MODEL DRIER WITH
½ H.P. MOTOR & BLOWER



Scale 1: 10

Plate 4. Modified C.P.C.R.I. model electric heated drier with blower - experimental Set-up.

3.2.6.1 Agitation type multistage cocoa drier of capacity 90 kg (Plate 5 to 12 and Fig. 3 to 22).

3.2.6.1.1 Design

The design details are given below:

a) Screw conveyer

The conveyer discharge capacity was assumed as 15 kg for one revolution of the scraper.

As per the data available for rotary type cocoa driers rpm of the drier should be below one. Hence assumed rpm of the drier was 0.9 i.e. time taken for one revolution = 1.1 minutes

Hence the discharge capacity $= \frac{15 \text{ kg}}{1.1 \text{ minutes}}$

$= 13.64$ kg/minute

It was found that 700 kg of cocoa had a volume of 1 m^3

$\therefore$ volume of 13.64 kg $= \frac{13.64}{700}$

$= 0.01949 \ m^3/\text{minute}$

$= 1949 \ cm^3/\text{minute}$

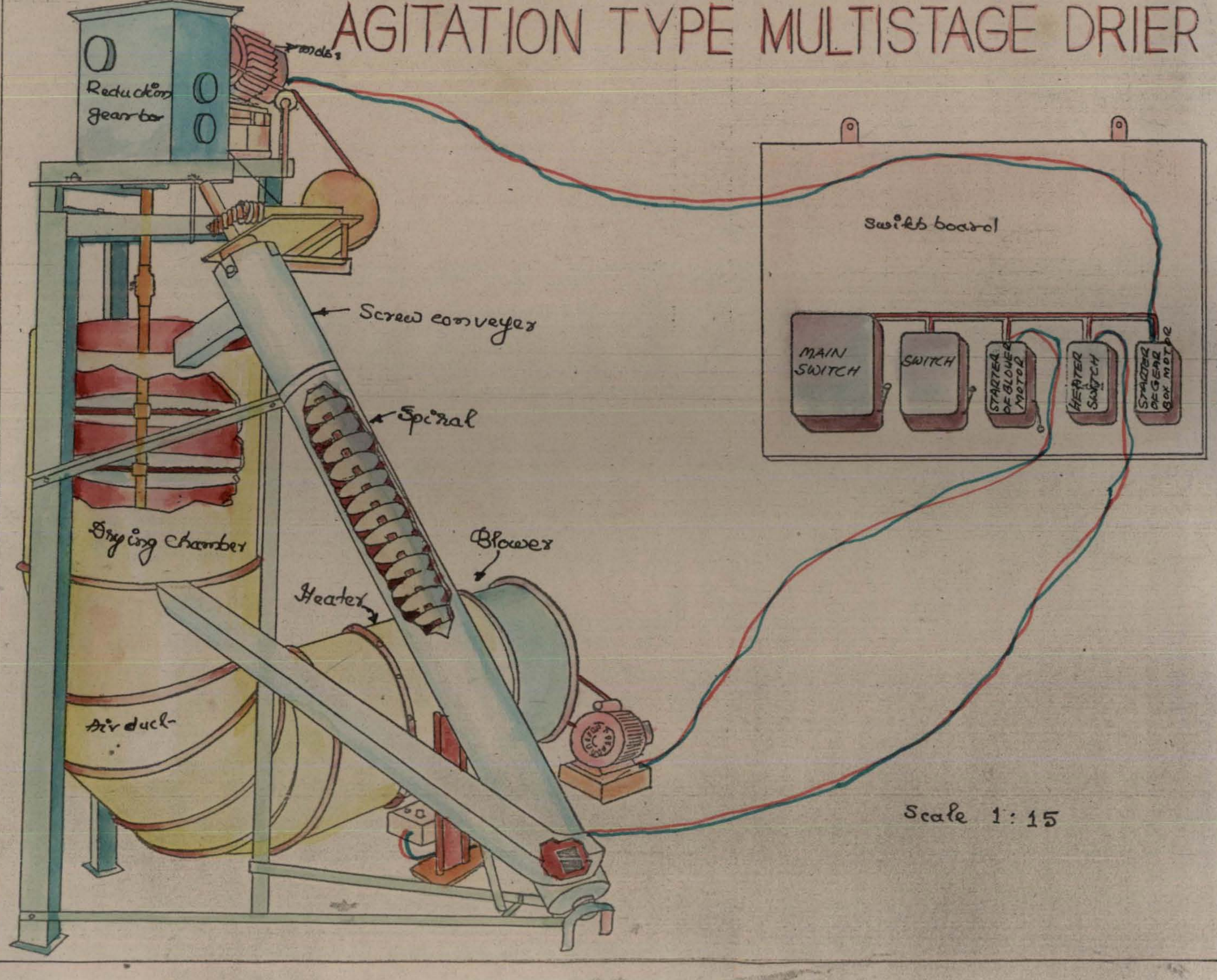
Giving space for two cocoa beans assumed,

$\therefore$ Pitch of the screw = 3.6 cm

Preliminary studies on the conveyer speed revealed that a speed between 70 to 75 rpm was optimum. Hence assumed that screw rotated at 72 rpm

FIG. No. 3

AGITATION TYPE MULTISTAGE DRIER



Scale 1 : 15

In a minute the axial displacement $= 3.6 \times 72$ cm

$= 259.2$ cm

Minimum diameter required could be calculated using the equation $\pi/4\ d^2 \times 259.2 = 1949$

From this equation 'd' was worked out as

Diameter $= \sqrt{\frac{1949}{259.2} \times \frac{4}{\pi}}$

$= 9.57$ cm

For the space occupied by the spindle, conveyer blade etc. an allowance of 25 per cent on the diameter was given

Hence the diameter of the spiral $= 11.96$ cm

Took 'd' $= 12$ cm

It was found that for uninterrupted fall of the cocoa beans from the drum through the chute and for a smooth upward travel the conveyer should be set at an angle of 45° and should have a length of 1 to 1.5 metre hence for comparability assumed 40 turns of the screw.

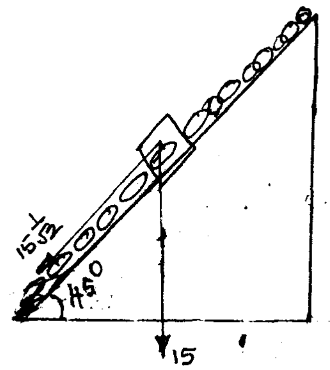
$\therefore$ Axial length $= 40 \times 3.6$ cm

$= 144$ cm

Took axial length $= 145$ cm

Since the conveyer can have a maximum inclination of 45° in similar cases, the conveyer screw was set at an angle 45° to the horizontal.

b) Spiral power and shaft diameter



15 kg → 0.9 rpm

1 Rev. = $\frac{1}{0.9}$

15 kg in 1.11 minutes

In the ideal case the work done by the conveyer is the work required to raise 13.5 kg (i.e. 15 x 0.9) of cocoa beans per minute, through a distance of 145 cm x sin 45°. But major work has to be done in order to overcome the resistance for the ideal case.

$13.5 \text{ kg} \times 1.45 \text{ m} \times \frac{1}{\sqrt{2}}$ = 13.84 kg metre/minute

Horse Power = $\frac{13.84}{4500}$

= 0.003

However, taking the friction into consideration assumed that the

Horse Power = 0.5

Torque on the conveyer shaft = $\frac{0.5 \times 4500}{2 \times \pi \times 72}$

= 4.974 x 100

= 497.4

Take Torque = 500 kg cm

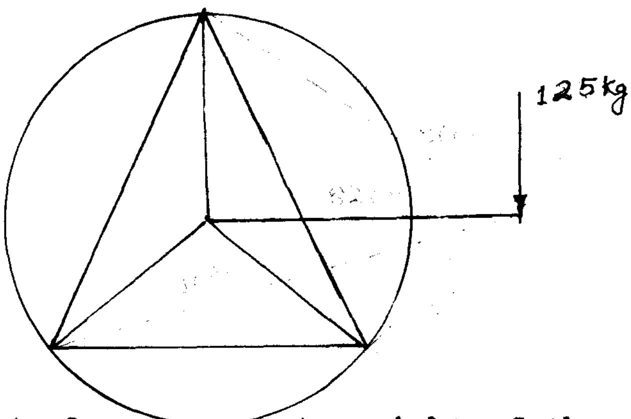
$\frac{\pi}{16} \times d^3 \times 350 \quad = 500$

i.e. $d \quad = \sqrt[3]{\frac{500 \times 16}{\pi \times 350}}$

$= 1.94$ cm

Assumed a shaft size of 25 mm to account for weakening of the shaft due to spiral groove to accommodate the conveyer blades (Fig. 3 and 4, Plate 5).

c) Support of the drier



From actual measurement, weight of the motor unit was 125 kg, weight of the reduction gear unit was 155 kg and the weight of the drying unit was 500 kg (including 90 kg of cocoa beans)

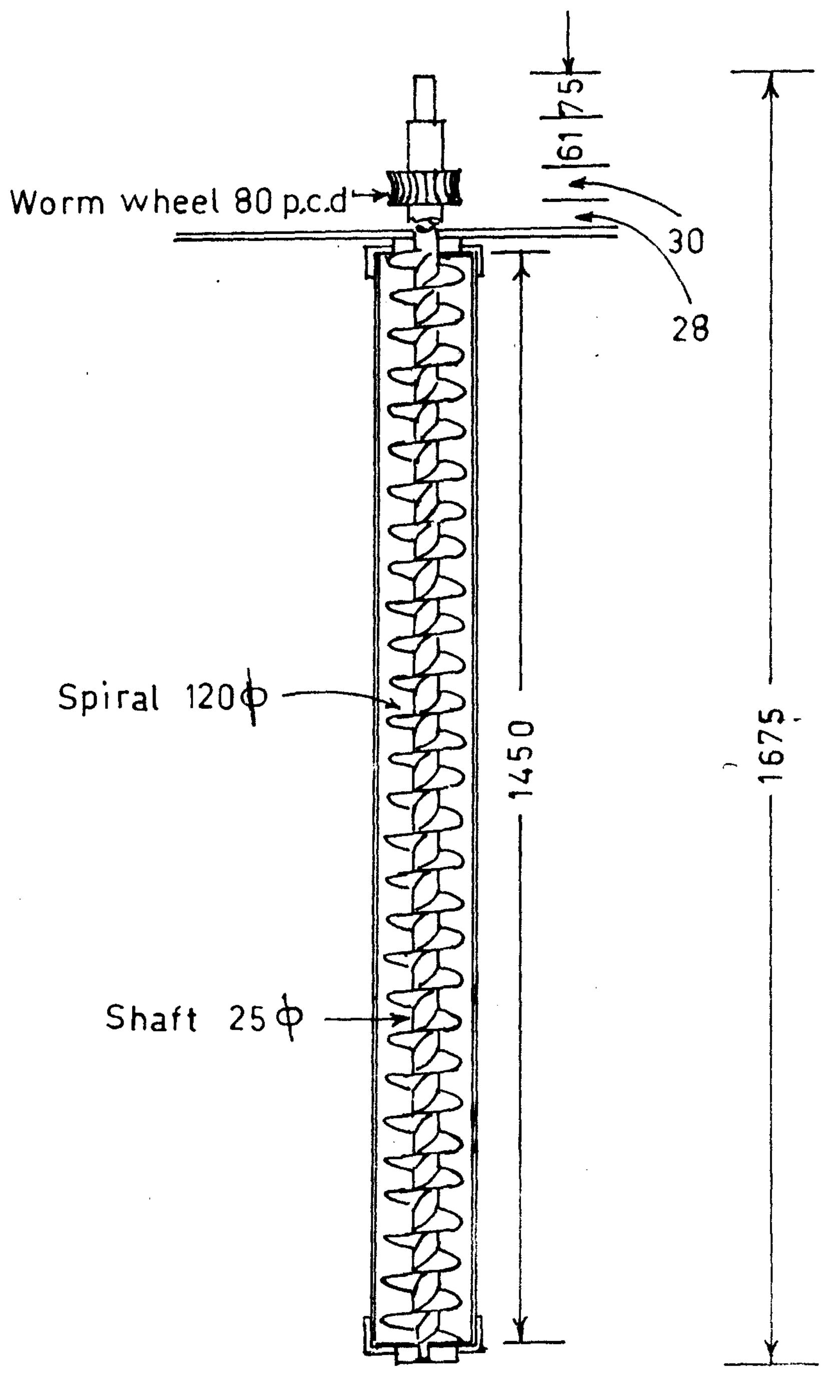
Effect of eccentric load

Direct load $= \frac{125}{3}$ on one column

Load due to resisting moment, let it be F_1.

FIG-4

CONVEYER



Dimensions in-mm

Scale - 1:10

Plate 5. Agitation type multistage drier - spiral of screw conveyer

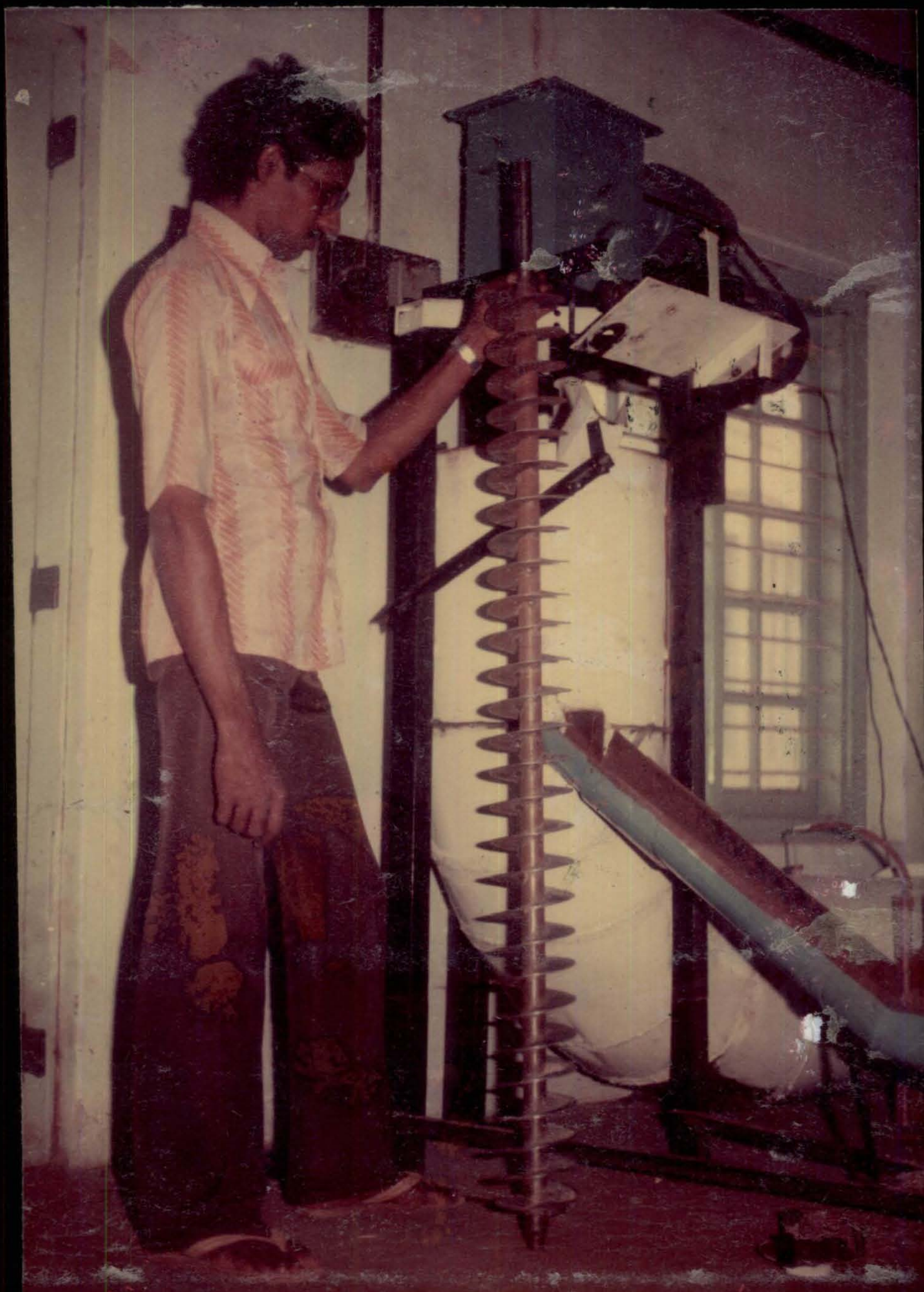
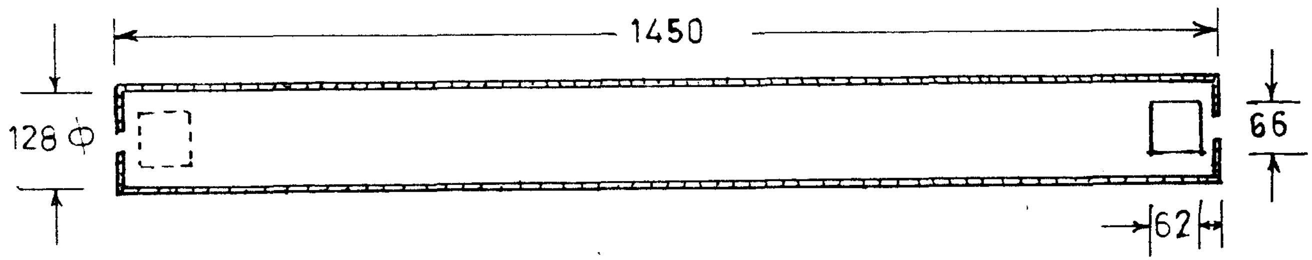


FIG-5

SPIRAL COVER



Dimensions in-mm

Scale -1: 10

Thus

$F_1 r_1 + F_1 r_2 + F_1 r_3$ $= 125 \times 82$

$(F_1 \times 104 + F_1 \times 62 + F_1 \times 86)$

F_1 $= \frac{125 \times 82}{252}$

$= 40.67$ kg

Load due to driving gears $= \frac{160}{3}$

$= 53.3$ kg

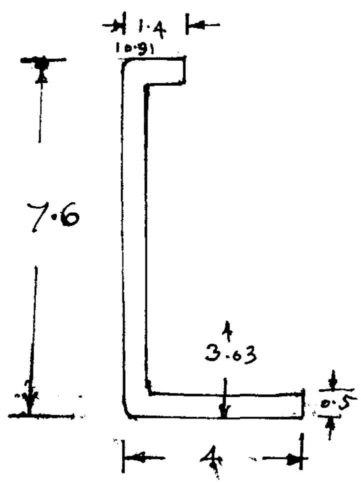
Load due to drum and contents $= \frac{500}{3}$

$= 166.67$ kg

Total $= \frac{125}{3} + 40.67 + 53.3 + 166.67$

$= 302.30$ kg

Assumed that a C section shown in the figure supported the set up.



C.G in xx = $\dfrac{4 \times 0.5 \times 0.25 + 6.6 \times 0.5 \times 3.8 + 1.4 \times 0.5 \times 7.35}{4 \times 0.5 + 6.6 \times 0.5 + 1.4 \times 0.5}$

$= 3.03$

C.G in y.y = $\dfrac{1.4 \times 0.5 \times \frac{1.4}{2} + 0.5 \times 6.6 \times \frac{0.5}{2} + 4 \times 0.5 \times \frac{4}{2}}{1.4 \times 0.5 + 6.6 \times 0.5 + 4 \times 0.5}$

$= 0.886$

$= 0.9$

Moment of inertia $= \frac{1}{12} \times 4 \times 0.5^3 + 4 \times 0.5$
$(3.03 - 0.25)^2 + \frac{1}{12} \times 0.5 \times$
$6.6^3 + 6.6 \times 0.5 \times$
$(3.8 - 3.03)^2 + \frac{1}{12} \times 1.4 \times$
$0.5^3 + 1.4 \times 0.5 \times (7.35 - 3.03)^2$

$= 42.51$

$K^2 = \dfrac{\text{Moment of inertia}}{\text{Area}}$

$= \dfrac{42.5}{4 \times 0.5 + 1.4 \times 0.5 + 6.6 \times 0.5}$

$= 7.085$

$K = 2.66$

$\dfrac{1}{K} = \dfrac{150}{2.66}$

$= 56.4$

This might be treated as a long column

Treating the support as long column, Rankain's formula,

$$P = \frac{fc.A}{1 + a\left(\frac{l}{K}\right)^2}$$

$$302.30\,kg = \frac{fc \times 6}{1 + \frac{1}{7500}\left(\frac{150}{2.66}\right)^2}$$

$$fc = 71.73\ kg/cm^2$$

Steel can safely take a compressive stress of more than 1000 kg/cm^2

Hence factor of safety $= \frac{1000}{71.73\ kg}$

$= 13.94$ Hence it is safe

d) **Fixed tray**

The plate might be considered as a circular plate supported at the ends and subjected to a uniformly distributed pressure over the entire area.

For a circular plate uniformly loaded, the thickness of the plate 't' with a diameter 'D' supported at the circumference and subjected to a uniformly distributed pressure 'P' over the total area,

$$t = C_1 . D . \sqrt{P/f}$$

Where C_1 = Coefficient which may be taken as 0.42 for M.S.

$f \quad = 800\ kg/cm^2$ for M.S.

$A \quad = \frac{\pi}{4}\ (D^2 - d^2)$

$= \frac{\pi}{4}\ (49^2 - 3^2)$

$= 1878.67\ cm^2$

$p \quad = \frac{50}{1878.67}$

$= 0.023\ kg/cm^2$

$t \quad = 0.42 \times 49 \times \sqrt{\frac{0.023}{800}}$

$= 0.11$ cm

For rigidity took, t = 2 mm

(Fig. 6 and 7, Plate 6)

e) Scraper

Torque on the scraper spindle was calculated from the following facts.

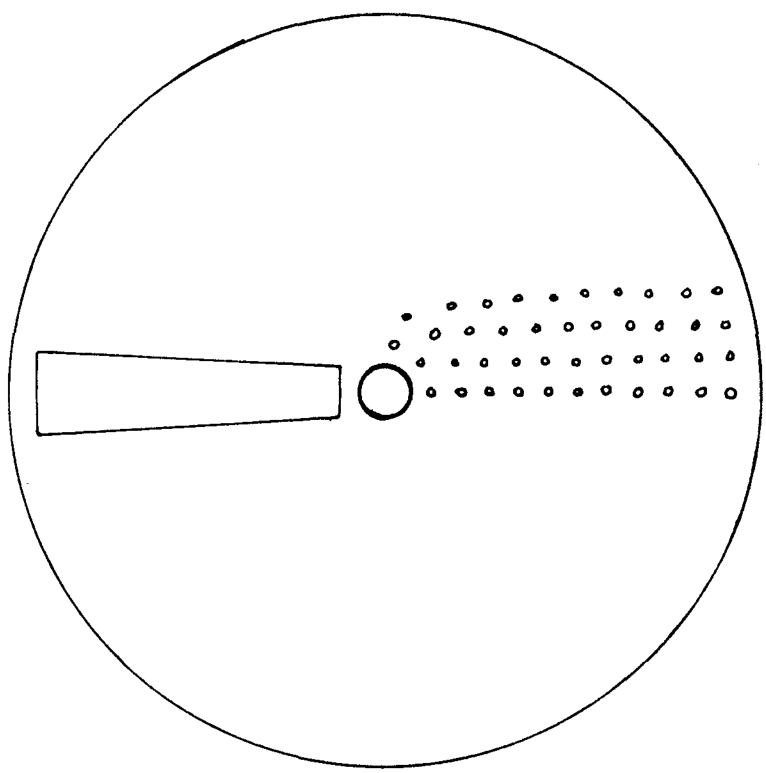
As the scraper has to distribute the cocoa over the plate, assumed

h.p. = 0.5

As per the data available, for rotary type cocoa driers rpm of the driers should be below one rpm. Hence, rpm of the drier was assumed as 0.9.

FIG-6

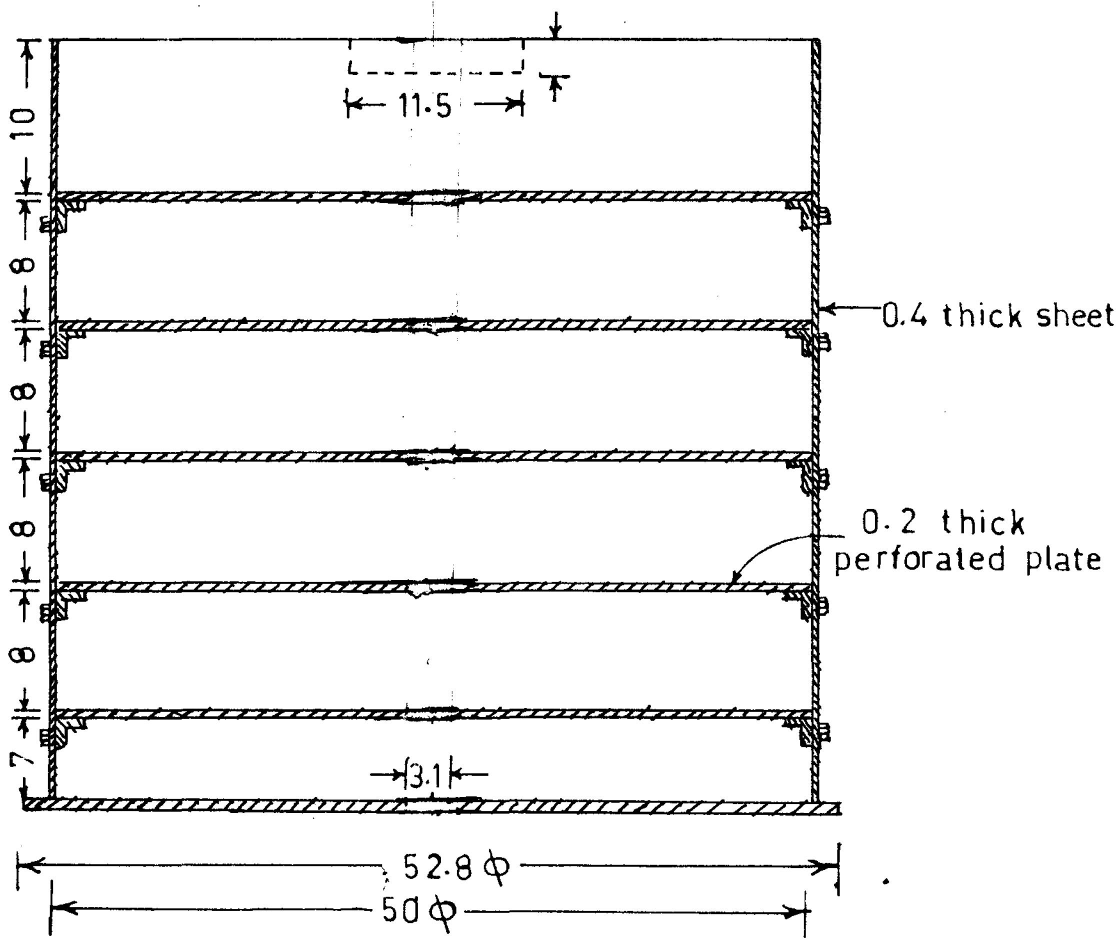
PLATE

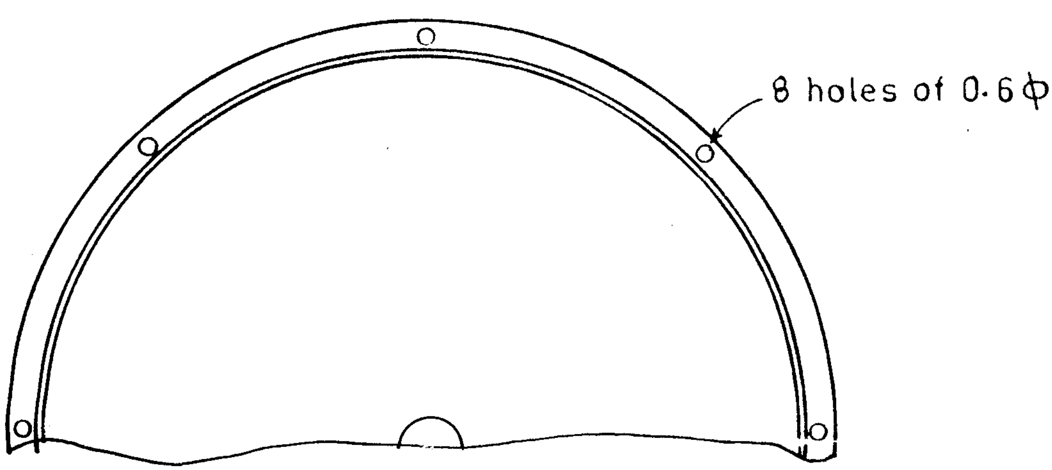


Dimensions in-mm

Scale-1:5

MAIN CYLINDER (With plates)

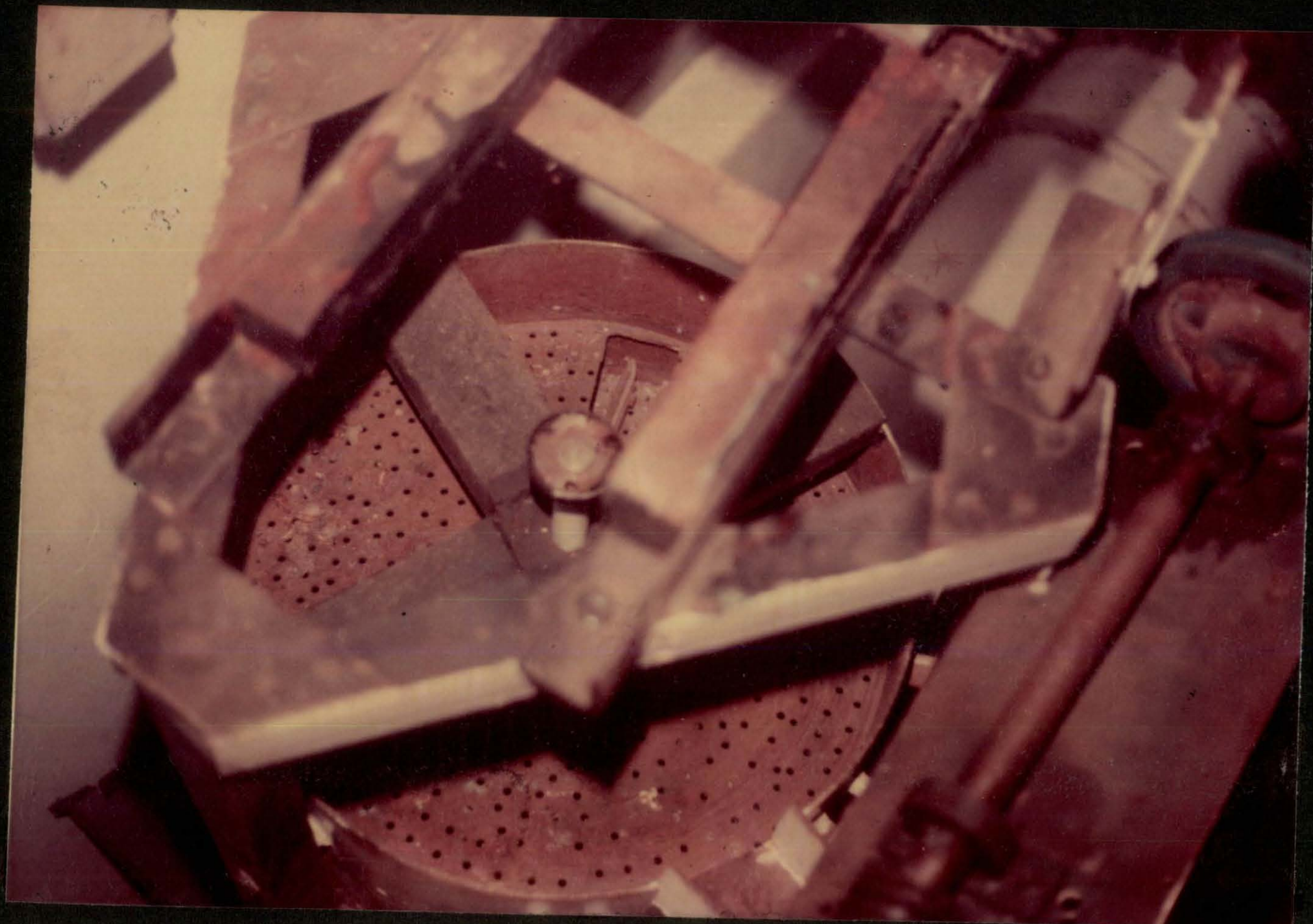




Dimensions in - CM

FIG-7.

Plate 6. Agitation type multistage drier - plate, coupling etc.



Torque $= \frac{hp \times 4500 \times 100}{2 \times \pi \times N}$

$= \frac{0.5 \times 4500 \times 100}{2 \times \pi \times 0.9}$

= Torque shared by 5 scrapers

$\therefore$ Torque of each scraper $= \frac{39788.736}{5}$

= 7957.75 kg cm

Length of each scraper = 24.5 cm

Assuming 2.5 per cent of this amount as a resistance moment offered by the cocoa beans created bending moment on the scraper,

Bending moment on each scraper $= \frac{2.5}{100} \times 7957.75$

But

Bending moment $= \frac{t \times b^2 \times f}{6}$

Where t = thickness in cm

b = width in cm

f = stress kg/cm^2

Assumed a width of 2 cm

$\frac{t \times (2)^2 \times 800}{6} = \frac{2.5}{100} \times 7957.75$

$t = \frac{6 \times 2.5 \times 7957.75}{100 \times 4 \times 800}$

= 0.373 cm

Took thickness t = 1 cm

(Fig. 8, Plate 7).

f) Coupling

The diameter of the output shaft	= 2.5 cm
The hub diameter	= 1.6 x the diameter of the shaft
∴ The hub diameter	= 1.6 x 2.5
	= 4 cm
Let the thickness of the flange	= ½ x D
	= ½ x 2.5
	= 1.25 cm

Let there be three pins arranged in the periphery of a circle of diameter 1.9 D. Say 48 cm

Let the pin diameter be 8 mm

The overall diameter of the flange would be

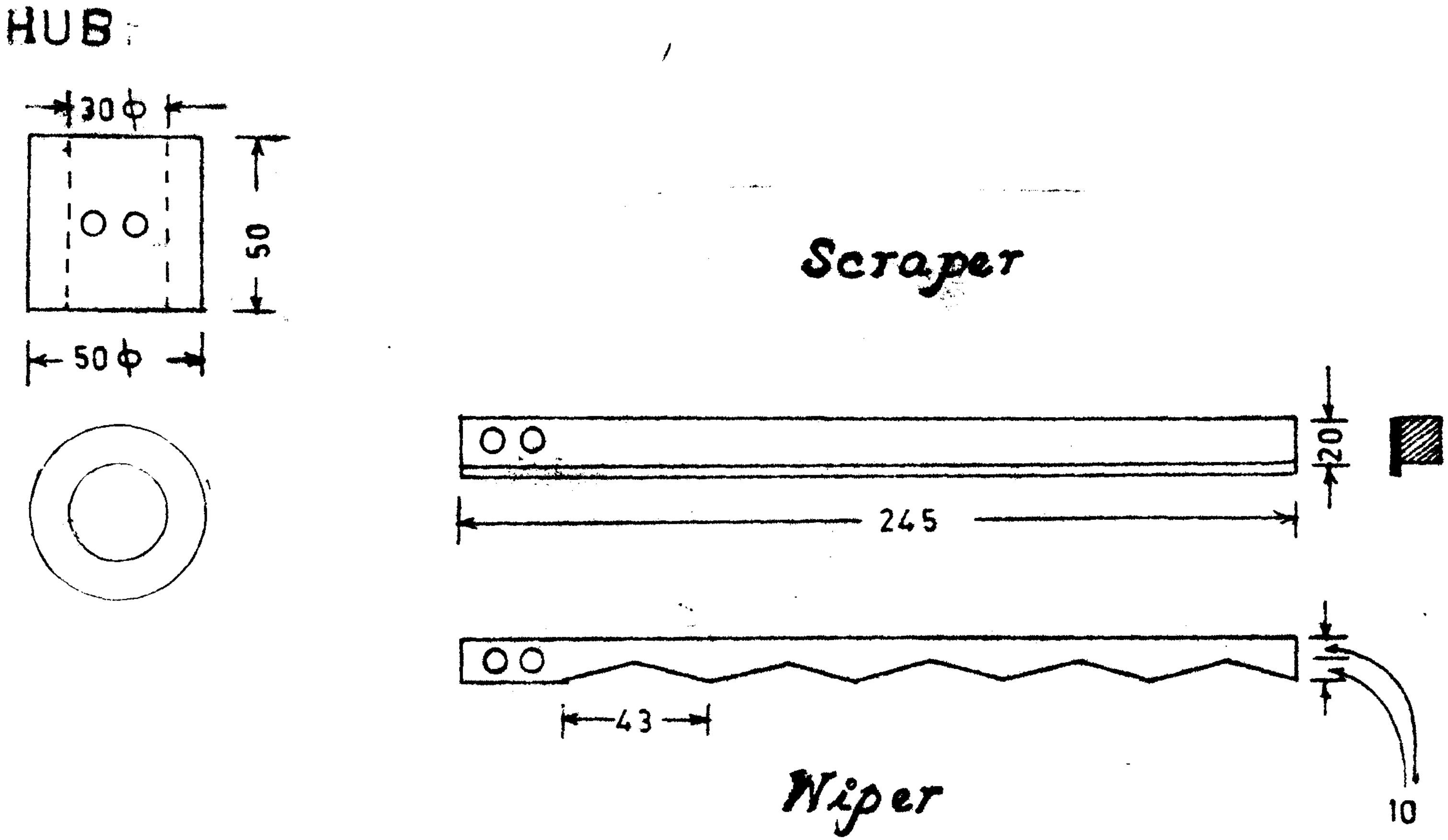
2.5 x diameter	= 2.5 x 2.5
	= 6.25
Tookit as	= 6.3 cm

The coupling of the drier shaft would be similar in dimensions but instead of the projecting pins, the flange would carry holes to house the projecting pins. The overall length of each flange including the hub could be taken as

1.5 d	= 1.5 x 2.5
	= 3.75 cm

(Fig. 9).

FIG-8



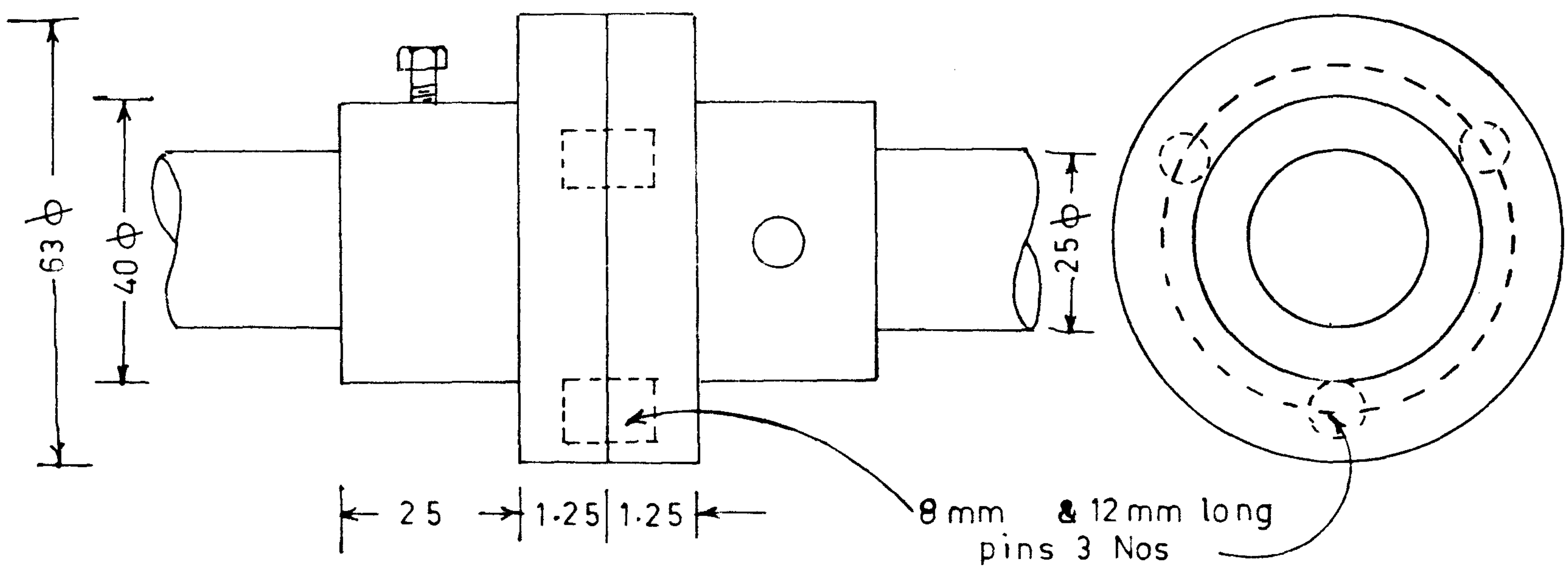
Dimensions in-mm

Scale - 1:2

Plate 7. Agitation type multistage drier - wiper, scraper, bush, top plate support, main shaft

FIG-9

COUPLING



Dimensions in-mm

Scale-1:1

g) Gear drive

Assumed that h.p. = 0.5

input speed = 1440 rpm (motor speed)

At the first stage, this could be reduced with the help of a worm to a speed ratio of 1:40. The wheel shaft at the first reduction with a spur gear, would drive another counter shaft, that would carry another step, the speed ratio again at 1:40. Thus the output shaft speed

$$= 1/40 \times 1/40 \times 1440$$

$$= 0.9 \text{ rpm}$$

The two worm drives were identical. The layout is shown in Fig. 10 & 11 and Plate 8 & 9. The worm and gear design and the spur gear design are as follows.

i) Spur gear

Let 'Dg' be the diameter of the gear and 'Dp' be the diameter of the pinion.

Assumed the centre distance to be 9 cm approximately.

$$\frac{Dg + Dp}{2} = 9 \text{ cm}$$

The gear ration,

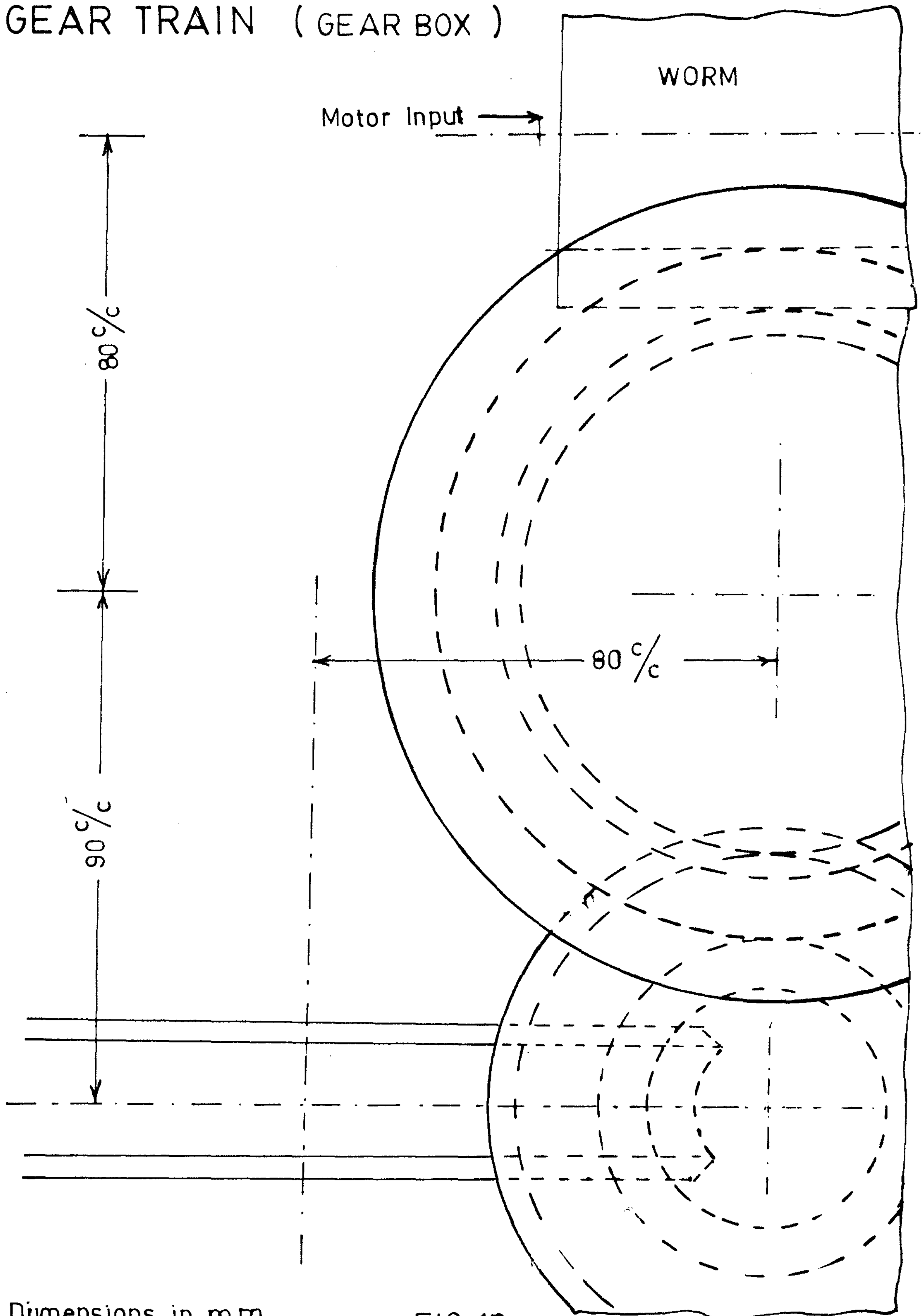
$$\frac{Dg}{Dp} = 1$$

$$Dg = Dp$$

$$Dg = 9 \text{ cm}$$

$$Dp = 9 \text{ cm}$$

GEAR TRAIN (GEAR BOX)



Dimensions in-mm

FIG-10

FIG-11

GEARBOX ASSEMBLY

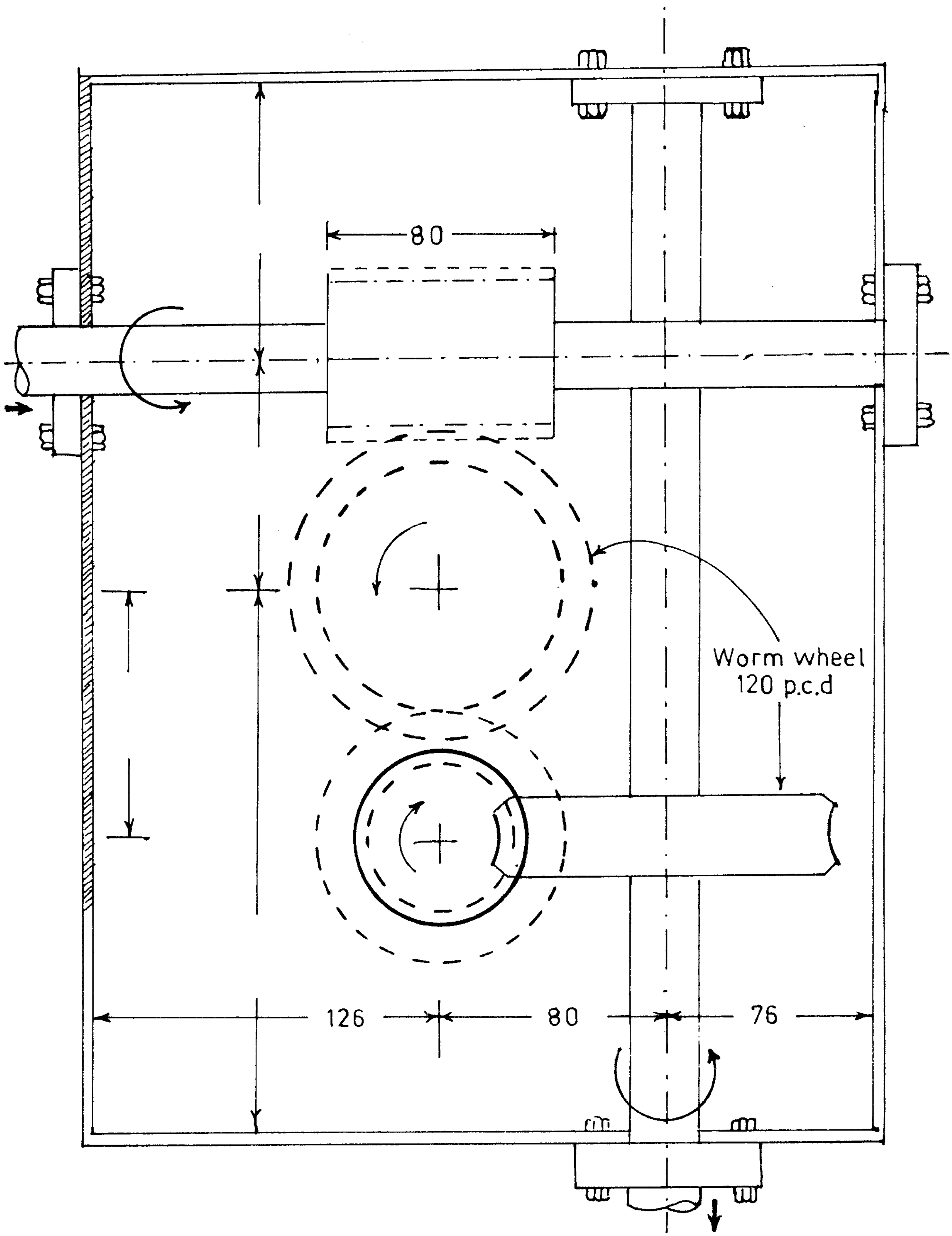


Plate 8. Agitation type multistage drier - inside of reduction gear box

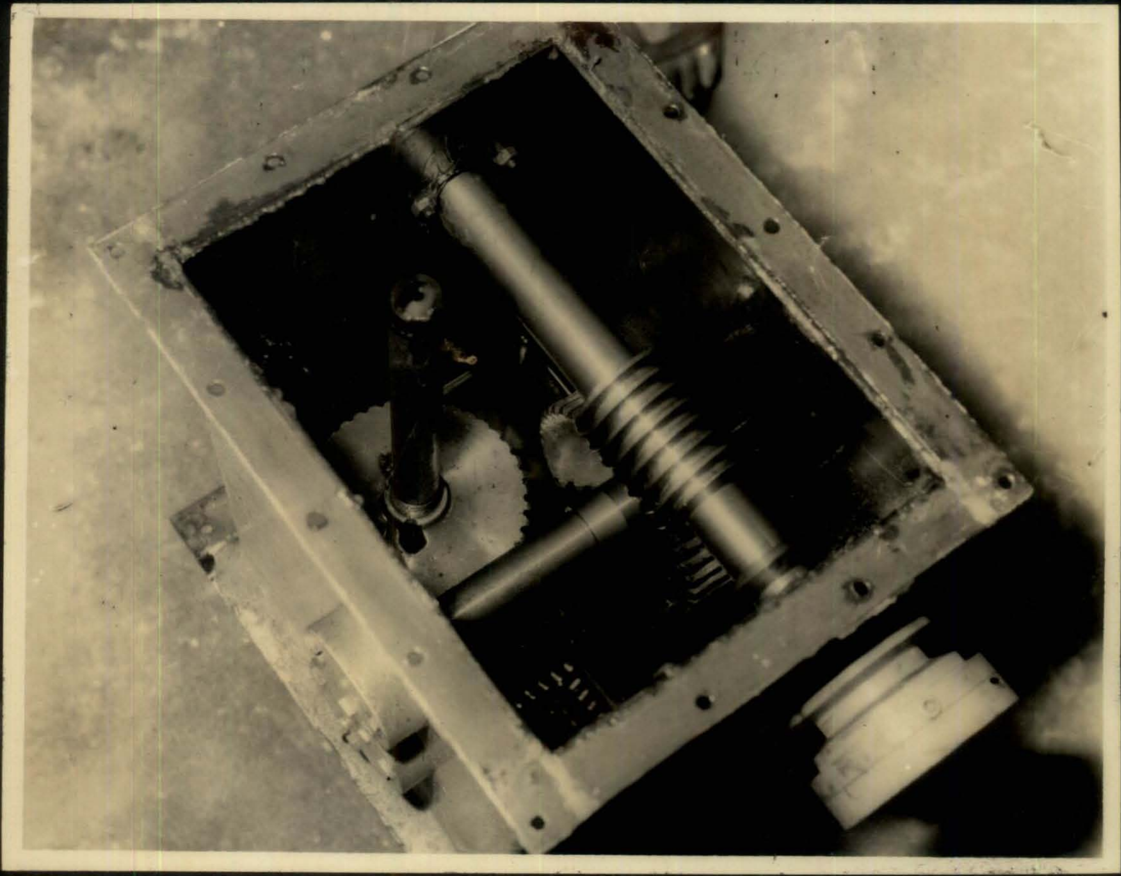
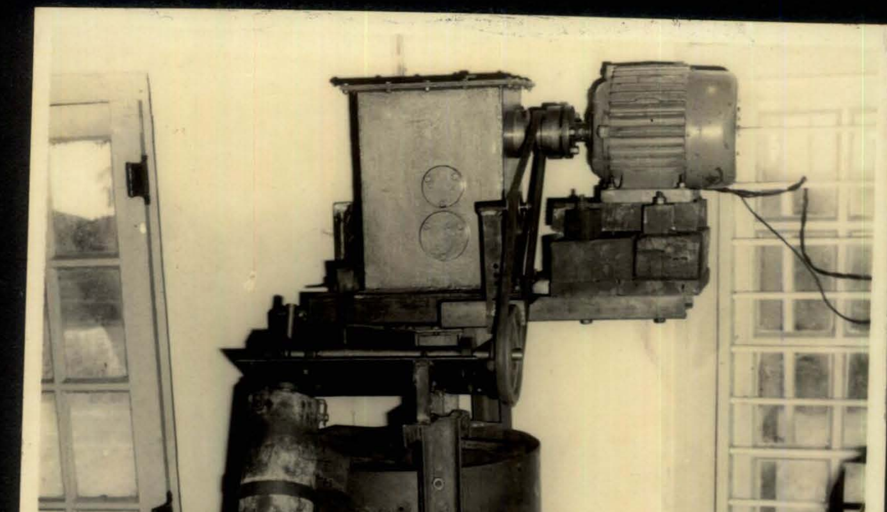


Plate 9. Agitation type multistage drier - motor, coupling and reduction gear box etc.



The speed of rotation of gears $= \frac{1440}{40}$

$= 36$ rpm

Pitch line velocity 'V' $= \pi Dg \times Ng$ metres/minute

where Ng = rpm of the gear

Pitch line velocity $= \pi \times 0.09 \times 36$

$= 10.18$ metres/minute

The tangential load, 'ft' $= \frac{hp \times 4500 \times Cs}{V}$

where Cs = Service factor

To take into account the uncertainty of the load where motor is started, stopped etc. and also the working is for more than 10 hours/day, assuming medium shaft,

Took, Cs $= 1.8$

Tangential load F_t $= \frac{hp \times 4500 \times 1.8}{10.18}$

$= \frac{0.5 \times 4500 \times 1.8}{10.18}$

$= 397.84$

Using the 'Lewis' equation

Ft = s.b.y.p

Where Ft = Tangential load

S = Allowable dinamic stress

b = Face width

y = Lewis factor

p = Circular pitch

s = $\rho d. Cv.$

$\rho d.$ = Permissible static stress

Assumed, $\rho d.$ = 1400 kg/cm^2

$$Cv = \frac{4.58}{4.58 + v}$$

$$= \frac{4.58}{4.58 + 10.18}$$

$$= 0.31$$

$$S = 1400 \times 0.31$$

$$= 434 \ kg/cm^2$$

b = Face width

= 10 module

= 10 m

$$y = 0.124 - \frac{0.684}{z}$$

$$m = D/z$$

Where

z = Number of teeth

$$y = 0.124 - \frac{0.684}{z}$$

$$= 0.124 - \frac{0.684}{D} \times m$$

$$= 0.124 - \frac{0.684}{0.09} \times m$$

$$Ft = s.b.y.p.$$

$$397.84 = 434 \times 10\ m \ \frac{(0.124 - 0.684 \times m)}{0.09} \times m$$

$$\frac{1036.23\ m^3}{1036.23} - \frac{1690.68\ m^2}{1036.23} + \frac{397.84}{1036.23} = 0$$

$$m^3 - 1.632\ m^2 + 0.384 = 0$$

put $m = 0.4$

$$m^3 - 1.632\ m^2 + 0.384 = 0.18688$$

put $m = 0.6$

$$m^3 - 1.632\ m^2 + 0.384 = 0.01248$$

put $m = 0.7$

$$m^3 - 1.632\ m^2 + 0.384 = -\ 0.07268$$

Module = Between 0.6 & 0.7

Assumed 6 module

$$m = D/z$$

$$z = \frac{90}{6}$$

$$= 15 \text{ teeth}$$

Module m	= 6 mm	
Addendum	= m	= 6 mm
Didendum	= 1.25 m	= 7.5 mm
Tooth thickness	= 1.5708 m	= 9.42 mm
Tooth space	= 1.5708 m	= 9.42 mm
Working depth	= 2 m	= 12 mm
Whole depth	= 2.25 m	= 13.5 mm
Clearance	= 0.25 m	= 1.5 mm
Pitch diameter	= zn	= 15 x 6
	= 90 mm	

Outside diameter	= (z + 2) m	= (15 + 2) 6
	= 102 mm	
Root diameter	= (z - 2.5 m)	= (15 -2.5x.6)
	= 12.5 mm	
Fillet radius	= 0.4 m	= 2.4 mm

ii) Worm gear

Mean diameter of worm,

$$dw = \frac{c^{0.875}}{1.89}$$

Where 'C' is the centre distance between the axis of the worm and gear in cm

Assumed C = 8

$$dw = \frac{8^{0.875}}{1.89}$$

$$dw = 3.26 \text{ cm}$$

To find the circular pitch of the wheel 'p_c'

$$3\,p_c = dw$$

$$d_w = 3.26$$

$$\therefore \quad p_c = \frac{3.26}{3} = 1.09 \text{ cm}$$

Pitch circle diameter of the gear 'dg' found out from

$$\frac{dw + dg}{2} = C$$

Where 'C' is the centre distance

$$8 \times 2 = 3.26 + dg$$

$$dg = 16 - 3.26 = 12.74 \text{ cm}$$

Velocity ratio $= \frac{\text{number of teeth on gear}}{\text{number of starts on worm}}$

Number of teeth of gear = Velocity ratio x number of start on worm

(Velocity ratio taken as 40) $= 40 \times 1 = 40$

Pitch of the gear (Circular pitch) $= \frac{\pi \times dg}{\text{Number of teeth}}$

$= \frac{\pi \times 12.74}{40} = 1$ cm

Module m = ?

$p_c = \pi m$

$m = \frac{p_c}{\pi} = \frac{1}{\pi}$

$= 0.32$ cm

Choose a module of 3 mm

$\therefore$ Circular pitch $p_c = \pi \times m = 0.94$ cm

Axial pitch of the worm = Circular pitch of the gear

$= 0.94$ cm

$p_c = \frac{\pi \times dg}{40}$

$d_g = \frac{0.94 \times 40}{\pi} = 11.97$ cm

$d_g = 12$ cm

$\frac{Dw + d_g}{2} = C$

$dw = 2 \times 8 - 12 = 4$ cm

Face width of the wheel

$b = 2.38\ p_c + 0.65$

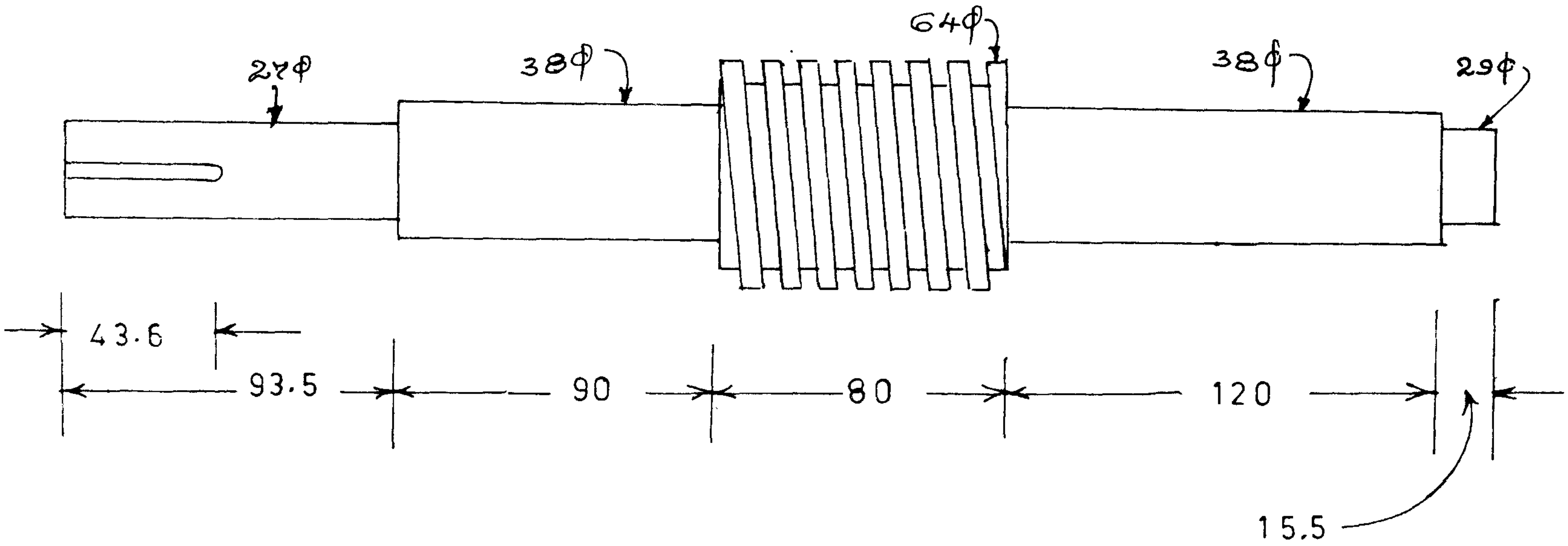
$= 2.38 \times 0.94 + 0.65$

$= 2.38 \times 0.94 + 0.65$

(Fig. 12 to 16). $= 2.8$ cm

FIG-12

INPUT SHAFT (With Worm)

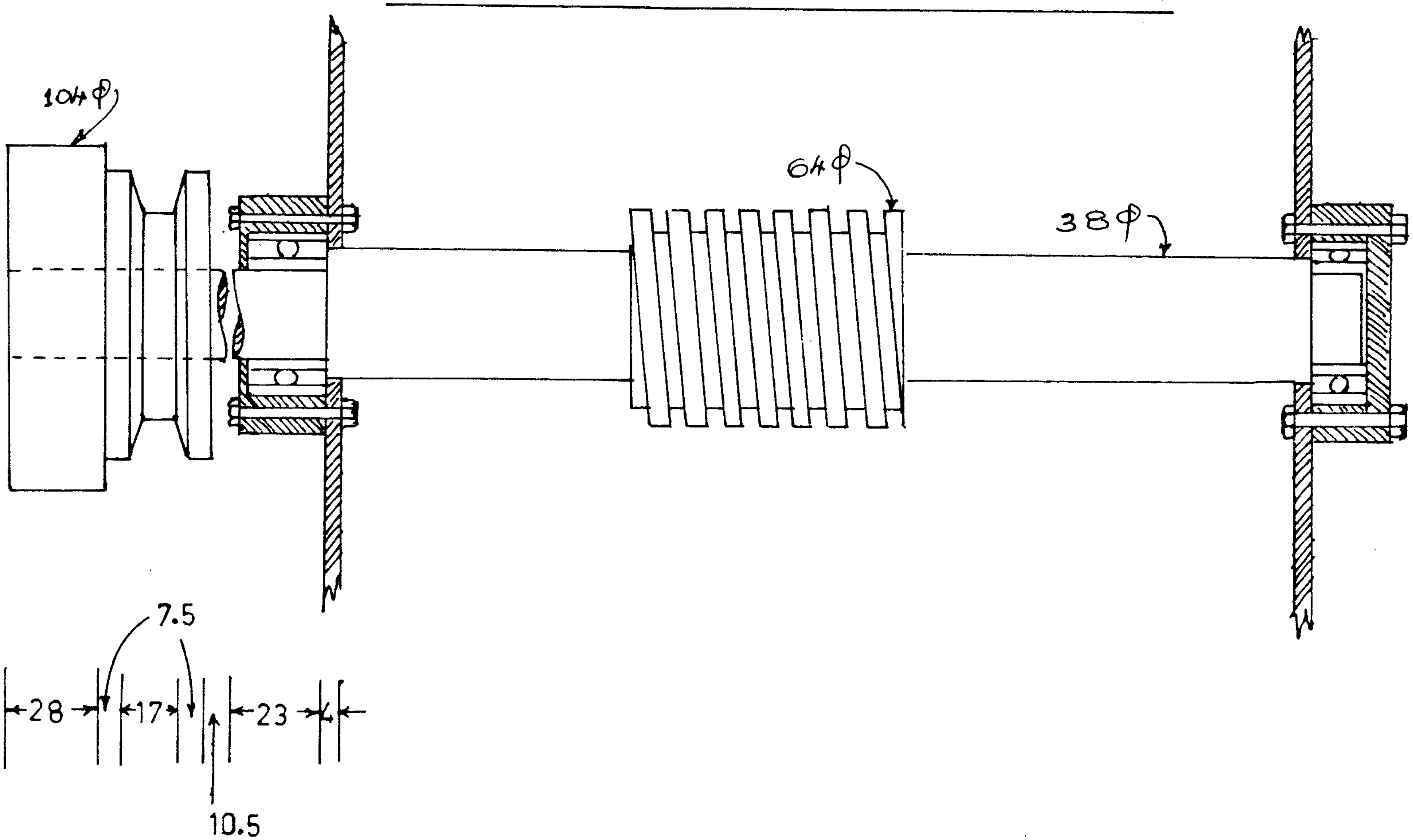


Dimensions in - mm

Scale - 1:2

FIG- 13

INPUT SHAFT (With Bearing & Pulley)

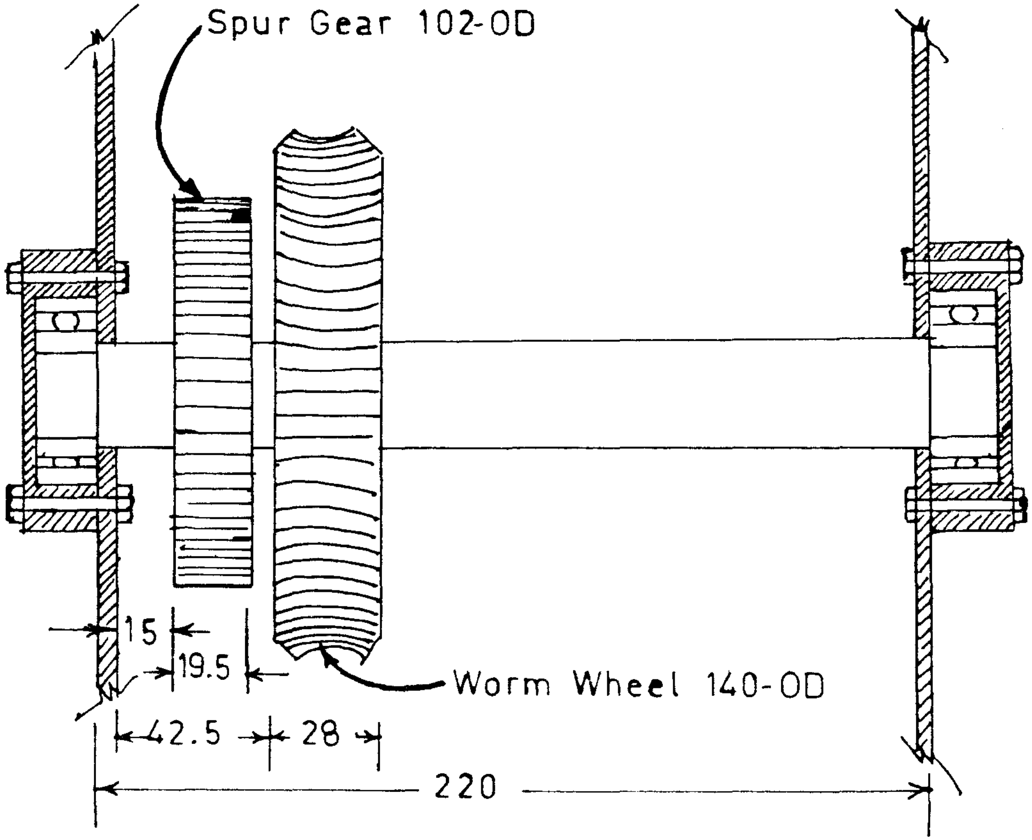


Dimensions in-mm

Scale 1:2

FIG-14

COUNTER SHAFT NO: 1 (With Gears & Bearings fitted)

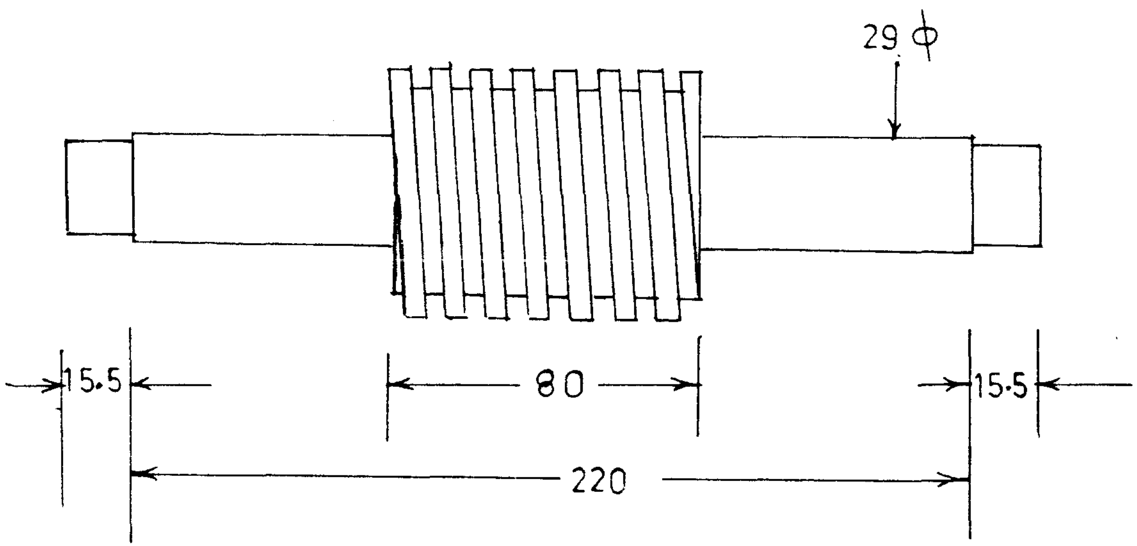


Dimensions in-mm

Scale-1:2

FIG-15

COUNTER SHAFT NO: 2

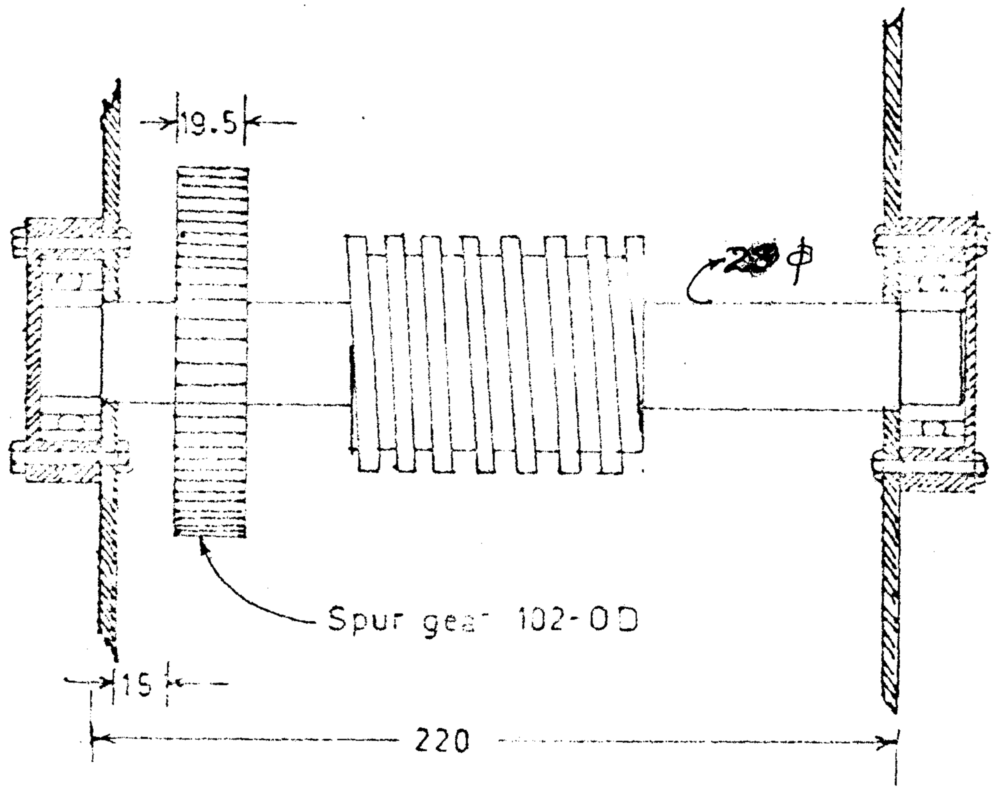


Dimensions in - mm

Scale - 1 : 2

FIG-16

Counter shaft NO: 2 (With Bearings)



Dimensions in-mm

Scale - 1: 2

The design should be checked from the stand point of strength, wear and heat dissipation considerations

Pitch line velocity of the gear $= \frac{\pi DN}{60}$

$= \frac{\pi \times 12 \times 1440}{100 \times 60 \times 40}$

$= 0.226$ metres/second

Velocity factor $= \frac{3}{(3 + v)}$

$= \frac{3}{(3 + 0.226)}$

$= 0.93$

Form factor of the gear $= 0.124 - \frac{0.684}{\text{number of teeth}}$

$= 0.124 - \frac{0.634}{40}$

$= 0.107$

Permissible stress = Static stress x velocity factor

(Assumed static stress = 1400 kg/cm^2)

Permissible stress (f) = 1400 x 0.93

= 1302 kg/cm^2

According to 'Lewis' formula tangential tooth load

f = f.b.p.y.

Where b = face width

p = circular pitch

y = form factor

$F = f.b.p.y.$

$= 1302 \times 2.8 \times 0.94 \times 0.107$

$= 366.67$

Horse power x transmitted $= \frac{366.67 \times \text{pitch line velocity of the gear}}{75}$

$= 366.67 \times \frac{0.226}{75}$

$= 1.1049$ h.p.

1.1049 h.p. $>$ 0.5 h.p.

hence safe

Check for wear $F = dg \times b \times W$

Where F = Limiting load for wear

W = A constant depending up on the materials of gear and worm

Assumed $W = 7$

$F = 12 \times 2.8 \times 7 = 235.2$

Horse power due to wear $= \frac{235.2 \times 0.226}{75}$

$= 0.709$ h.p

0.709 h.p. $>$ 0.5 h.p.

hence safe

Check for heat dissipation

The permissible input power for heat dissipation is given by

Horse power $= \frac{2C^{1.7}}{R+5}$

Where C = Centre distance in cm and

R = Speed reduction ratio

Horse power $= \frac{2 \times 8^{1.7}}{40 + 5}$ = 1.52 h.p.

The value being more than required the design is safe

h) Screw conveyer gear

Assumed velocity ratio = 10

centre distance = 5 cm

Mean diameter of the worm, given by, dw $= \frac{C^{0.875}}{1.89}$

Where C = Centre distance between the axis of the worm on in cm,

Assumed C = 5 cm

dw $= \frac{5^{0.875}}{1.89}$ = 2.16

The circular pitch of the wheel is such that,

$3\ p_c$ = dw

dw = 2.16

$p_c = \frac{2.16}{3}$ = 0.72 cm

Pitch circle diameter of the gear dg found out from

$\frac{d_w + d_g}{2}$ = C

Where C = Centre distance

$5 \times 2 = 2.16 + d_g$

$d_g = 10 - 2.16 = 7.84$ cm

Velocity ratio $= \dfrac{\text{number of teeth on gear}}{\text{number of starts on worm}}$

Number of teeth on gear = velocity ratio x number of starts on worm

Number of start on worm, assumed to be 2 (double start)

Number of teeth on gear = 10 x 2

= 20 (velocity ratio taken as 10)

Pitch of the gear $= \dfrac{\pi \times d_g}{\text{number of teeth}}$

$= \dfrac{\pi \times 7.84}{20} = 1.23$ cm

Module, $m = ?$

$p_c = m$

$m = \dfrac{1.23}{\pi} = 0.39$ cm

Choose a module of 4 mm

Circular pitch $p_c = \pi \times m = 1.26$ cm

Axial pitch of the worm = Circular pitch of the gear

= 1.26 cm

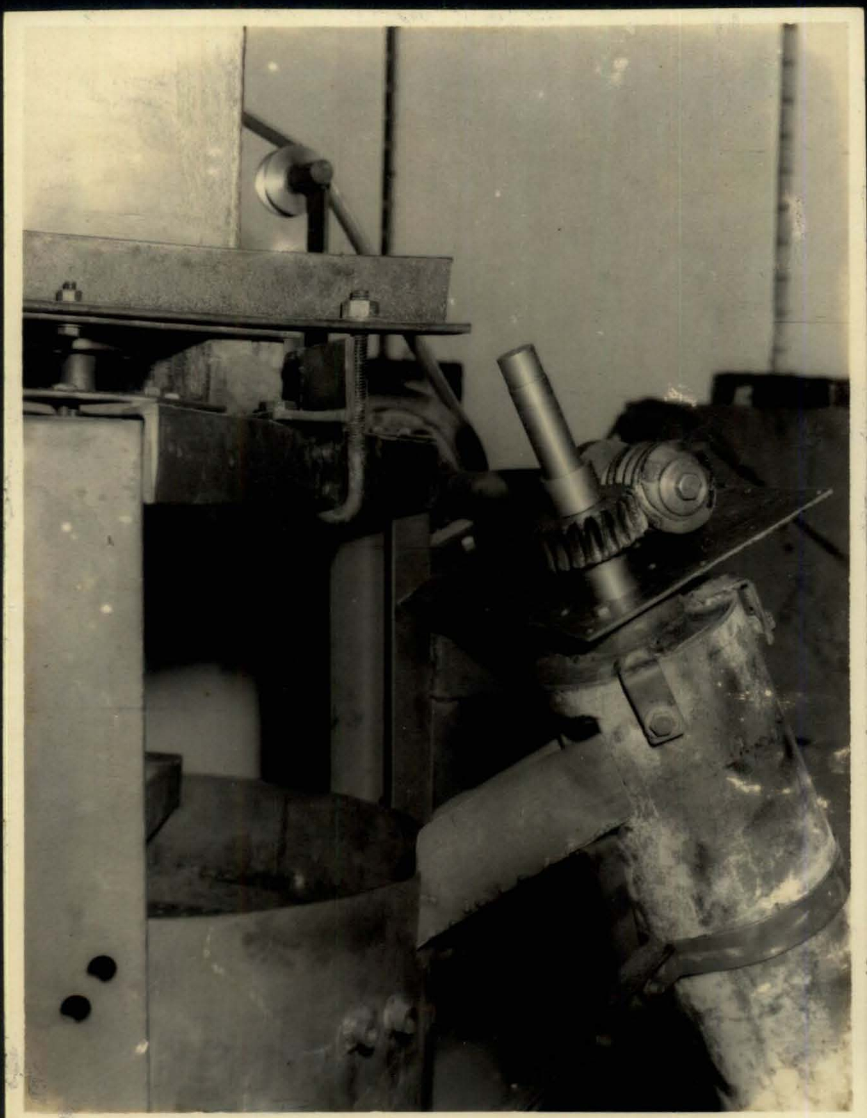
$p_c = \dfrac{\pi \times d_g}{20}$

$d_g = \dfrac{1.26 \times 20}{\pi} = 8$ cm

$\frac{d_w + d_g}{2}$	$= c$
$d_w + d_g$	$= 2\ c$
d_w	$= 2\ c - d_g$
d_w	$= 10 - 8 \quad = 2$ cm
Pitch diameter integral with shaft D_w	$= 2.35\ p + 1$
	$= 2.35 \times 1.26 + 1$
	$= 4$ cm
Face length of worm	$= (4.5 + 0.02 \times N_w)\ p$
	$= (4.5 + 0.02 \times 20)\ 1.26$
	$= 6$ cm
Depth of tooth h	$= 0.686\ p$
	$= 0.686 \times 1.26 \quad = 0.864$ cm
Addendum 'a'	$= 0.318\ p$
	$= 0.318 \times 1.26 \quad = 0.4$ cm
Outside diameter of worm gear	
Do	$= D_g + 1.0\ \ 135\ p$
	$= 8 + 1.0135 \times 1.26$
	$= 9.28$ cm
Normal pressure angle of worm gear	$= 14\frac{1}{2}°$
Face width in cm, 'b'	$= 2.38\ p + 0.65$
	$= 30$ cm

(Plate 10).

Plate 10. Agitation type multistage drier - reduction gear of screw conveyer



The design should be checked from the stand point of strength, wear and heat dissipation consideration.

Pitch line velocity of the gear $= \frac{\pi DN}{60}$

$= \frac{\pi \times 8 \times 720}{100 \times 60 \times 10}$

$= 0.302$ metres/second

Velocity factor $= \frac{3}{3 + v} = \frac{3}{3 + 0.302}$

$= 0.91$

Form factor of the gear $= 0.124 - \frac{0.684}{\text{number of teeth}}$

$= 0.124 - \frac{0.684}{20}$

$= 0.09$

Permissible stress = Static stress x velocity factor

Assumed static stress $= 1400\ kg/cm^2$

Permissible stress (f) $= 1400 \times 0.91 = 1274\ kg/cm^2$

According to 'Lewis' formula

Tangential tooth load F = f.b.p.y.

Where b = Face width

p = Circular pitch

y = Form factor

F $= \underline{1274} \times 3 \times 0.09 \times 1.26$

$= 433.41$

Horse power transmitted $= \frac{433.41 \text{ x pitch line velocity of the gear}}{75}$

$= \frac{433.41 \times 0.302}{75}$

= 1.75 h.p.

1.75 h.p. > 0.5 h.p.

hence safe

Check for wear

Limiting load for wear 'f' is given by the formula,

	F	$= d_g \times b \times w$
	W	= a constant depending upon the materials of the worm
Assumed,	W	= 7
	F	= 8 x 3 x 7 = 168

Horse power due to wear $= \frac{168 \times 0.302}{75}$

= 0.677 h.p.

0.677 h.p. > 0.5 h.p.

hence safe

Check for heat dissipation

The permissible input power for heat dissipation is given by

Horse power $= \frac{2\ c^{1.7}}{R + 5}$

Where C = centre distance in cm

R = speed reduction ratio

Horse power $= \frac{2 \times 5^{1.7}}{10 + 5} = 2.1$ h.p.

2.1 h.p. > 0.5 h.p.

hence safe

i) Heating coil

Assuming the moisture content of freshly fermented beans to be 55 per cent and the recommended moisture content for safe storage to be six per cent

Capacity of the drier = 90 kg

Amount of moisture to be removed, calculated by the following formula

$$m = \frac{Q1\ (Mwb_1 - Mwb_2)}{(1 - Mwb_2)}$$

Where m = Amountoof moisture removed in kg

Mwb_1 = Initial moisture content

Q_1 = Capacity of the drier in kg

∴ Amount of moisture removed $= \frac{Q1\ (Mwb_1 - Mwb_2)}{(1 - Mwb_2)}$

$$= \frac{90\ (0.55 - 0.06)}{1 - 0.06)}$$

= 46.91 kg

Assuming the latent heat of vapourisation of water while drying to be 600 Kcal/kg of water the thermal efficiency of the drier to be 50 per cent, the heat energy required to dry 90 kg of beans from an initial moisture content of 55 per cent to a final moisture content of 6 per cent

$$= \frac{m \times 600}{\eta_t}$$

$$= \frac{46.91 \times 600}{0.5}$$

$$= 56292 \text{ K.calories}$$

But 860 K.calories = 1 KWH

∴ Electric energy required $= \frac{56292}{860}$

$= 65.45$ KWH

Assuming the total drying time required to be 15 hours.

∴ The heating coil capacity $= \frac{65.45}{15} = 4.36$ KW

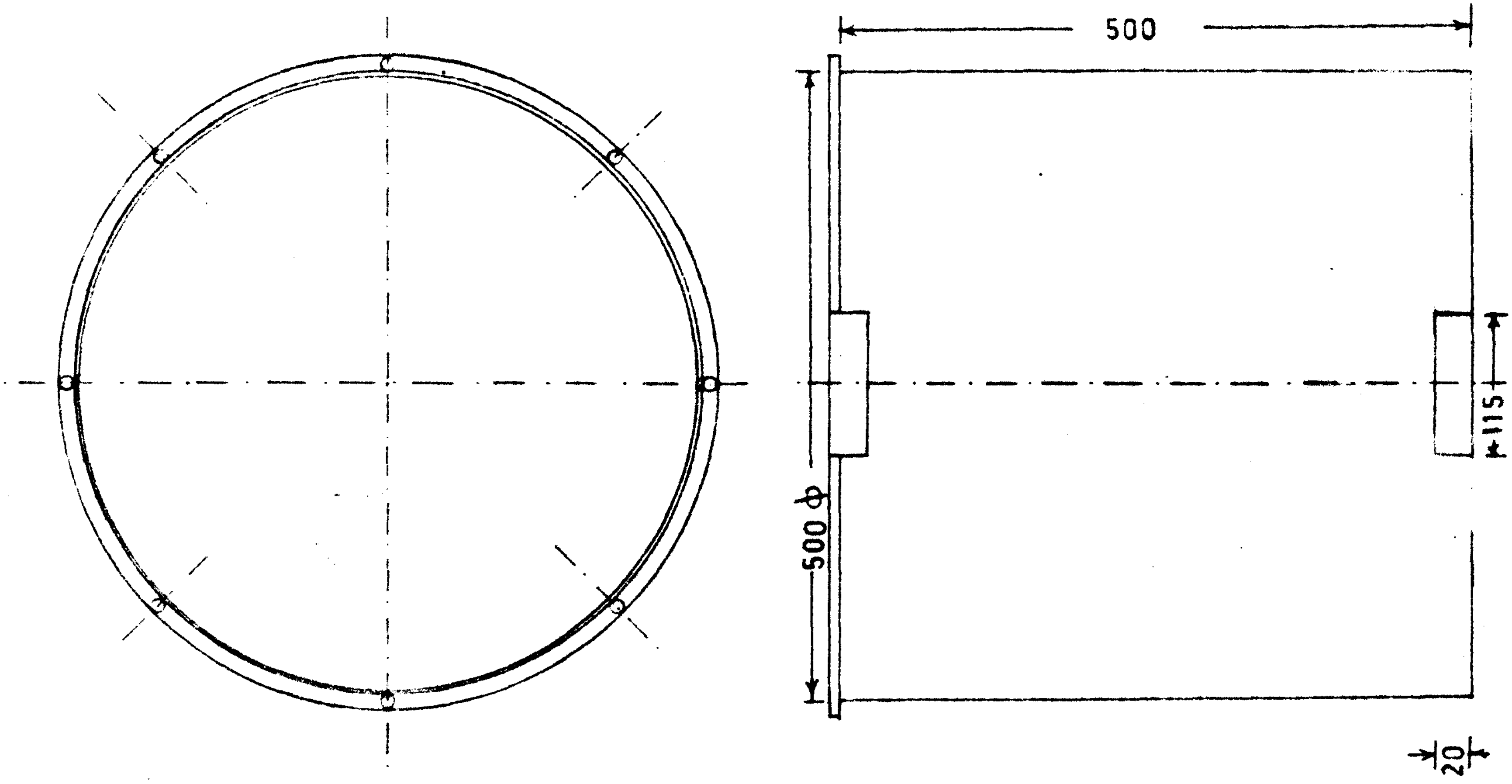
∴ The heating coil capacity, taken as 4.5 KW

3.2.6.1.2 Fabrication

The drier mainly consisted of a drying section, agitator, screw conveyer, a heater and a blower. The drying unit having 50 cm diameter was made of 8 gauge M.S. sheet and was cylinderical in shape (Fig. 17). This cylinder was framed on a three legged C. channel stand of size, 153 cm height and 7.6 cm width (Fig. 18 and 19).

FIG 17

MAIN CYLINDER

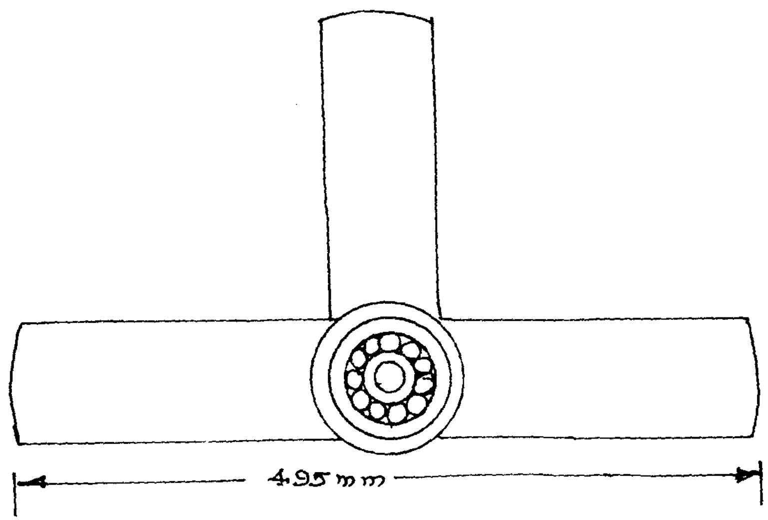


Dimensions in-mm

Scale. 1:5

FIG-18

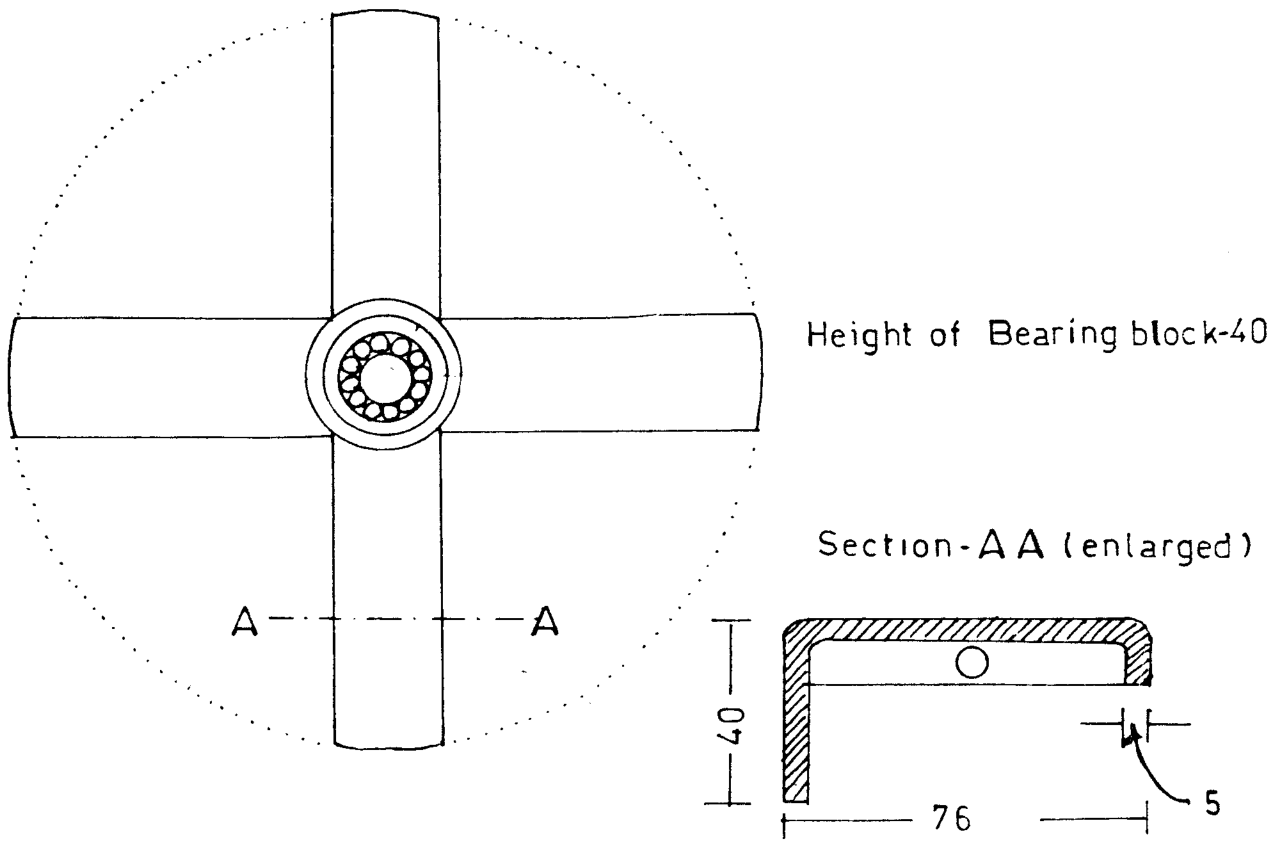
MAIN SHAFT SUPPORT (TOP)



Scale 1:5

FIG-19

MAIN SHAFT SUPPORT (BOTTOM)



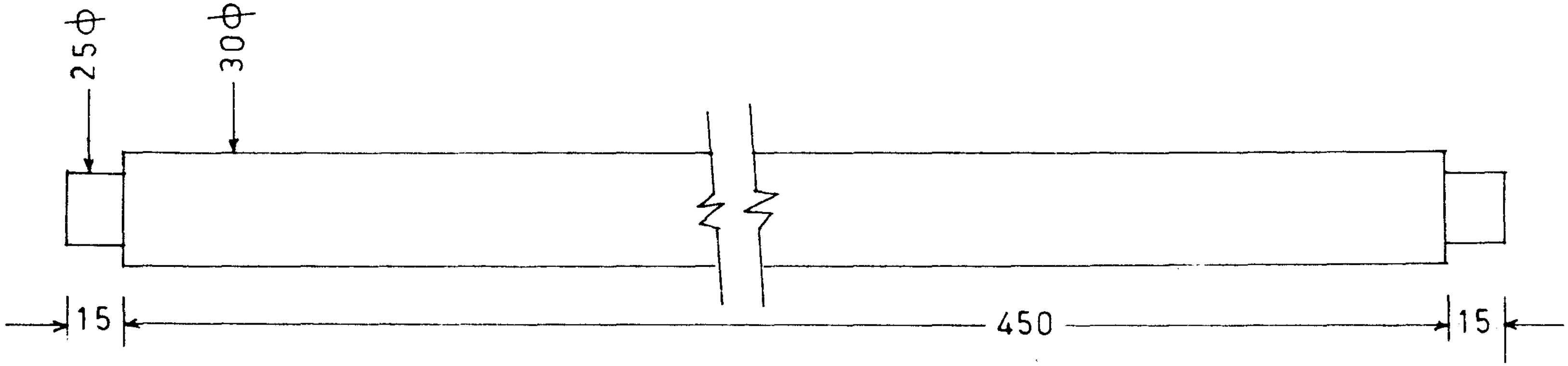
Dimensions in -mm

Five perforated circular plates having 2 mm thickness were placed horizontally inside the cylinder. The plates were placed in such a way that the distance between them were equal. Above these Plates a scraper and a wiper were fixed on a vertical shaft (Fig. 20). The vertical shaft was rotated at 0.9 r.p.m. by a 1 h.p. motor through a reduction gear box. This facilitated necessary mixing for the beans. The plates were provided with radial slots of size 4 x 6 x 24.5 cm. The fermented beans after passing through each plate for about 350° dropped to the next bottom plates through each slot, finally falling to the chute provided at the bottom which carried them to the bottom of the screw conveyer against the heated air.

Below the bottommost disc a chute was provided for conveying the beans to the screw conveyer. The screw conveyer was made of 12.8 cm diameter M.S. tube and 145 cm length fitted inclined to the drying unit at an angle of 45°. The screw conveyer was having a spiral, with a 25 mm diameter central shaft. The beans were lifted by the conveyer and discharged at the top of the drying unit. This cycle was continued till the beans were uniformly dried to the required moisture content. The blower was driven by a 0.5 h.p. electric motor to supply necessary air draught.

FIG-20

MAIN SHAFT



Dimensions in-mm

Scale-1:2

The heater in front of the blower, was having a capacity of 4.5 KW (1.5 KW, 3 KW and 4.5 KW). An air duct was provided from the heater to the drying unit (Fig. 21).

The motor speed of 1440 rpm was reduced in stages, and the output shaft that drove the spindle rotated at 0.9 rpm. The conveyer was belt driven from the same motor through worm and gear reduction. The worm rotated at 720 rpm because of the belt drive. The reduction from 720 to 72 rpm was achieved by worm and gear unit (Fig. 22).

3.2.6.1.3 Operation

The fermented beans were supplied to the top plate after switching of the motor, blower and the heater. As the main shaft was rotated, the wiper spread the beans evenly on the plate. At the same time the scraper swept the beans and passed them to the next plate. This operation was continued from one plate to the other until they reached the bottom of the drying unit. The beans from the bottom of the drier found its way through the chute to the screw conveyer. The conveyer conveyed the materials again to the top plate of the drier. The operation was repeated.

FIG-21

BLOWER DUCT

All Dimensions in CM
Scale – 1 : 10

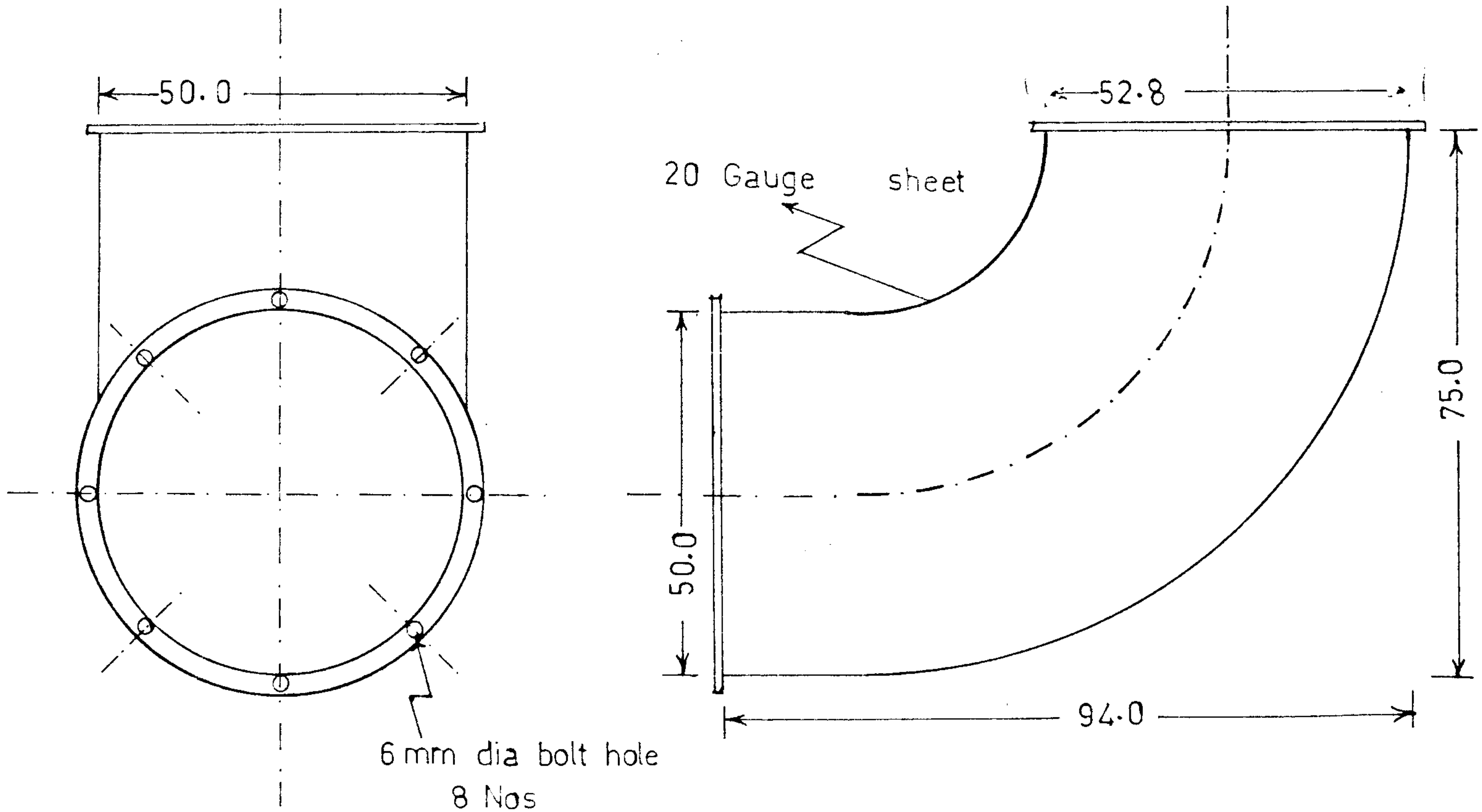
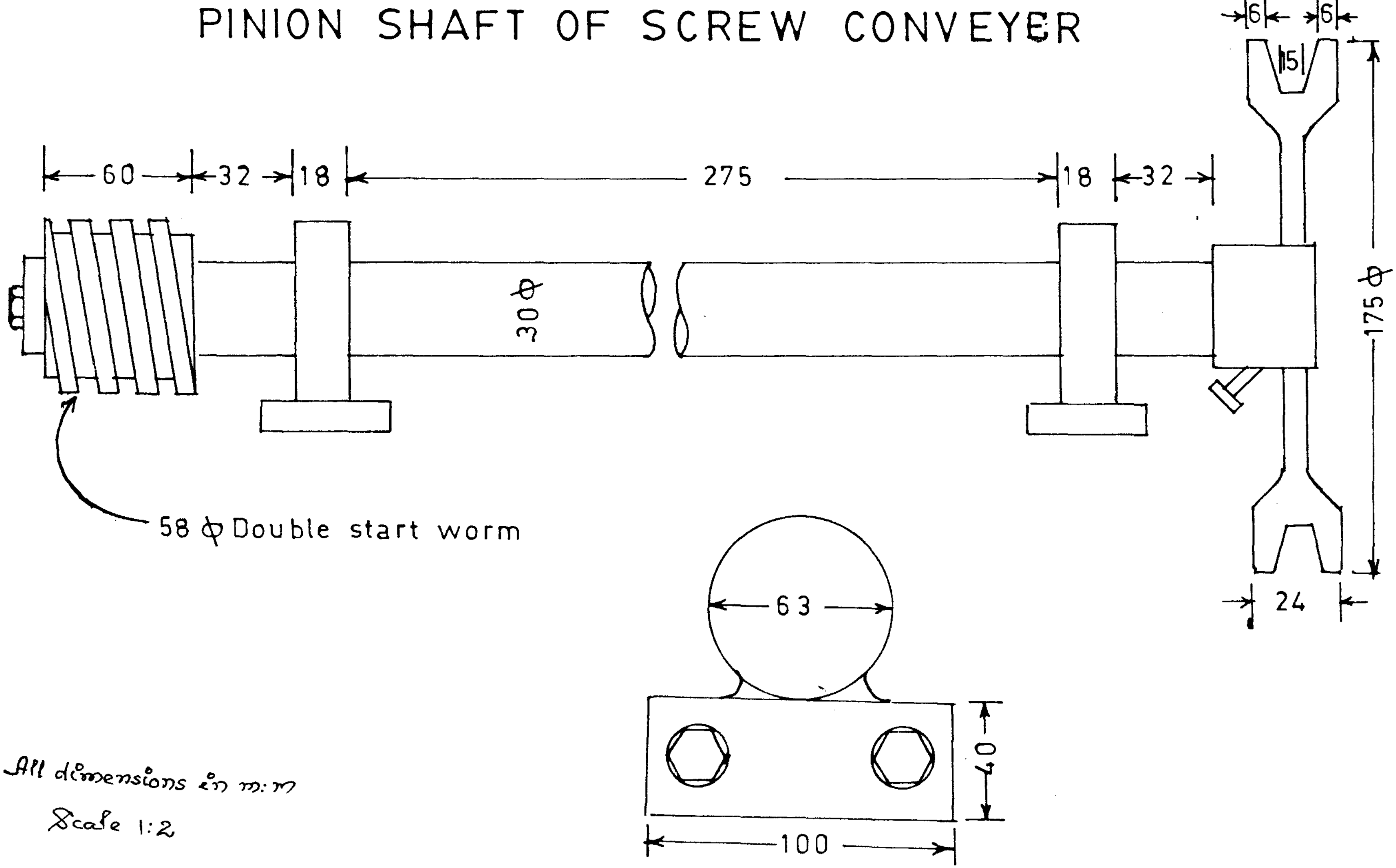


FIG-22

PINION SHAFT OF SCREW CONVEYER



All dimensions in m:m

Scale 1:2

The blower transported the heat energy produced by the heater through the air duct into the drying chamber. Hence, as the beans passed through the plates they were dried with the outgoing heated air. The heat energy in the heater was absorbed, in stages by the beans. Due to the absorption of heat in stages the energy loss in the outgoing air was reduced to a low value.

3.2.6.1.4 Testing

The beans after fermentation were put on the top plate after starting the motor blower, and the heater. The quantity of cocoa beans used was 90 kg. Air flow was 0.4 m^3/second and the inlet temperature was maintained at 56°C. Inlet temperature, intermediate temperatures and outlet temperature were recorded. The humidity of the heated air in different stages were noted and tabulated. A ½ h.p. variable speed motor was used on the prime mover of the blower. The quantity of air varied with the help of the variable speed motor, by running at different levels of speed (Plate 11).

During the first set of experiment 90 kg of fermented cocoa beans was loaded on the top of the drier. Air flow rate was adjusted to 0.4 m^3/second by adjusting the speed of the motor. The temperatures at different stages were noted.

Plate 11. Test on Agitation type multistage drier.- Also showing screw conveyer, chute, main cylender etc.

At every hours of interval the moisture losses were also calculated.

The test was repeated, at the following levels of operation (Plate 12).

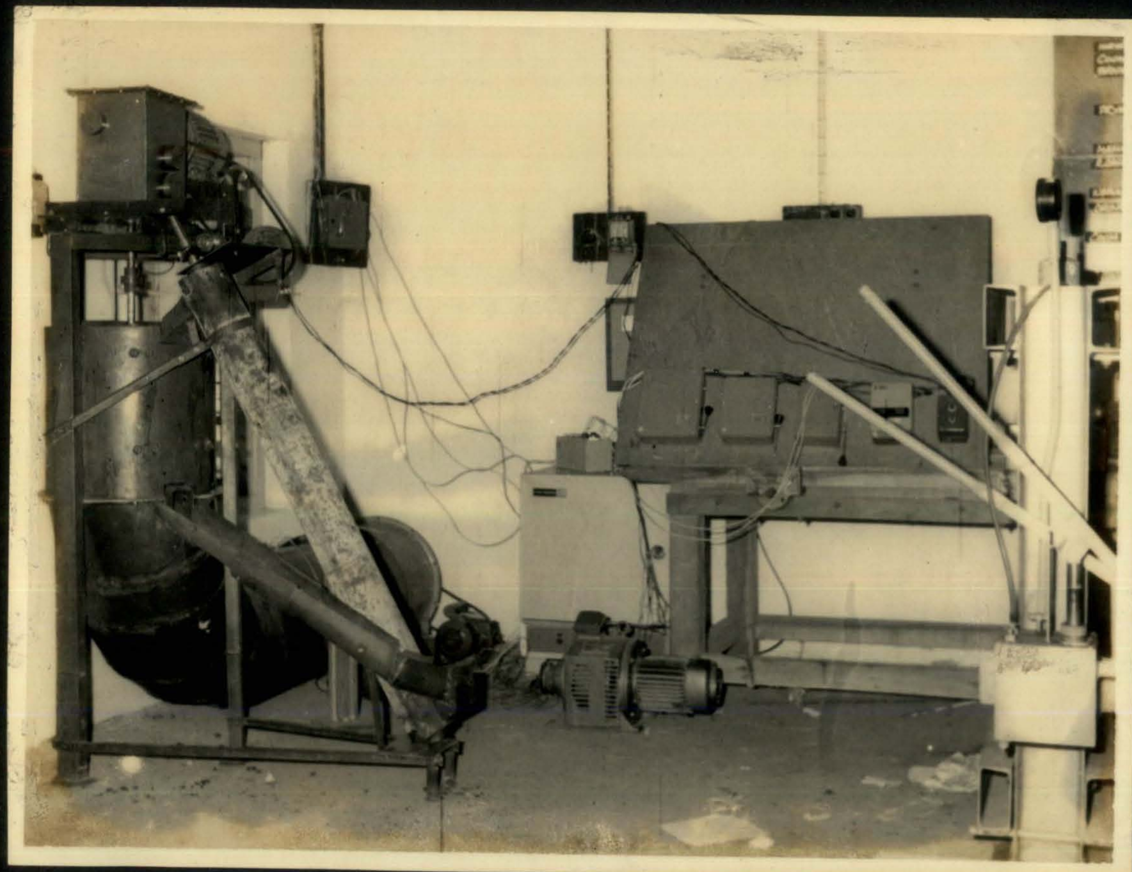
Quantity (kg)	Initial temperature (°C)	Air flow m^3/Sec.
90	56	0.4
90	47	0.4
90	42	0.4
60	56	0.4
60	47	0.4
60	42	0.4
90	56	0.2
90	47	0.2
90	42	0.2
60	56	0.2
60	47	0.2
60	42	0.2

3.3.6.2 Agitation type multistage drier (capacity 2000 kg)

One of the objectives of this project was to evolve suitable design of equipment for drying large quantities of cocoa beans.

With this in view an agitation type multistage drier of capacity 2000 kg of fermented beans was designed (Appendix-I), and its economics worked out.

Plate 12. Experimental set-up of Agitation type multistage drier



Results and Discussion

RESULTS AND DISCUSSION

During the conduct of this research work the following results were obtained.

4.1 Fermentation

The results of the experiments conducted on fermentation using mini box method are given in Table 1 .

A graph showing the temperature variations is given in Fig. 23. The mean weight loss during fermentation was 30.2 per cent (Table 2). The quality of the beans after fermentation was found satisfactory in the cut test.

The maximum temperature attained during fermentation was 46°C and fluctuations in temperature were noticed up to seventh day. 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. This could be due to the smaller size of the boxes used 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.

Table 1. Temperature variations during fermentation

Time (hours)	Temperature (°C)				
	Box I 2 kg	Box II 5 kg	Box III 11 kg	Box IV 16 kg	average
0	30.0	30.0	30.0	30.0	30.0
8	30.0	30.0	30.0	30.0	30.0
16	30.5	30.0	31.0	30.5	30.5
24	34.0	32.0	31.0	31.0	32.0
32	34.0	34.0	33.0	33.0	33.5
40	36.0	35.0	34.0	36.0	35.25
48	35.0	35.0	36.0	36.0	35.5
56	39.0	39.0	37.0	37.0	38.0
64	45.0	45.0	43.0	41.0	43.5
72	44.0	44.0	45.0	45.0	44.5
80	43.0	43.5	44.5	45.0	44.0
88	44.0	42.0	40.0	42.0	42.0
96	38.0	38.0	39.0	41.0	39.0
104	39.0	40.5	42.0	42.5	41.0
112	44.0	43.0	42.0	43.0	43.0
120	47.0	46.0	46.0	45.0	46.0
128	43.5	44.5	46.0	46.0	45.0
136	43.5	44.0	44.0	43.0	43.5
144	44.0	44.0	44.0	44.0	44.0

FIG. No. 23

GRAPH No. 1

TEMPERATURE VARIATION CURVE DURING FERMENTATION

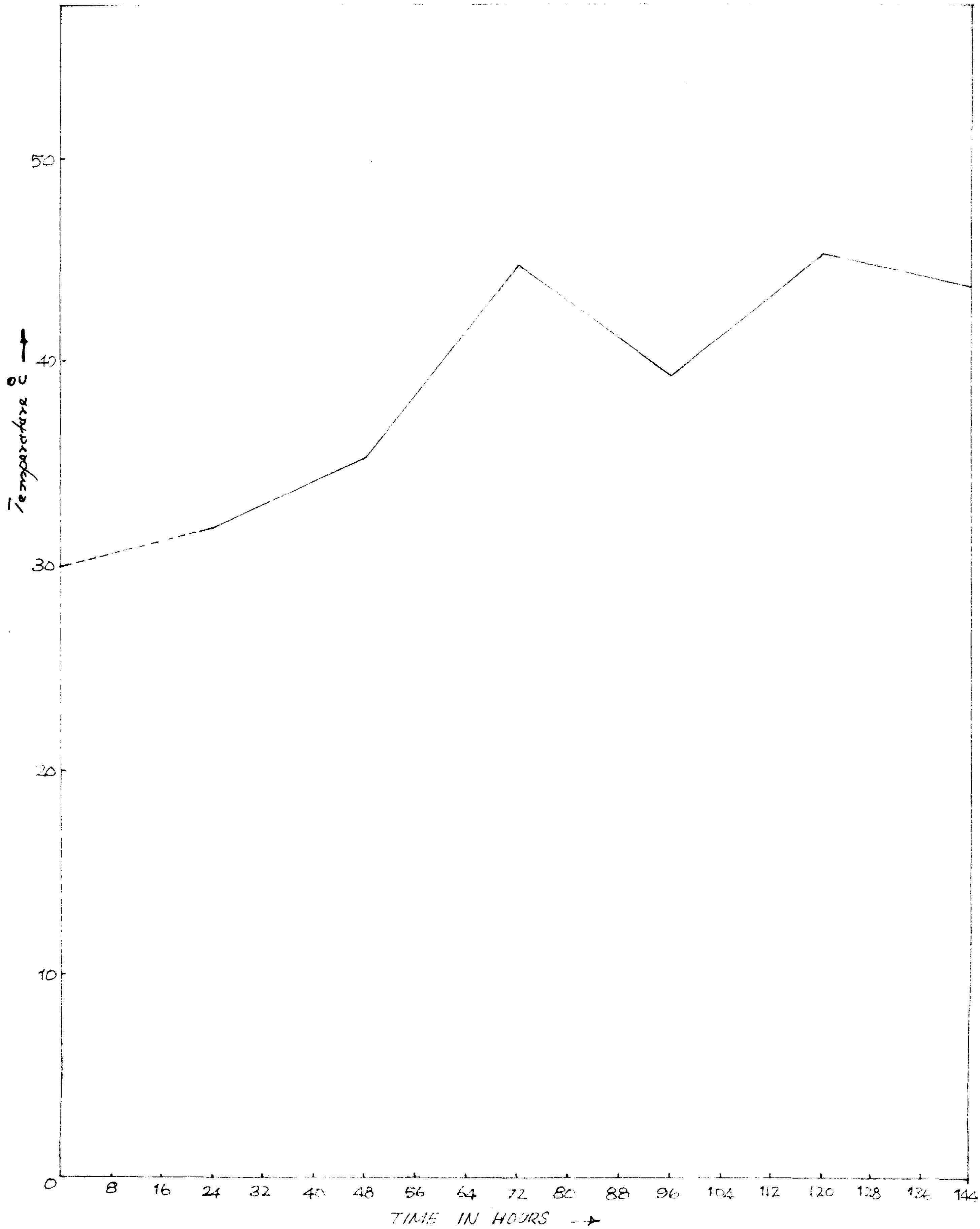


Table 2. Mean weight loss during fermentation

Weight of wet beans (kg)	Weight of fermented beans (kg)	Weight loss (%)
16	11.04	30.8
11	7.70	30.0
5	3.50	30.0
2	1.40	30.0

4.2 Drying

4.2.1 Sun drying

The results of the experiment on sun drying of cocoa beans are given in Table 3 and are graphically recorded in Fig. 24.

The weight of beans reduced from 30.0 kg to 14.64 kg in seven days, showing a moisture loss of 51.2 percent (Table 3 and Fig. 24). The result is comparable with the standard data available on sun drying of cocoa beans. Though the method of sun drying is cheap, it requires constant attention. The duration of drying is dependent on atmospheric weather conditions. Final pH of the sun dried beans was 5.2 which was very close to the pH range, 5.3 to 5.5 for good quality beans as per international standards. Hence, the quality of the beans was considered satisfactory.

4.2.2 Bulb heated drier

The results of drying cocoa beans with bulb heated drier are given in Table 4 and are graphically represented in Fig. 25.

Table 3. **Sun drying of fermented cocoa beans moisture loss vs. time,**

Days	Weight before drying (kg)	Weight after drying (kg)	Cumulative Moisture loss (%)	pH
1	30.00	22.80	24.00	
2	23.00	17.00	43.33	
3	17.30	16.20	46.00	
4	16.20	15.45	48.50	
5	15.45	15.09	49.70	
6	15.09	14.79	50.70	
7	14.79	14.64	51.20	
8	14.64	14.64	51.20	5.20

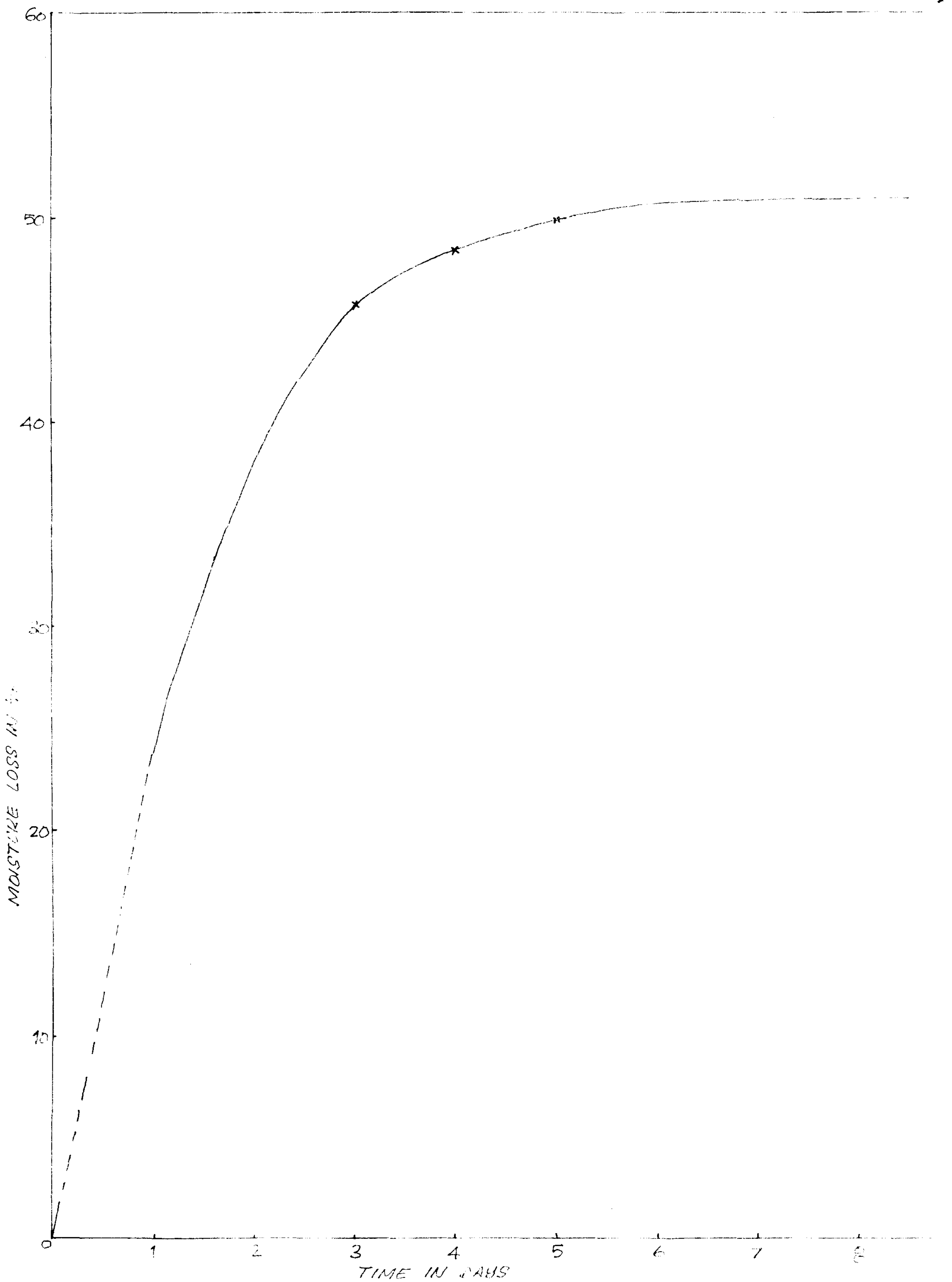
Table 4. Drying of fermented cocoa beans using bulb heated drier, moisture loss vs. time, [illegible]

Time (hours)	Moisture content
0	54.0
3	45.0
6	38.0
9	32.0
12	25.0
15	21.0
18	18.0
21	16.0
24	14.0
27	13.0
30	10.4
33	9.0
36	8.6
38	7.6

GRAPH No. 2

SUN DRYING - TIME VS MOISTURE LOSS IN %

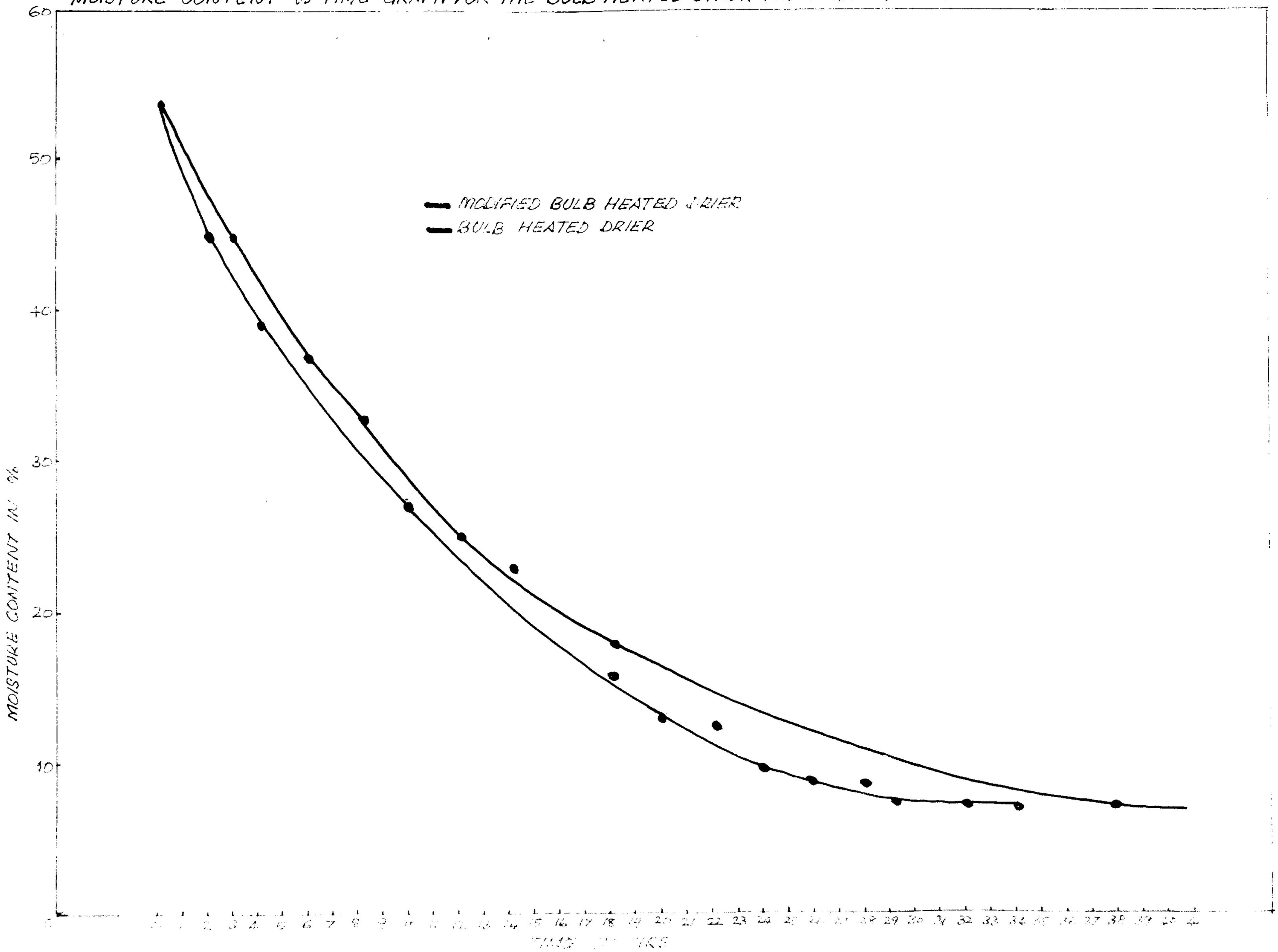
FIG. No. 2A



GRAPH No. 3

FIG. No. 25

MOISTURE CONTENT Vs TIME GRAPH FOR THE BULB HEATED DRIER AND MODIFIED BULB HEATED DRIER



From the graph and the table it can be observed that the moisture content of about 7.6 per cent was achieved in 38 hours of drying. The result revealed that for drying one kilogram of fermented beans, approximately 0.76 K.W.H. of electrical energy was necessary. Bulb heated driers require less time for drying cocoa beans compared to sun drying. pH of the dried beans was 5.00.

4.2.3 Modified bulb heated drier

The results of the experiments conducted on this drier are given in Table 5, and they are graphically represented in Fig. 25.

Thirty kilogram of fermented beans could be dried to 7.6 per cent moisture level in a period of 34 hours in the modified bulb heated drier (Table 5, Fig. 25).

For drying one kilogram of fermented beans in this drier 0.566 K.W.H. of electrical energy is required, whereas the bulb heated drier required 0.76 K.W.H. of energy per kilogram of fermented beans. Hence about 0.195 K.W.H. of energy can be saved per kilogram of fermented beans, which means that there is a net saving of about 25 per cent of energy. Hence the cost of drying can be reduced. pH of the dried beans was 5.00.

Table 5. Moisture reduction table for the modified bulb heated drier

Time (hours)	Moisture content (%)
0	54.0
2	45.0
4	39.0
6	37.0
8	33.0
10	27.5
12	26.0
14	23.0
16	20.0
18	16.0
20	13.0
22	12.5
24	10.0
26	9.0
28	8.2
30	7.9
32	7.6
34	7.6

In the drier where the bulbs are used as a heat source are least efficient for heating, because most of the energy produced by the bulb is in the form of light energy. The radiant heat produced by the bulb alone can be used for raising the temperature of the air inside the drier. The advantage of this drier is that, it is easy to fabricate and operate. The maintenance cost also will be low. The life of the coil heated drier is more than the bulb heated drier. This modification also saves energy by 25 per cent.

4.2.4 Modified C.P.C.R.I. model electric heated drier

The results of the experiment on drying fermented beans using modified C.P.C.R.I. model are given in Table 6. A graph showing moisture loss vs time is given in Fig. 26. The moisture content and pH of the dried beans were 7.6 per cent and 5.10 respectively. Energy consumption of this drier was 0.5333 K.W.H./kg and cost of drying was minimum (Rs.0.36/kg)

The benefits of the modified drier over the C.P.C.R.I. drier are as follows:

1) In the C.P.C.R.I. model the temperature of the drying air is about 80°C which is not suitable for cocoa drying. In the modified drier, the drying temperature is only 55°C which is suitable for cocoa drying.

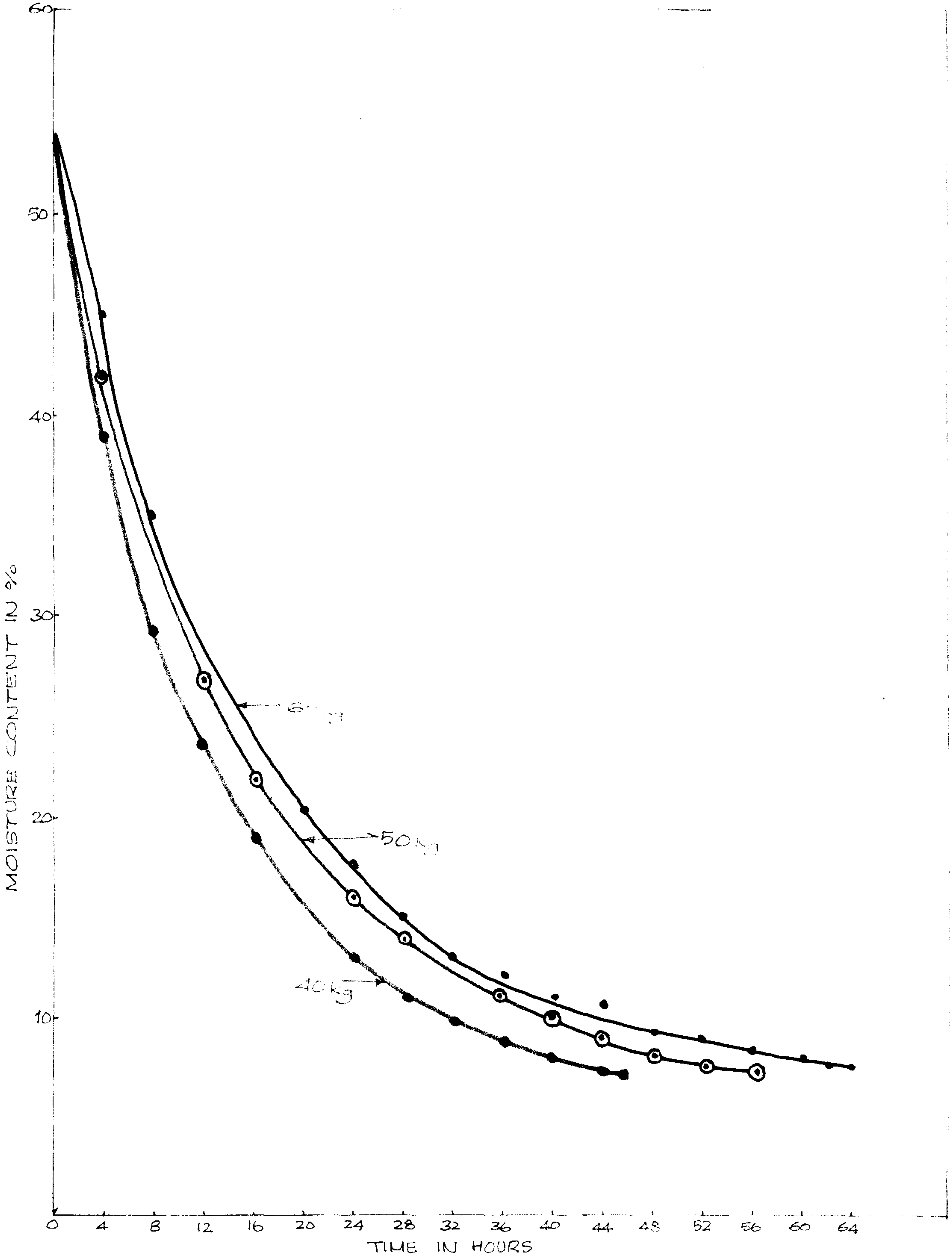
Table 6. Moisture reduction table for the modified C.P.C.R.I. model drier

Time (hours)	60 kg moisture content (%)	50 kg moisture content (%)	40 kg moisture content (%)
0	54.0	54.0	54.0
4	45.0	42.0	39.0
8	35.0	34.0	29.0
12	30.0	27.0	24.0
16	28.0	22.0	19.0
20	21.0	19.0	16.0
24	18.0	16.0	13.0
28	15.0	14.0	11.0
32	13.0	13.5	10.0
36	12.0	11.5	8.5
40	11.0	10.0	8.0
44	10.5	9.0	7.5
48	9.5	8.0	
52	9.0	7.5	
56	8.5		
60	8.0		
62	7.5		
64	7.5		

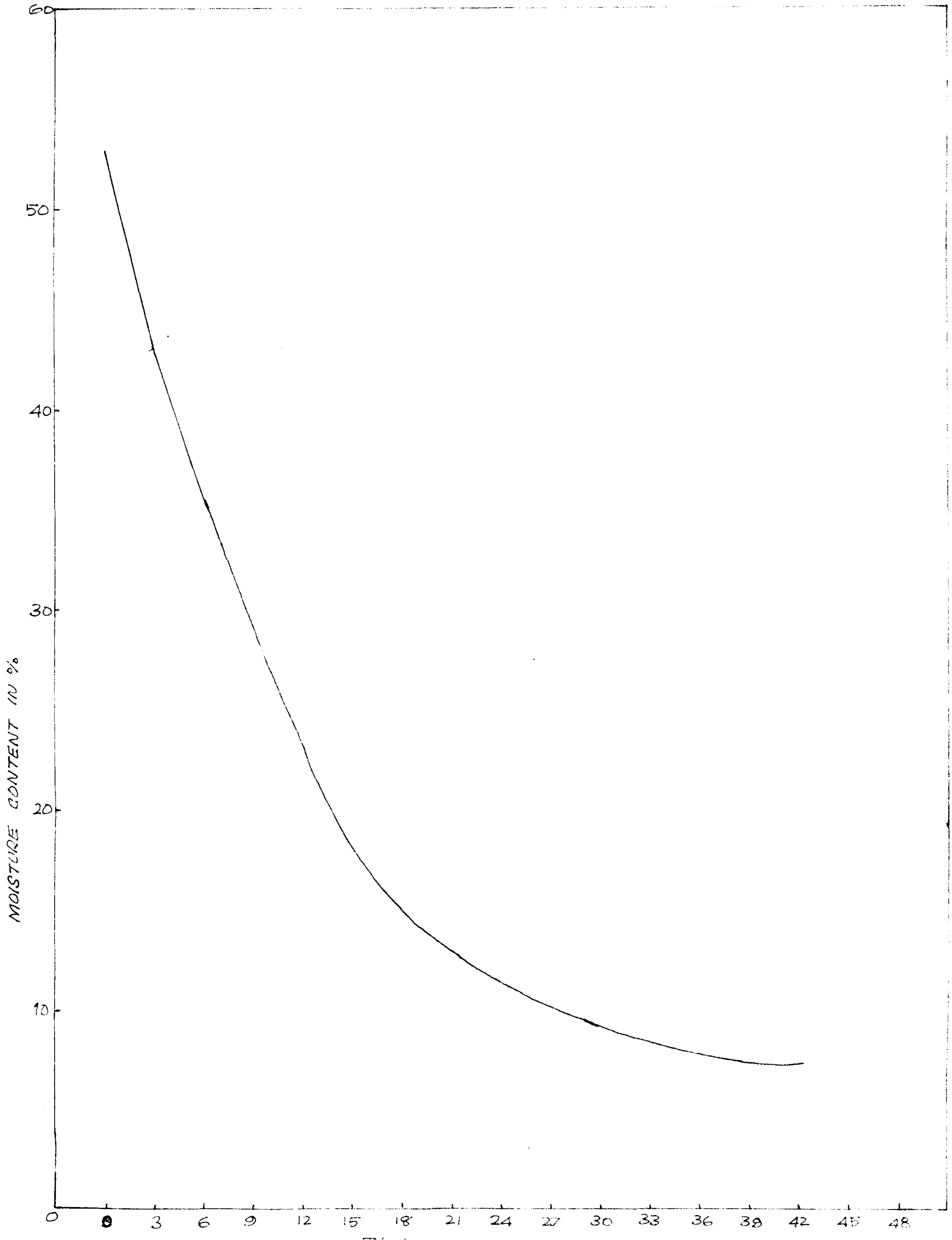
GRAPH No. 4

FIG. No. 26

MOISTURE CONTENT vs TIME GRAPH FOR THE MODIFIED [illegible] MODEL [illegible]



MOISTURE CONTENT vs TIME GRAPH FOR THE MODIFIED CPCRI MODEL DRIER WITH ½ HP ELECTRIC MOTOR AND BLOWER



2) The cost of fabrication of the modified drier is only Rs.1,250/- which is lower than that of C.P.C.R.I. model (Rs.1,500.00).

3) Instead of aluminium trays used in the C.P.C.R.I. model, wire meshes were used in the new model.

4.2.5 Modified C.P.C.R.I. model cocoa drier with blower

The changes in moisture content of fermented beans using modified C.P.C.R.I. model cocoa drier with electric motor are given in Table 7. A graph showing moisture loss vs time is furnished in Fig. 27. The moisture content of the dried bean was about 7.6 per cent which was achieved in 42 hours. The result showed that for drying one kg of fermented beans approximately 0.611 K.W.H. of electrical energy was necessary which was higher than modified C.P.C.R.I. model. The pH of the dried beans was 5.2 and cost of drying was 56 Ps/kg.

4.2.6 Agitation type multistage drier

The capacity of the drier was 90 kg. The results of the experiment for drying cocoa beans using this drier with 90 kg of fermented cocoa beans at 47°C with an air flow rate of 0.4 m^3/second are given in Table 8. The graphical representation of the result is also given

Table 7. Moisture content vs time, table for the modified C.P.C.R.I. model cocoa drier with blower

Time (hours)	Moisture content (%)
0	54.0
3	44.0
6	37.5
9	29.0
12	23.0
15	18.0
18	15.0
21	14.0
24	13.5
27	12.0
30	10.0
33	9.0
36	8.0
39	7.6
42	7.6

Table 8. Test on Agitation type multistage drier (Initial weight of cocoa beans 90 kg; Initial air temperature 47°C; Air quantity 0.4 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0												54.4
1	39.0	37.0	36.0	34.0	32.5	40	44.0	51.5	56.5	63.0	69.0	48.4
2	39.0	37.0	36.0	34.0	32.5	40	44.0	51.5	56.5	63.0	69.0	44.8
3	39.5	37.0	36.0	34.0	32.5	40	44.0	51.5	56.5	63.0	69.0	40.4
4	39.5	37.5	36.0	34.5	33.0	40	44.0	51.0	56.0	63.0	69.0	46.0
5	39.5	37.5	36.0	34.5	33.0	40	43.5	51.0	56.0	62.5	68.5	32.0
6	40.0	37.5	36.5	35.0	33.5	40	43.5	51.0	55.5	62.5	68.5	28.0
7	40.0	38.0	37.0	35.0	33.5	40	43.0	50.5	55.5	62.5	68.5	25.0
8	40.0	38.0	37.0	35.5	34.0	40	43.0	50.5	55.5	62.0	68.0	21.0
9	40.0	38.0	37.0	36.0	34.0	40	43.0	50.5	55.0	62.0	68.0	17.2
10	40.0	38.0	37.5	36.0	34.0	40	43.0	50.0	55.0	62.0	67.5	14.4
11	40.0	38.0	37.5	36.0	34.5	40	42.5	50.0	54.5	61.5	67.5	11.0
12	40.0	38.0	37.5	36.0	34.5	40	42.5	50.0	54.5	61.5	67.5	9.2
13	40.5	38.0	38.0	36.5	35.0	40	42.5	50.0	54.0	61.5	67.5	8.0
14	41.0	38.5	38.0	36.5	35.0	40	42.0	49.5	54.0	61.0	67.5	7.6
15	41.0	39.0	38.0	36.5	35.0	40	42.0	49.5	54.0	61.0	67.5	7.6

in Fig. 28 to 30. The moisture content of the beans was reduced from 54.4 to 7.6 per cent in 15 hours of operation.

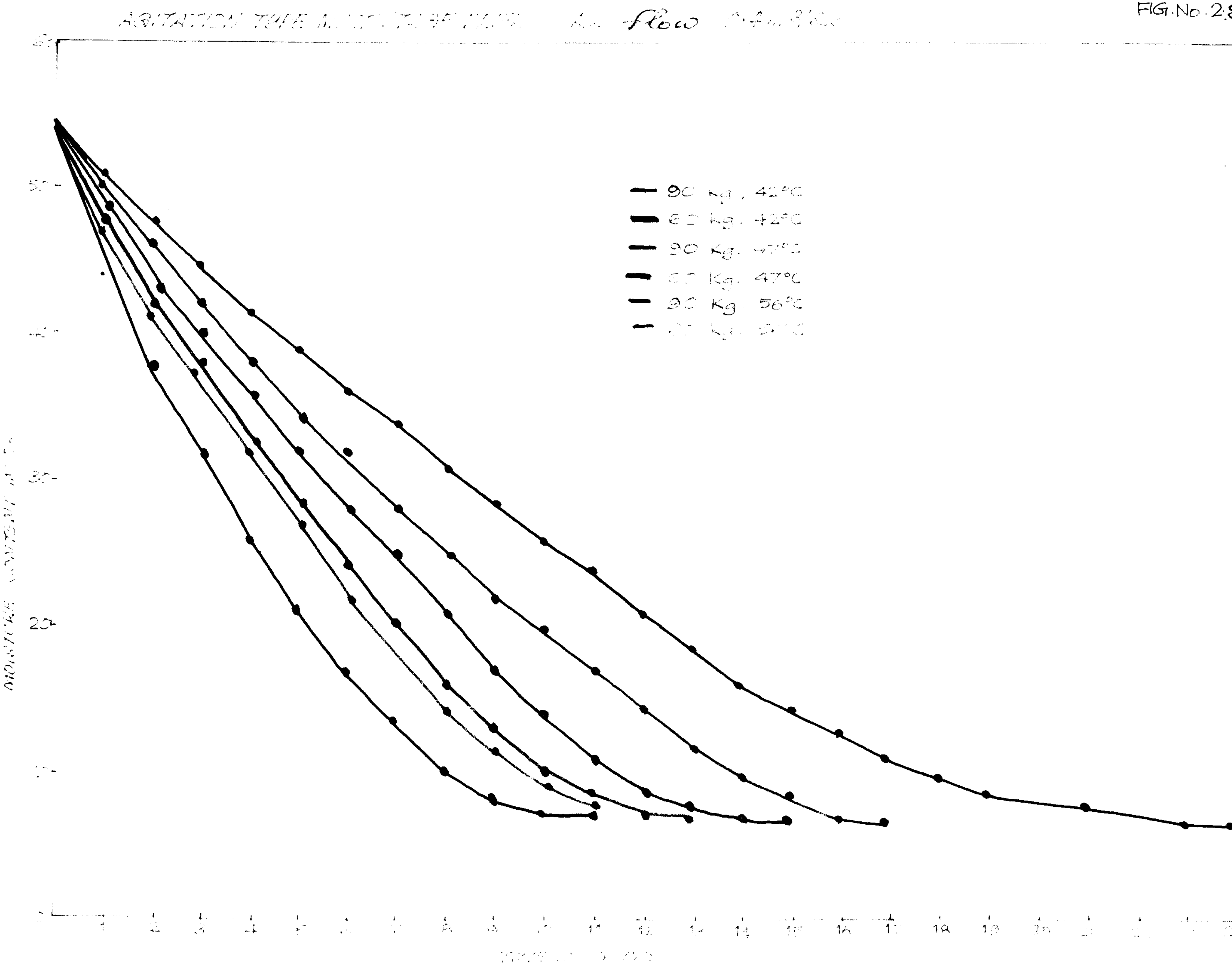
The atmospheric humidity during the experiment was 80 per cent. The humidity of the air and its temperature at various stages that is at the inlet, intermediate positions and at the outlet are given in Table 8, and graphically recorded in Fig. 29 and 30. The multistage drier conserved heat by 45 per cent which otherwise would have been wasted as in the other driers.

Also the results obtained for drying the beans at three temperatures (56°C, 47°C and 42°C), at two air flow rates (0.4 m^3/second and 0.2 m^3/second) and two quantities (90 kg and 60 kg) were also found out and were tabulated in Table 9.

The details of the result of the experiment are given in Table 10 to 20 and are graphically recorded in Fig. 28, 31, 32, 33, 34 and 35.

From the experiment conducted for drying, using various quantities of beans, with different temperature and air flow, it can be seen that for drying 90 kg of fermented cocoa beans, a temperature of 47°C and an air flow rate of 0.4 m^3/second is ideal for this type of drier as the energy consumed/kg of bean is least in this case (0.6865 K.W.H.).

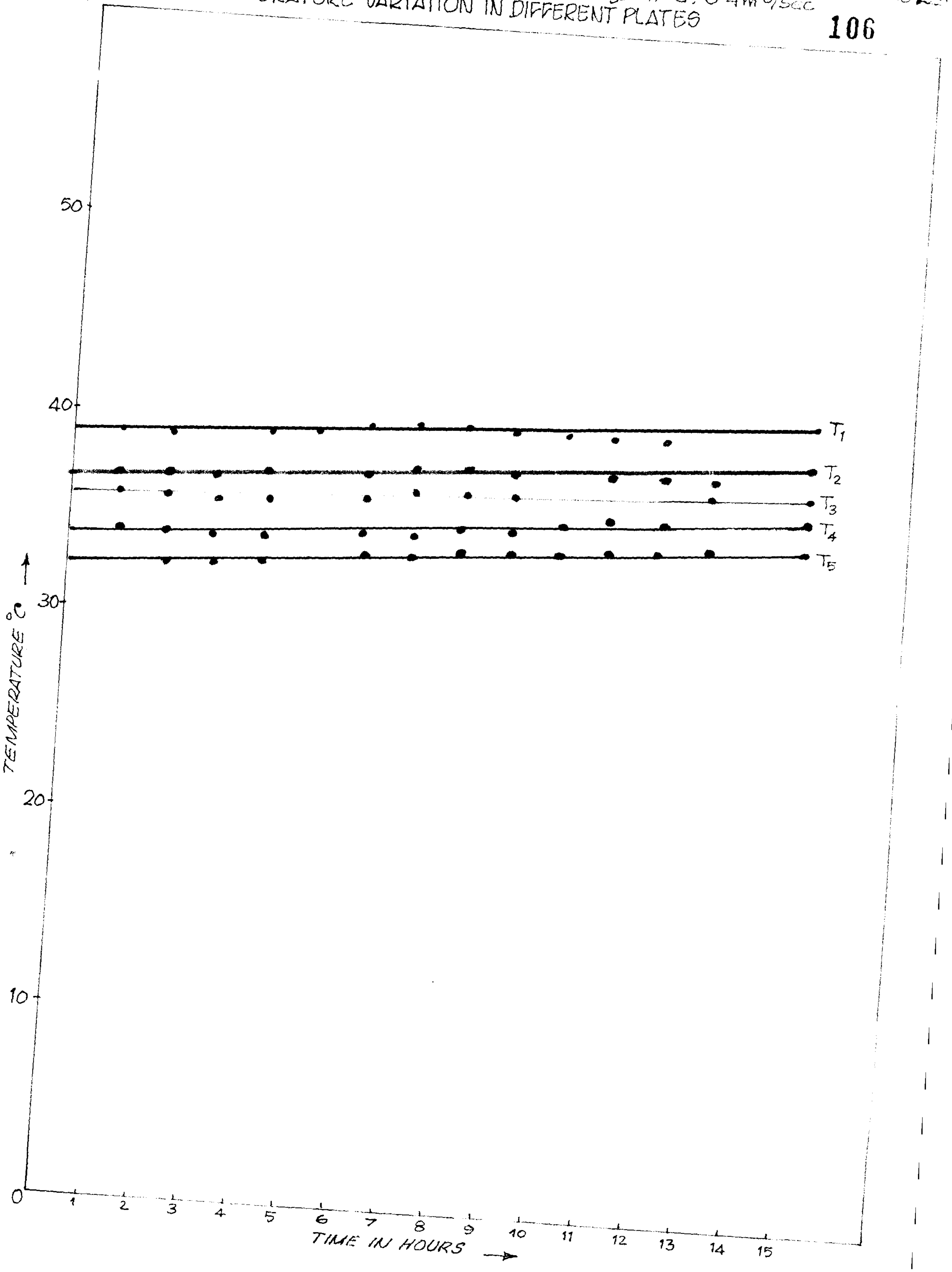
FIG.No.28



GRAPH No. 10

AGITATION TYPE MULTISTAGE DRIER, 90 Kgs 47°C, 0·4 m 3/sec
TEMPERATURE VARIATION IN DIFFERENT PLATES

FIG. No 25



GRAPH No. 11

FIG. No. 30

HUMIDITY PROFILE IN AGITATION TYPE MULTISTAGE DRIER 90Kg, 47°C, 0·4m³/Sec

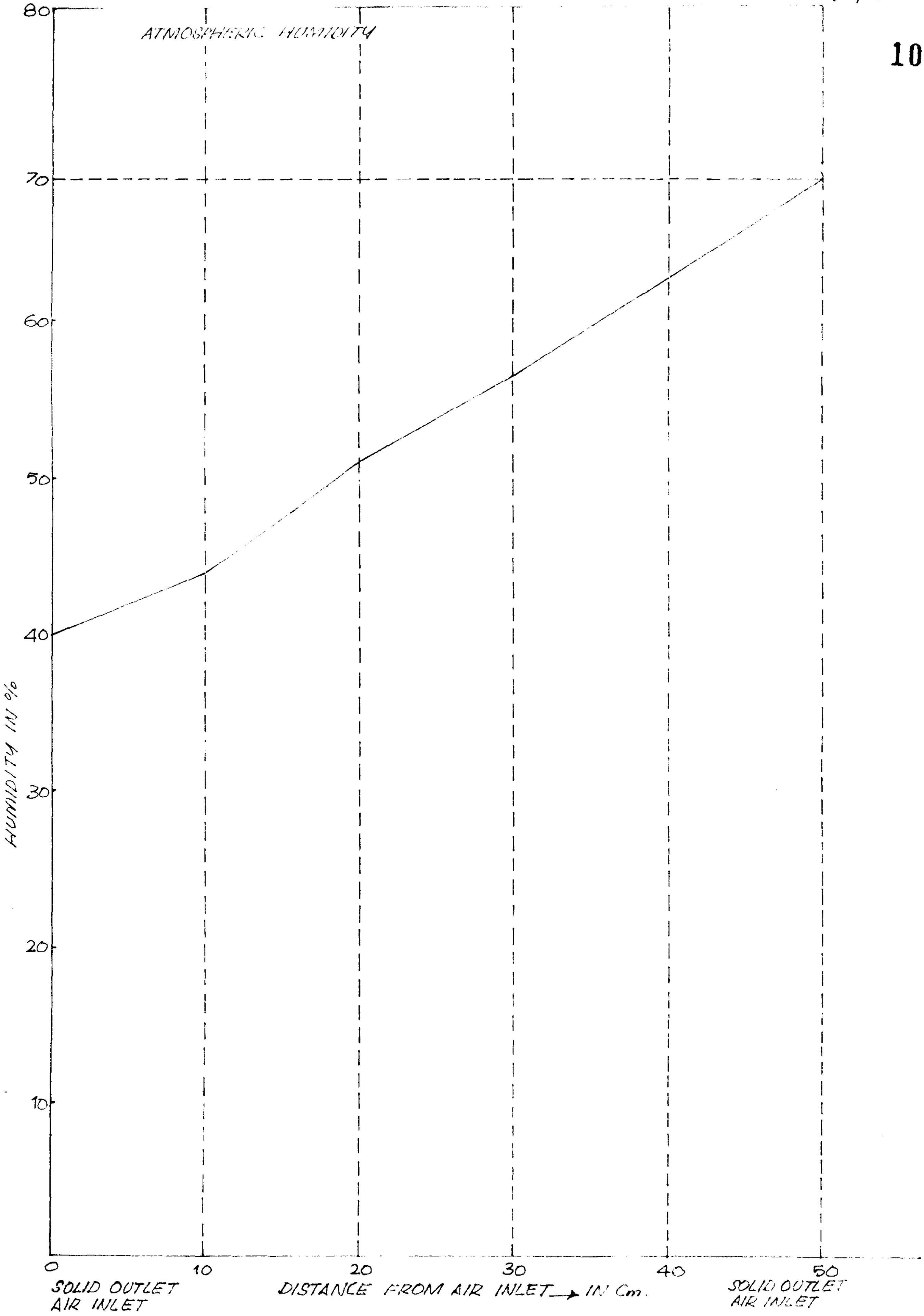


Table 9. Agitation type multistage drier

Sl. No.	Quantity of beans (kg)	Temperature (°C)	Air flow m^3/Sec.	Time taken (hours)	Energy consumption K.W.H.	pH
1	90	56	0.4	13	0.81163	5.1
2	90	47	0.4	15	0.6865	5.3
3	90	42	0.4	24	0.6984	5.3
4	60	56	0.4	11	0.99843	5.1
5	60	47	0.4	13	0.85496	5.2
6	60	42	0.4	17	0.69303	5.3
7	90	56	0.2	14	0.84715	5.2
8	90	47	0.2	16	0.70151	5.3
9	90	42	0.2	26	0.70662	5.4
10	60	56	0.2	12	1.10892	5.3
11	60	47	0.2	14	0.920	5.3
12	60	42	0.2	19	0.69303	5.4

Table 10. Test on Agitation type multistage drier (Initial weight of cocoa beans 90 kg; Initial air temperature 56°C; Air quantity 0.4 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		(%)
0												54.4
1	45.0	44.0	42.5	41.0	39.5	38	41.0	44.0	51.0	62.0	65.0	48.4
2	45.5	44.0	42.5	41.0	39.5	38	41.0	44.0	51.0	62.0	65.0	43.0
3	45.5	44.0	42.5	41.0	39.5	38	41.0	44.0	51.0	62.0	65.0	37.0
4	46.0	44.5	42.5	41.5	40.0	38	40.5	43.5	51.0	61.0	64.5	32.0
5	46.0	44.5	42.5	41.5	40.0	38	40.5	43.5	50.5	61.0	64.5	27.0
6	46.5	44.5	43.0	41.5	40.5	38	40.5	43.5	50.5	61.0	64.0	22.0
7	47.0	45.0	43.0	41.5	40.5	38	40.5	43.5	50.5	61.0	64.0	19.2
8	47.0	45.0	43.0	42.0	40.5	38	40.0	43.5	50.5	60.0	64.0	14.4
9	47.5	45.0	43.0	42.0	40.5	38	40.0	43.0	50.0	60.0	64.0	11.6
10	47.5	45.0	43.0	42.5	41.0	38	40.0	43.0	50.0	60.0	63.5	9.4
11	47.5	45.5	43.5	42.5	41.0	38	40.0	43.0	50.0	60.0	63.5	8.0
12	47.5	45.5	43.5	42.5	41.0	38.	40.0	42.5	49.5	60.0	63.0	7.6
13	47.5	45.5	43.5	42.5	41.0	38	39.5	42.5	49.5	59.0	63.0	7.6

Table 11. Test on Agitation type multistage drier (Initial weight of cocoa beans 90 kg; Initial air temperature 42°C; Air quantity 0.4 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Mositure content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0												54.4
1	39.5	38.0	36.0	34.5	31.5	41	51.0	57.0	63.0	67.0	70.0	51.0
2	39.5	38.0	36.0	34.5	31.5	41	51.0	57.0	63.0	67.0	70.0	47.6
3	39.5	38.0	36.0	34.5	31.5	41	51.0	57.0	63.0	67.0	70.0	44.4
4	39.5	38.0	36.0	34.5	31.5	41	51.0	57.0	63.0	67.0	70.0	41.4
5	39.5	38.0	36.0	34.5	31.5	41	50.5	57.0	62.5	66.5	70.0	39.0
6	39.5	38.0	36.0	34.5	32.0	41	50.5	56.5	62.5	66.5	69.5	36.0
7	39.5	38.0	36.0	34.5	32.0	41	50.5	56.5	62.5	66.5	69.5	34.0
8	39.5	38.0	36.0	34.5	32.0	41	50.5	56.5	62.5	66.5	69.5	31.0
9	39.5	38.0	36.0	34.5	32.0	41	50.0	56.0	62.5	66.0	69.5	28.4
10	40.0	38.0	36.0	34.5	32.5	41	50.0	56.0	62.0	66.0	69.5	26.0
11	40.0	38.0	36.0	35.0	32.5	41	50.0	56.0	62.0	66.0	69.5	24.0
12	40.0	38.0	36.0	35.0	32.5	41	50.0	56.0	62.0	66.0	69.0	21.0
13	40.0	38.0	36.0	35.0	32.5	41	50.0	56.0	62.0	66.0	69.0	18.6
14	40.0	38.5	36.5	35.0	32.5	41.	50.0	56.0	61.5	65.5	69.0	16.2
15	40.0	38.5	36.5	35.0	32.5	41	49.5	56.0	61.5	65.5	69.0	14.6
16	40.5	38.5	36.5	35.0	33.0	41	49.5	56.0	61.5	65.5	69.0	12.8
17	40.5	38.5	36.5	35.0	33.0	41	49.5	56.0	61.5	65.5	69.0	11.2

Table 11. (Contd.)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
18	40.5	38.5	36.5	35.0	33.0	41	49.5	55.5	61.0	65.5	68.5	10.0
19	40.5	38.5	37.0	35.0	33.0	41	49.5	55.5	61.0	65.5	68.5	9.0
20	40.5	38.5	37.0	35.0	33.0	41	49.5	55.5	61.0	65.0	68.5	8.4
21	40.5	38.5	37.0	35.0	33.0	41	49.5	55.0	60.5	65.0	68.0	8.0
22	40.5	38.5	37.0	35.0	33.5	41	49.0	55.0	60.5	65.0	68.0	7.8
23	40.5	38.5	37.0	35.0	33.5	41	49.0	55.0	60.5	65.0	67.5	7.6
24	40.5	38.5	37.0	35.0	33.5	41	49.0	55.0	60.5	64.5	67.5	7.6

Table 12. Test on Agitation type multistage drier (Initial weight of cocoa beans 60 kg; Initial air temperature 56°C; Air quantity 0.4 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0	44.0	42.0	40.0	38.0	35.5	38	41.0	46.0	52.0	56.0	59.0	54.4
1	44.0	42.0	40.0	38.0	35.5	38	41.0	46.0	52.0	56.0	59.0	44.0
2	44.0	42.0	40.0	38.0	35.5	38	41.0	46.0	52.0	56.0	59.0	37.8
3	44.0	42.0	40.5	38.0	35.5	38	41.0	46.0	52.0	55.5	59.0	32.0
4	44.5	42.0	40.5	38.0	36.0	38	40.5	46.0	51.5	55.5	58.5	26.0
5	44.5	42.0	41.0	39.0	36.0	38	40.5	45.5	51.5	55.5	58.5	21.0
6	44.5	42.5	41.0	39.0	36.5	38	40.5	45.5	51.0	55.0	58.5	17.0
7	44.5	42.5	41.5	39.5	36.5	38	40.5	45.5	51.0	55.0	58.5	13.6
8	44.5	43.0	41.5	39.5	37.0	38	40.5	45.5	51.0	55.0	58.0	10.4
9	45.0	43.0	41.5	39.5	37.5	38	40.0	45.0	51.0	54.5	58.0	8.4
10	45.0	43.5	42.0	40.0	37.5	38	40.0	45.0	50.5	54.5	58.0	8.0
11	45.0	43.5	42.0	40.0	38.0	38	40.0	45.0	50.5	54.5	58.0	7.6

Table 13. Test on Agitation type multistage drier (Initial weight of cocoa beans 60 kg; Initial air temperature 47°C; Air quantity 0.4 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0						40	44.0	51.0	55.0	59.0	65.0	54.6
1	42.5	40.5	38.5	36.0	34.5	40	44.0	51.0	55.0	59.0	65.0	49.0
2	42.5	40.5	38.5	36.0	34.5	40	44.0	51.0	55.0	59.0	65.0	43.0
3	42.5	40.5	38.5	36.0	34.5	40	44.0	51.0	55.0	59.0	64.5	38.0
4	43.0	41.0	39.0	36.5	34.5	40	44.0	50.5	54.5	58.5	64.5	32.0
5	43.0	41.5	39.0	36.5	35.0	40	43.5	50.5	54.5	58.5	64.5	28.0
6	43.0	41.5	39.0	36.5	35.0	40	43.5	50.5	54.5	58.5	64.0	24.0
7	43.5	41.5	39.0	37.0	35.0	40	43.5	50.0	54.5	58.0	64.0	20.0
8	43.5	41.5	39.5	37.0	35.5	40	43.5	50.0	54.5	58.0	64.0	16.0
9	43.5	41.5	39.5	37.0	35.5	40	43.0	50.0	54.0	58.0	63.5	12.6
10	44.0	42.0	39.5	37.5	35.5	40	43.0	50.0	54.0	58.0	63.5	10.0
11	44.0	42.0	40.0	37.5	36.0	40	43.0	49.5	54.0	57.5	63.0	8.4
12	44.0	42.0	40.0	38.0	36.0	40	43.0	49.5	54.0	57.5	63.0	7.6
13	44.0	42.0	40.0	38.0	36.0	40	42.5	49.5	53.5	57.5	63.0	7.6

Table 14. Test on Agitation type multistage drier (Initial weight of cocoa beans 60 kg; Initial air temperature 42°C; Air quantity 0.4 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0												54.0
1	38.0	37.0	35.0	33.0	31.5	41	47.0	52.0	59.0	61.0	72.0	50.0
2	38.0	37.0	35.0	33.0	31.5	41	47.0	52.0	59.0	61.0	72.0	46.0
3	38.0	37.0	35.0	33.0	31.5	41	47.0	52.0	59.0	61.0	72.0	42.0
4	38.5	37.0	35.0	33.0	31.5	41	47.0	52.0	59.0	61.0	72.0	38.0
5	38.5	37.5	35.5	33.0	31.5	41	47.0	52.0	58.5	60.5	71.5	34.6
6	38.5	37.5	35.5	33.5	31.5	41	47.0	51.5	58.5	60.5	71.5	31.0
7	38.5	37.5	35.5	33.5	32.0	41	46.5	51.5	58.5	60.5	71.5	28.0
8	39.0	38.0	35.5	33.5	32.0	41	46.5	51.5	58.5	60.5	71.0	25.0
9	39.0	38.0	36.0	33.5	32.0	41	46.5	51.5	58.5	60.0	71.0	22.0
10	39.0	38.0	36.0	33.5	32.0	41	46.5	51.5	58.0	60.0	71.0	20.0
11	39.0	38.0	36.0	33.5	32.0	41	46.5	51.5	58.0	60.0	70.5	17.0
12	39.0	38.0	36.0	34.0	32.0	41	46.5	51.5	58.0	59.5	70.5	14.8
13	39.5	38.5	36.5	34.0	32.5	41	46.5	51.5	58.0	59.5	70.5	12.0
14	39.5	38.5	36.5	34.0	32.5	41	46.5	51.0	57.5	59.0	70.0	10.0
15	40.0	38.5	36.5	34.0	32.5	41	46.0	51.0	57.5	59.0	70.0	8.6
16	40.0	38.5	36.5	34.0	32.4	41	46.0	51.0	57.5	59.0	70.0	7.6
17	40.0	38.5	36.5	34.0	32.4	41	46.0	51.0	57.5	59.0	70.0	7.6

Table 15. Test on Agitation type multistage drier (Initial weight of cocoa beans 90 kg; Initial air temperature 56°C; Air quantity 0.2 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0												54.0
1	45.0	42.5	39.0	35.5	32.5	36	48.0	55.0	60.0	65.0	71.0	46.0
2	45.0	42.5	39.0	35.5	32.5	36	48.0	55.0	60.0	65.0	71.0	37.0
3	45.5	43.0	39.0	35.5	32.5	36	48.0	55.0	60.0	65.0	71.0	33.0
4	45.5	43.0	39.5	36.0	32.5	36	48.0	55.0	60.0	65.0	70.5	24.0
5	46.0	43.5	39.5	36.0	33.0	36	47.5	54.5	60.0	64.5	70.5	23.6
6	46.0	43.5	39.5	36.0	33.0	36	47.5	54.5	59.5	64.5	70.5	19.6
7	46.5	43.5	39.5	36.5	33.5	36	47.5	54.5	59.5	64.5	70.0	16.8
8	46.5	44.0	39.5	36.5	33.5	36	47.5	54.5	59.5	64.5	70.0	14.6
9	47.0	44.5	39.5	37.0	33.5	36	47.5	54.5	59.5	64.5	70.0	12.0
10	47.5	44.5	40.0	37.0	34.0	36	47.0	54.0	59.0	64.5	70.0	10.0
11	47.5	44.5	40.0	37.0	34.0	36	47.0	54.0	59.0	64.5	69.5	9.4
12	48.0	45.0	40.5	37.0	34.0	36	47.0	54.0	59.0	64.5	69.5	8.0
13	48.0	45.5	40.5	37.5	34.0	36	47.0	54.0	58.5	64.0	69.0	7.6
14	48.0	45.5	40.5	37.5	34.0	36	47.0	54.0	58.5	64.0	69.0	7.6

Table 16. Test on Agitation type multistage drier (Initial weight of cocoa beans 90 kg; Initial air temperature 47°C; Air quantity 0.2 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0						39						54.6
1	41.0	39.0	36.5	34.0	33.0	39	49.0	54.0	59.0	64.0	69.0	48.0
2	41.0	39.0	36.5	34.0	33.0	39	49.0	54.0	59.0	64.0	69.0	41.8
3	41.5	39.5	36.5	34.5	33.5	39	49.0	54.0	59.0	64.0	69.0	36.2
4	41.5	40.0	37.0	34.5	33.5	39	49.0	53.5	58.5	64.0	69.0	31.0
5	42.0	40.5	37.0	35.0	33.5	39	38.5	53.5	58.5	63.5	68.5	26.2
6	42.5	40.5	37.5	35.0	34.0	39	48.5	53.5	58.5	63.5	68.5	22.4
7	42.5	41.0	38.0	35.5	34.0	39	48.5	53.5	58.0	63.5	68.5	19.4
8	42.5	41.0	38.0	35.5	34.0	39	48.5	53.5	58.0	63.0	68.0	16.6
9	43.0	41.5	38.5	36.0	34.0	39	48.5	53.0	58.0	63.0	68.0	14.4
10	43.0	41.5	39.0	36.0	34.5	39	48.5	53.0	57.5	62.5	68.0	12.4
11	43.5	42.0	39.5	36.5	34.5	39	48.5	53.0	57.5	62.5	68.0	11.2
12	43.5	42.0	39.5	37.0	34.5	39	38.0	52.5	57.5	62.5	67.5	10.2
13	44.0	42.0	40.0	37.0	34.5	39	48.0	52.5	57.0	62.5	67.5	9.0
14	44.0	42.5	40.0	37.5	34.5	39	47.5	52.5	57.0	62.5	67.5	8.0
15	44.5	42.5	40.5	37.5	35.0	39	47.5	52.0	56.5	62.5	67.3	7.6
16	45.0	42.5	40.5	37.5	35.0	39	47.5	52.0	56.5	62.5	67.0	7.6

Table 17. Test on Agitation type multistage drier (Initial weight of cocoa beans 90 kg; Initial air temperature 42°C; Air quantity 0.2 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0						40	53.0	59.0	63.0	67.0	72.0	54.4
1	39.5	38.0	36.0	34.5	32.0	40	53.0	59.0	63.0	67.0	72.0	51.4
2	39.5	38.0	36.0	34.5	32.0	40	53.0	59.0	63.0	67.0	72.0	48.0
3	39.5	38.0	36.0	34.0	32.0	40	53.0	59.0	63.0	67.0	72.0	45.0
4	39.5	38.0	36.0	34.5	32.0	40	52.5	58.5	62.5	67.0	72.0	42.5
5	39.5	38.5	36.5	34.5	32.0	40	52.5	58.5	62.5	66.5	71.5	40.0
6	39.5	38.5	36.5	34.5	32.0	40	52.5	58.5	62.5	66.5	71.5	37.2
7	40.0	38.5	36.5	34.5	32.0	40	52.5	58.5	62.5	66.0	71.5	35.0
8	40.0	38.5	36.5	34.5	32.5	40	52.5	58.5	62.5	66.0	71.5	32.0
9	40.0	38.5	36.5	34.5	32.5	40	52.0	58.5	62.5	66.0	71.5	29.6
10	40.0	38.5	36.5	35.0	33.0	40	52.0	58.5	62.5	65.5	71.5	27.6
11	40.0	38.5	36.5	35.0	33.0	40	52.0	58.0	62.5	65.5	71.5	25.6
12	40.0	38.5	37.0	35.0	33.0	40	52.0	58.0	62.5	65.5	71.0	25.6
13	40.0	38.5	37.0	35.0	33.0	40	52.0	58.0	62.0	65.5	71.0	21.8
14	40.0	38.5	37.0	35.5	33.0	40	51.5	58.0	62.0	65.5	71.0	19.6
15	40.0	38.5	37.5	35.0	33.0	40	51.5	57.5	62.0	65.0	71.0	17.2
16	40.0	39.0	37.5	35.0	33.0	40	51.5	57.5	62.0	65.0	71.0	15.8
17	40.5	39.0	37.5	35.5	33.0	40	51.5	57.5	62.0	65.0	71.0	14.0
18	40.5	39.0	37.5	35.5	33.5	40	51.5	57.5	61.5	64.5	71.0	13.0
19	40.5	39.0	37.5	35.5	33.5	40	51.5	57.5	61.5	64.5	70.5	12.0
20	40.5	39.0	37.5	35.5	33.5	40	51.5	57.0	61.5	64.5	70.5	11.0
21	40.5	39.5	37.5	35.5	33.5	40	51.5	57.0	61.5	64.5	70.5	10.0
22	41.0	39.5	37.5	35.5	33.5	40	51.0	57.0	61.5	64.5	70.5	9.0
23	41.0	39.5	38.0	35.5	34.0	40	51.0	57.0	61.5	64.0	70.0	8.2
24	41.5	39.5	38.0	36.0	34.0	40	51.0	57.0	61.5	64.0	70.0	8.0
25	41.5	39.5	38.0	36.0	34.0	40	50.5	57.0	61.0	64.0	70.0	7.6
26	41.5	39.5	38.0	36.0	34.5	40	50.5	57.0	61.0	64.0	69.5	7.6

Table 18. Test on Agitation type multistage drier (Initial weight of cocoa beans 60 kg; Initial air temperature 56°C; Air quantity 0.2 m^3/second)

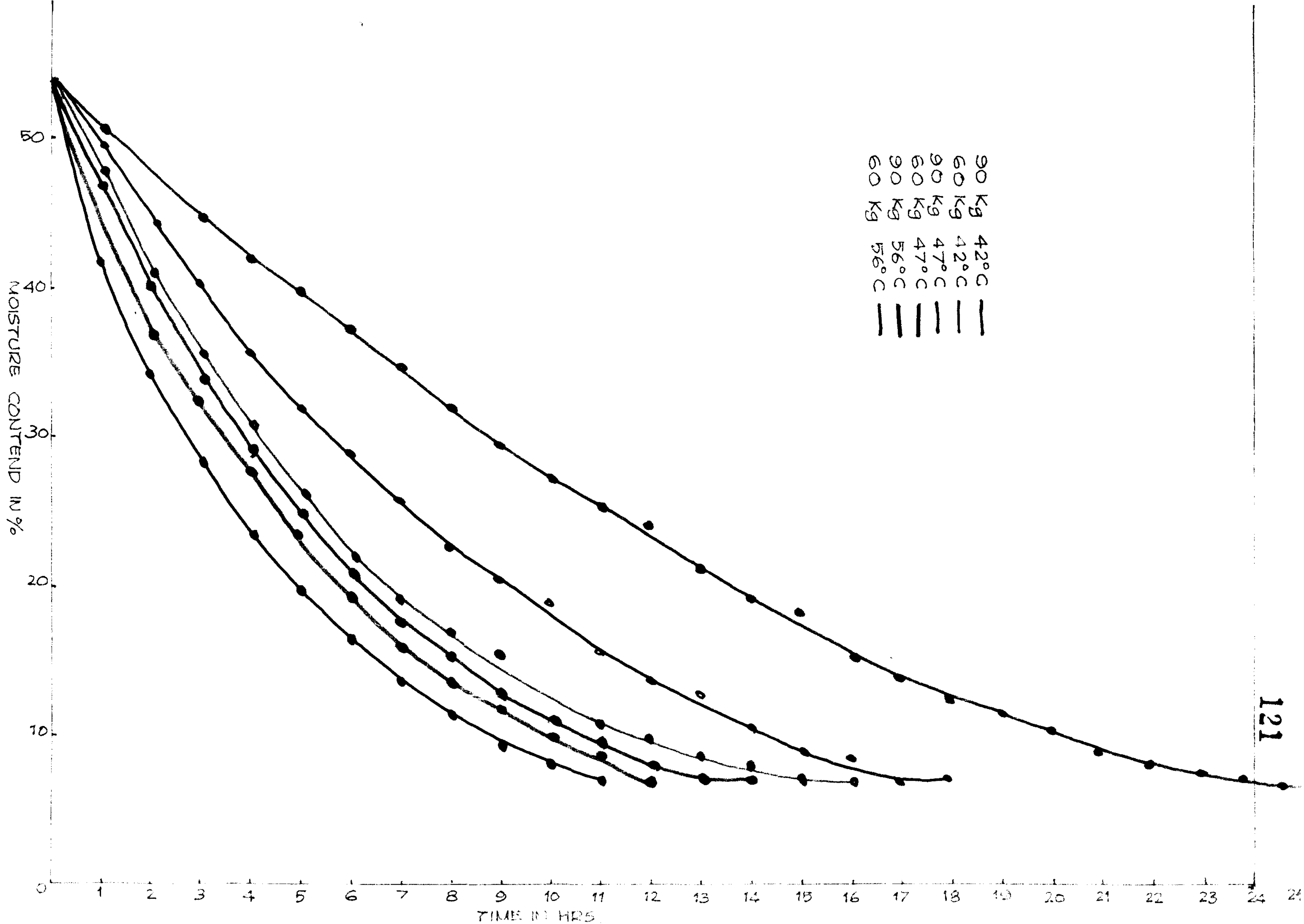
Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0												54.6
1	48.5	47.0	45.0	42.5	40.0	36	43.0	52.0	56.0	60.0	65.0	42.0
2	48.5	47.0	45.0	42.5	40.0	36	43.0	52.0	56.0	60.0	65.0	34.4
3	48.5	47.0	45.0	42.5	40.5	36	43.0	52.0	56.0	60.0	65.0	29.0
4	48.5	47.5	45.0	43.0	40.5	36	42.5	52.0	55.5	59.5	64.5	24.0
5	49.0	47.5	45.5	43.5	41.0	36	42.5	51.5	55.5	59.5	64.5	20.0
6	49.0	47.5	45.5	43.5	41.0	36	42.5	51.5	55.5	59.5	64.5	17.0
7	49.5	47.5	46.0	43.5	41.0	36	42.0	51.0	55.0	59.0	64.0	14.0
8	49.5	47.5	46.0	43.5	41.5	36	42.0	51.0	55.0	59.0	64.0	11.8
9	49.5	48.0	46.0	44.0	41.5	36	42.0	51.0	55.0	59.0	63.5	9.8
10	50.0	48.0	46.5	44.0	42.0	36	41.5	51.0	54.5	58.5	63.5	8.4
11	50.0	48.5	46.5	44.5	42.5	36	41.5	50.5	54.5	58.5	63.0	7.6
12	50.0	48.5	46.5	44.5	42.5	36	41.5	50.5	54.0	58.5	63.0	7.6

Table 19. Test on Agitation type multistage drier (Initial weight of cocoa beans 60 kg; Initial air temperature 47°C; Air quantity 0.2 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H1	H2	H3	H4		
0						39	45.0	57.0	59.0	64.0	69.0	54.0
1	41.5	39.0	37.5	36.0	34.5	39	45.0	57.0	59.0	64.0	69.0	47.0
2	41.5	39.0	37.5	36.0	34.5	39	45.0	57.0	59.0	64.0	69.0	40.6
3	41.5	39.0	37.5	36.0	35.0	39	45.0	56.5	59.0	64.0	69.0	34.6
4	42.0	39.5	37.5	36.5	35.0	39	44.5	56.5	58.5	64.0	68.5	29.4
5	42.0	39.5	38.0	36.5	35.0	39	44.5	56.5	58.5	63.5	68.5	25.0
6	42.0	39.5	38.0	37.0	35.5	39	44.5	56.5	58.5	63.5	68.5	21.2
7	42.0	39.5	38.5	37.0	35.5	39	44.0	56.5	58.5	63.5	68.5	17.8
8	42.5	40.0	38.5	37.5	35.5	39	44.0	56.0	58.0	63.0	68.5	15.4
9	42.5	40.0	39.0	37.5	35.5	39	44.0	56.0	58.0	63.0	68.0	13.0
10	42.5	40.5	39.0	37.5	36.0	39	43.5	56.0	58.0	63.0	68.0	11.0
11	42.5	40.5	39.0	38.0	36.0	39	43.5	56.0	57.5	62.5	68.0	9.4
12	42.5	40.5	39.5	38.0	36.0	39	43.0	56.0	57.5	62.5	67.5	8.0
13	43.0	41.0	39.5	38.0	36.0	39	43.0	55.5	57.5	62.5	67.5	7.6
14	43.0	41.0	39.5	38.0	36.0	39	43.0	56.0	57.5	62.5	62.0	7.6

Table 20. Test on Agitation type multistage drier (Initial weight of cocoa beans 60 kg; Initial air temperature 42°C; Air quantity 0.2 m^3/second)

Time (hours)	Intermediate temperature (°C)				Exit temperature (°C)	Inlet air humidity	Intermediate air humidity				Exit air humidity	Moisture content (%)
	T_1	T_2	T_3	T_4			H_1	H_2	H_3	H_4		
0												54.4
1	38.5	37.0	35.0	33.5	32.0	40	48.0	54.0	63.0	67.0	69.0	49.4
2	38.5	37.0	35.0	33.5	32.0	40	48.0	54.0	63.0	67.0	69.0	44.8
3	38.5	37.0	35.5	33.5	32.0	40	48.0	54.0	63.0	67.0	69.0	40.4
4	38.5	37.5	35.5	34.0	32.0	40	47.5	54.0	63.0	66.5	68.5	36.6
5	39.0	37.5	35.5	34.0	32.5	40	47.5	53.5	62.5	66.5	68.5	32.6
6	39.0	37.5	35.5	34.0	32.5	40	47.5	53.5	62.5	66.5	68.5	28.8
7	39.0	37.5	35.5	34.0	32.5	40	47.5	53.5	62.5	66.0	68.0	26.4
8	39.5	38.0	36.0	34.5	33.0	40	47.0	53.5	62.0	66.0	68.0	23.2
9	39.5	38.0	36.0	34.5	33.0	40	47.0	53.5	62.0	65.5	67.5	20.4
10	39.5	38.5	36.5	35.0	33.0	40	47.0	53.5	62.0	65.5	67.5	18.4
11	39.5	38.5	36.5	35.0	33.0	40	47.0	53.0	62.0	65.5	67.5	16.0
12	39.5	38.5	36.5	35.0	33.0	40	47.0	53.0	61.5	65.5	67.0	14.6
13	40.0	38.5	37.0	35.0	33.0	40	46.5	53.0	61.5	65.0	67.0	13.0
14	40.0	38.5	37.0	35.5	33.0	40	36.5	53.0	61.5	65.0	67.0	11.8
15	40.0	39.0	37.0	35.5	33.5	40	46.5	53.0	61.0	65.0	66.5	10.4
16	40.0	39.0	37.0	35.5	33.5	40	46.0	53.0	61.0	65.0	66.0	9.2
17	40.5	39.0	37.5	35.5	33.5	40	46.0	52.5	60.5	64.5	66.0	8.2
18	40.5	39.0	37.5	35.5	33.5	40	45.5	52.5	60.5	64.5	66.0	7.6
19	40.5	39.0	37.0	35.5	33.5	40	45.5	52.0	60.5	64.5	65.5	7.6

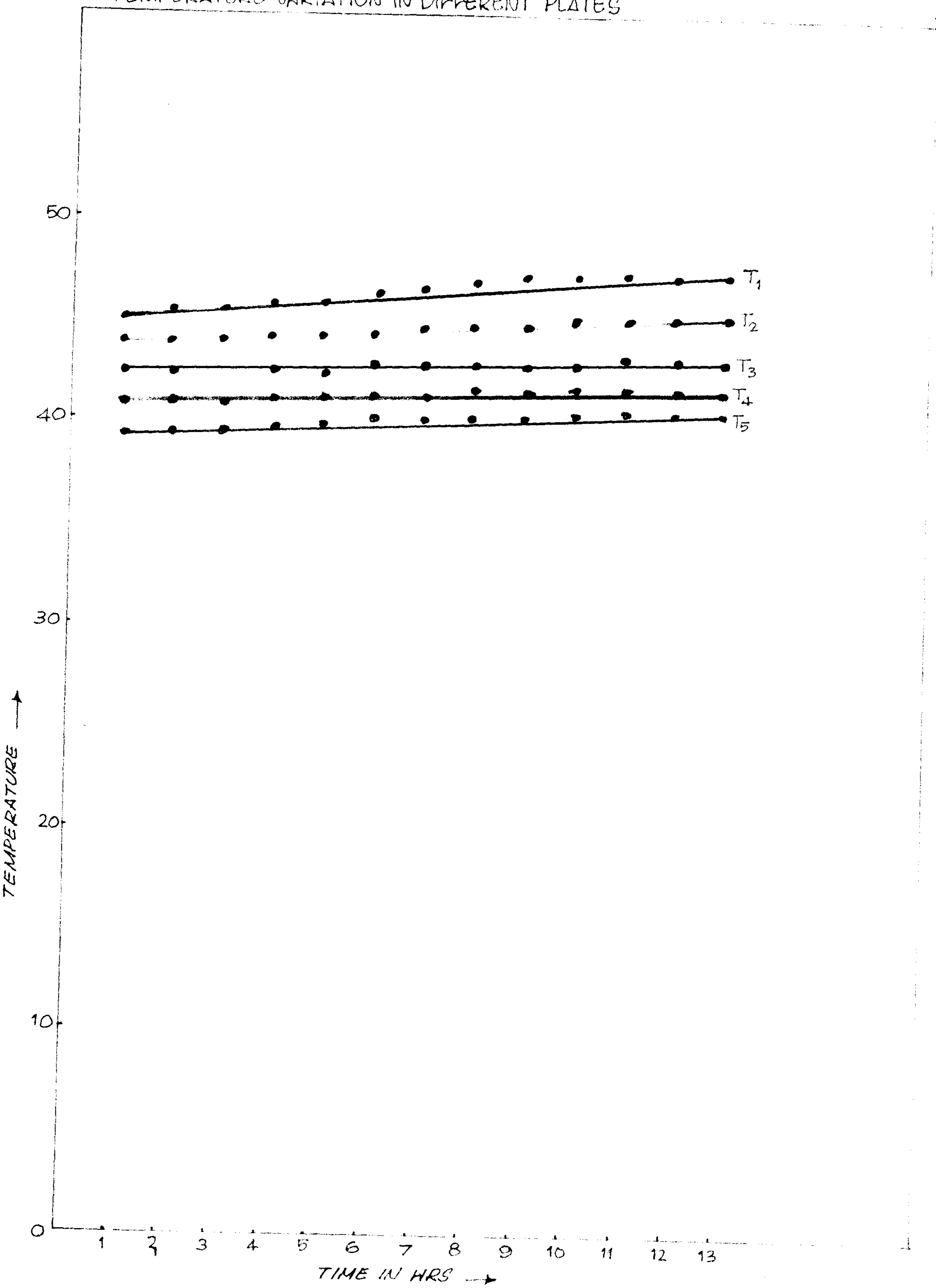


MOISTURE CONTEND IN %
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
TIME IN HRS
90 Kg 42°C
60 Kg 42°C
90 Kg 47°C
60 Kg 47°C
90 Kg 56°C
60 Kg 56°C

GRAPH No. 8

FIG. No. 32

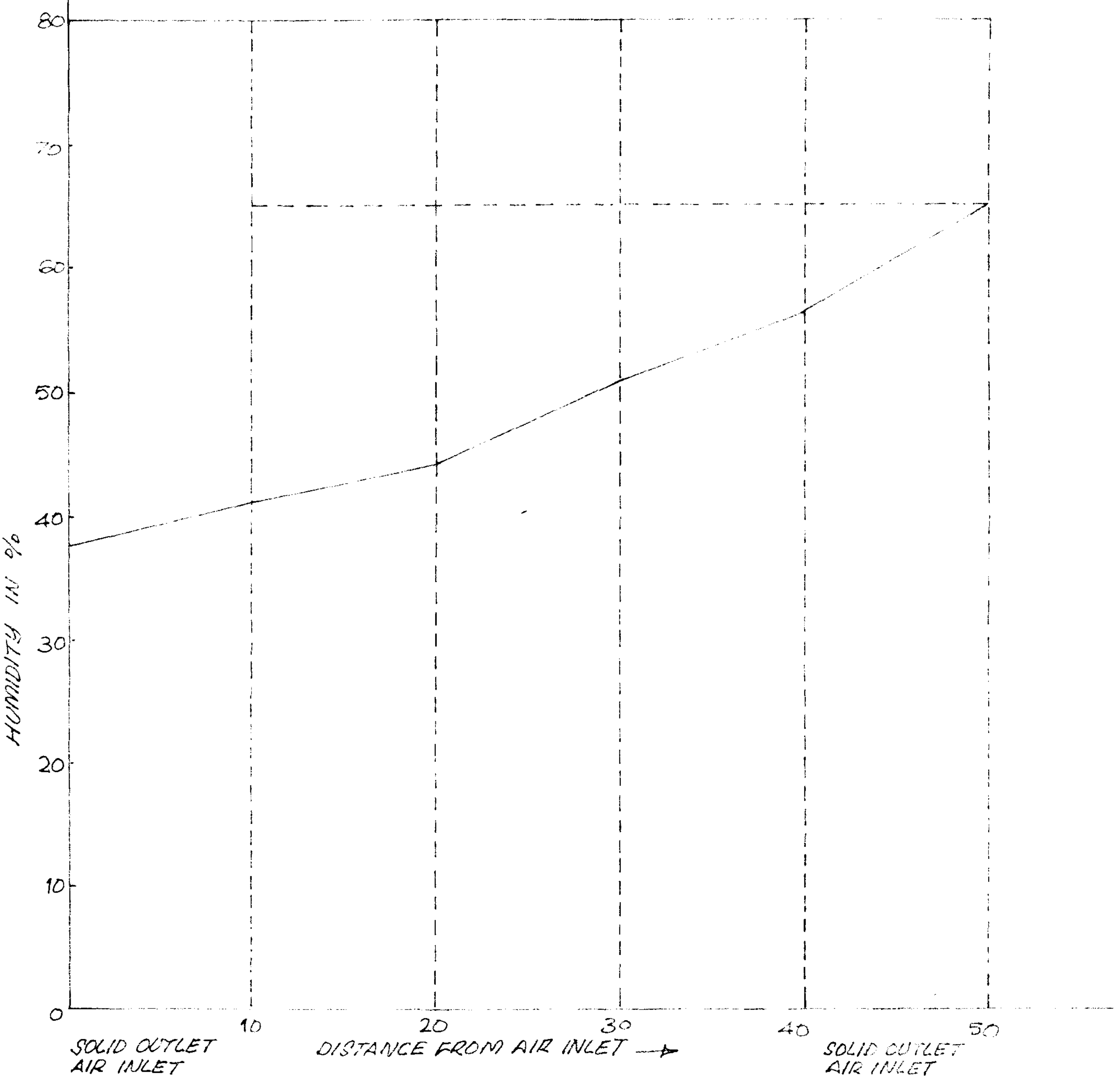
AGITATION TYPE MULTI STAGE DRIER 90Kg 56°C, 0·4m³/Sec.
TEMPERATURE VARIATION IN DIFFERENT PLATES



GRAPH No. 7

FIG. No. 33

HUMIDITY PROFILE IN AGITATION TYPE MULTISTAGE DRIER
90 Kg. 56°C, 0·4 m 3/sec



Electric energy for heater	= 3 K.W.H.
Blower motor (0.5 HP)	= 0.373 K.W.H.
Prime mover of reduction gear box (1 h.p. motor)	= 0.746 K.W.H.
Total energy required for one hour of operation	= 4.119 K.W.H.
Total energy required for 15 hours of operation	= 4.119 x 15
	= 61.785 K.W.H.
For drying 1 kg of fermented cocoa beans, electrical energy required	$= \frac{61.785}{90}$
	= 0.6865 K.W.H.

The moisture content of the dried beans was about 7.6 per cent.

The pH of the dried beans was 5.1 to 5.4, hence the quality of the beans was better than other types of driers tested. As the beans were moving in the drier better uniformity in drying was achieved and they were not exposed to high temperature continuously which helped in maintaining the quality of the beans. The drying time was reduced considerably. Energy consumption was less and cost of drying was only 50 per cent compared to other driers (Fig.36). Due to stage by stage drying, the loss of heat is reduced and hence the thermal efficiency is high. (73%)

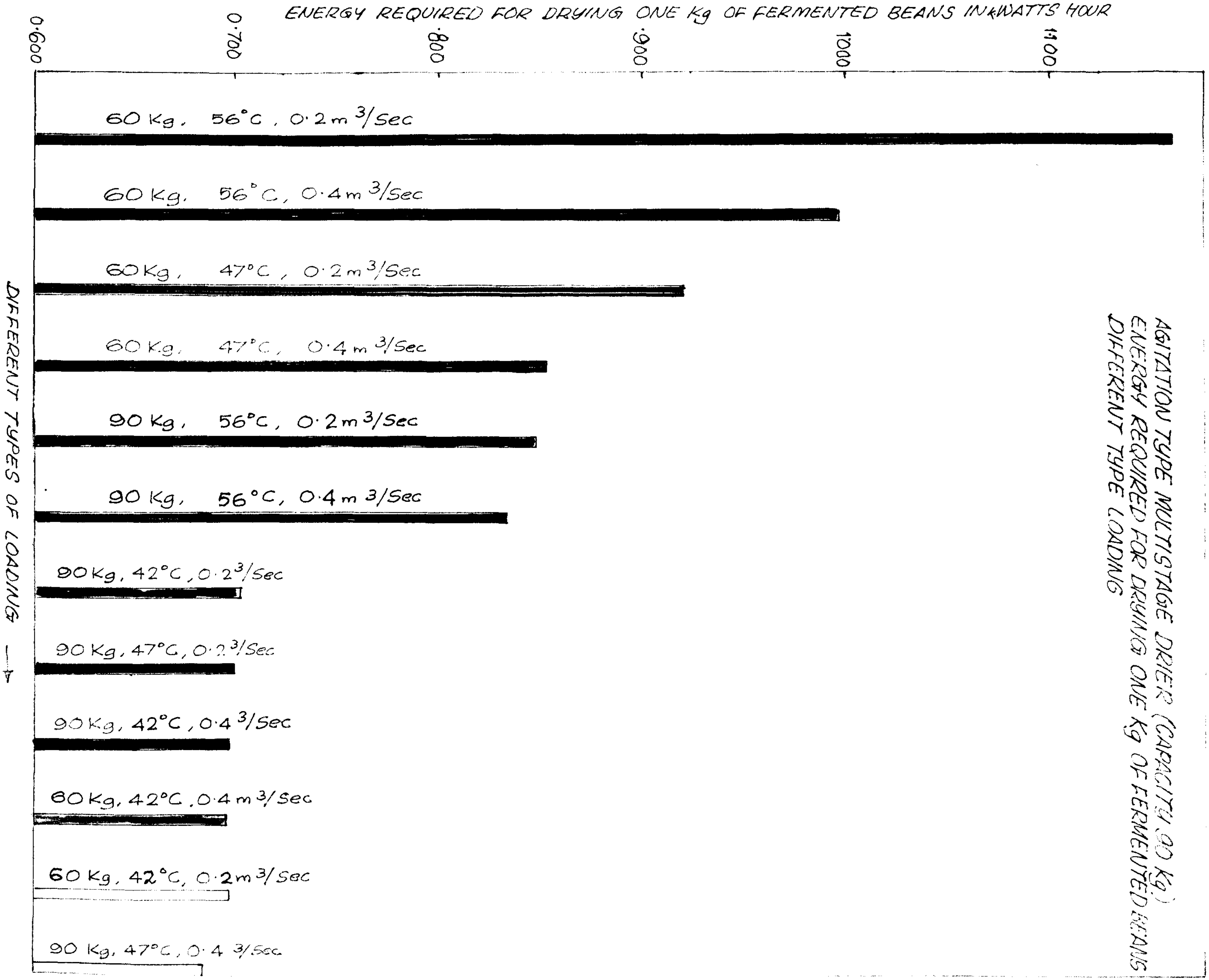
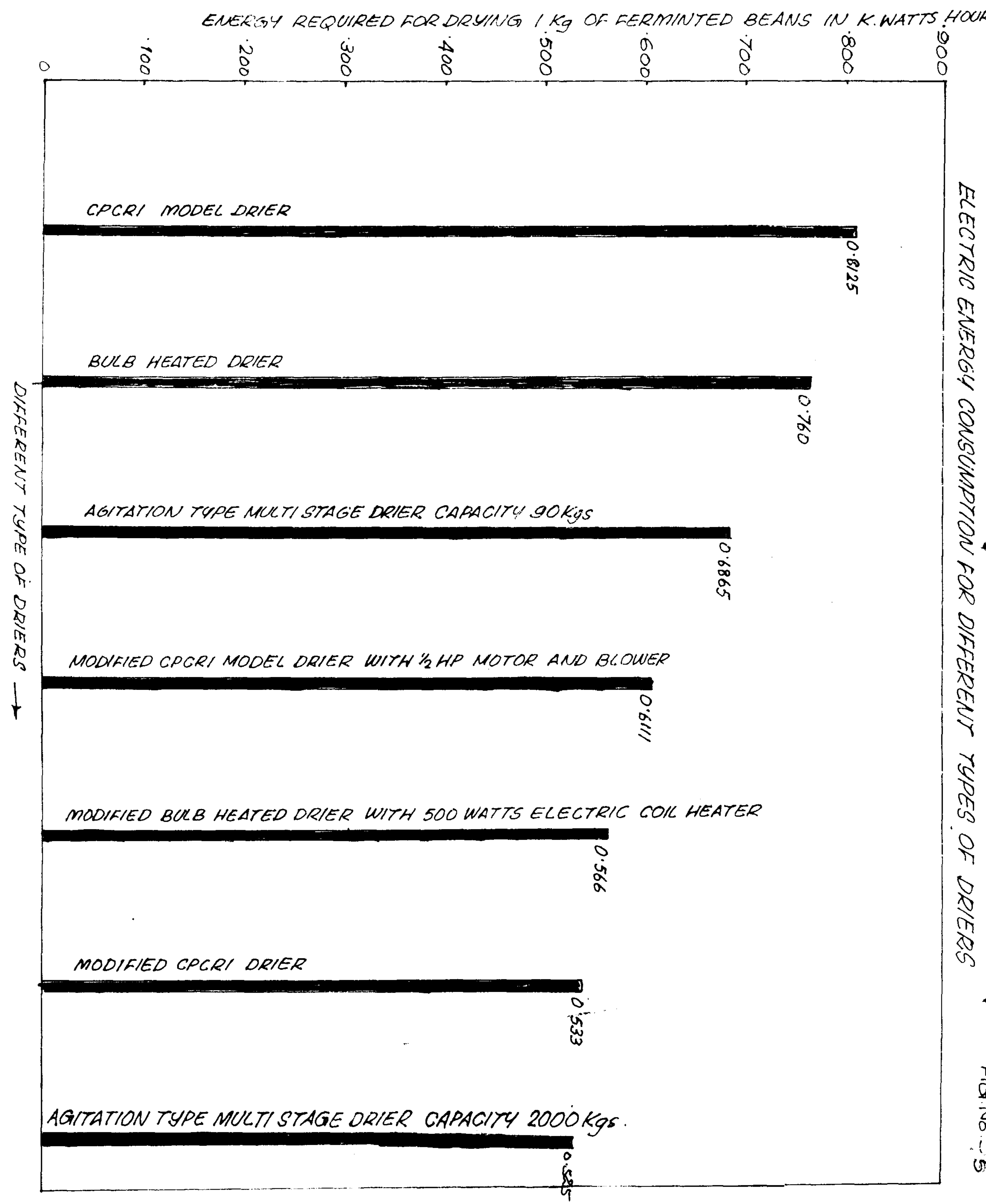

GRAPH No. 12
ENERGY REQUIRED FOR DRYING ONE Kg OF FERMENTED BEANS IN kWATTS HOUR
0·600
0·700
·800
·900
1000
1100
60 Kg, 56°C, 0·2 m 3/Sec
60 Kg, 56°C, 0·4 m 3/Sec
60 Kg, 47°C, 0·2 m 3/Sec
60 Kg, 47°C, 0·4 m 3/Sec
90 Kg, 56°C, 0·2 m 3/Sec
90 Kg, 56°C, 0·4 m 3/Sec
90 Kg, 42°C, 0·2 3/Sec
90 Kg, 47°C, 0·2 3/Sec
90 Kg, 42°C, 0·4 3/Sec
60 Kg, 42°C, 0·4 m 3/Sec
60 Kg, 42°C, 0·2 m 3/Sec
90 Kg, 47°C, 0·4 3/Sec
DIFFERENT TYPES OF LOADING
AGITATION TYPE MULTISTAGE DRIER (CAPACITY 90 Kg)
ENERGY REQUIRED FOR DRYING ONE Kg OF FERMENTED BEANS
DIFFERENT TYPE LOADING

FIG. No. 24



ELECTRIC ENERGY CONSUMPTION FOR DIFFERENT TYPES OF DRIERS

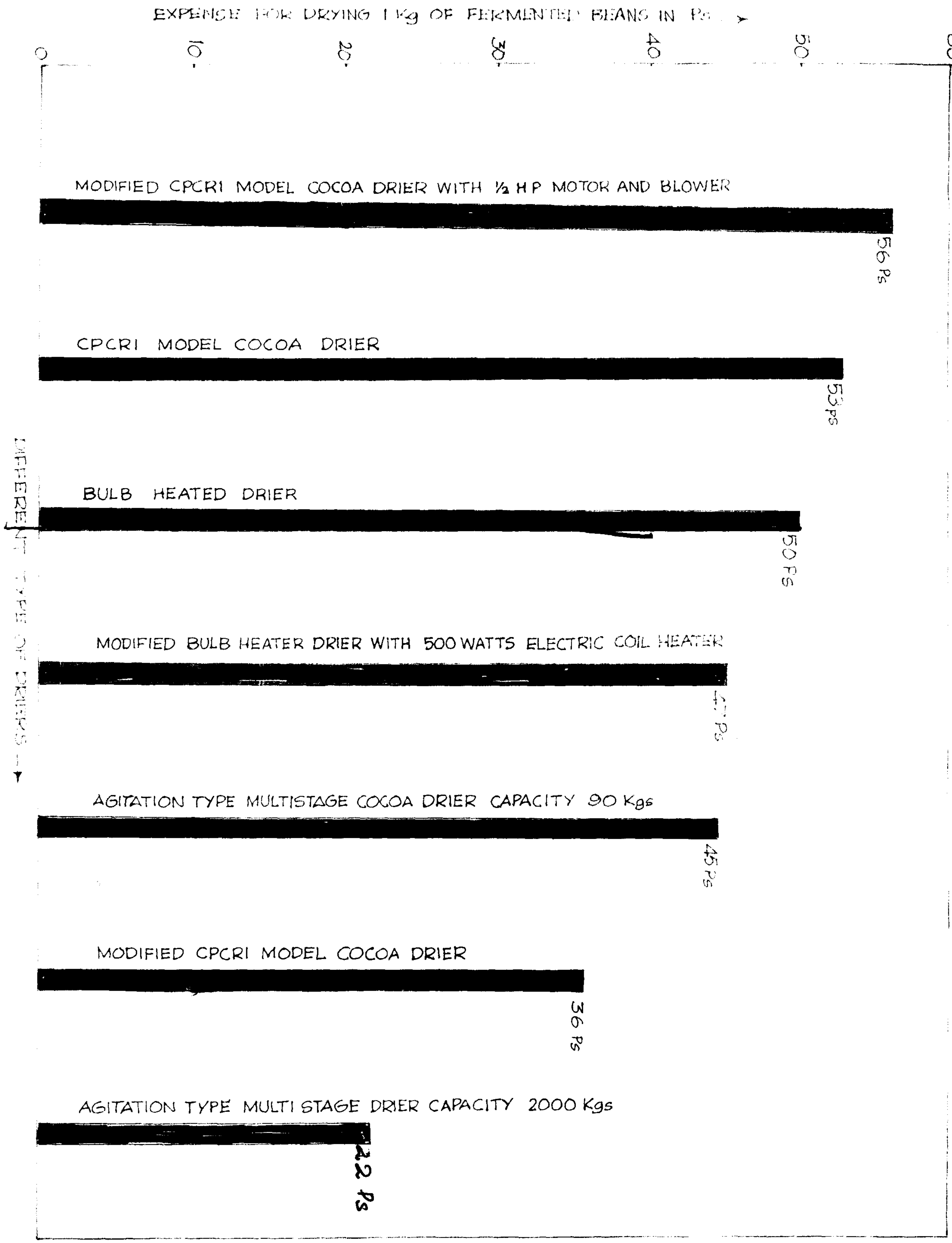
The cost calculated for drying in the various types of driers are appended (Appendix-II) and illustrated in Fig. 36. From the results the cost of drying 1 kg of fermented bean in different types of driers tested are given in Table 21.

From the data furnished in Table 21, it can be observed that the cost of drying 1 kilogram of fermented beans was least in Agitation type Multistage Drier having a capacity of 2000 kg (Re. 0.22), followed by modified C.P.C.R.I. model (Re. 0.36) and Agitation type multistage drier, having a capacity 90 kg (Re. 0.45). In modified C.P.C.R.I. model with blower, the cost of drying 1 kg of fermented bean was as high as Re.0.56. Considering the quality of the dried beans in terms of moisture content and pH, the agitation type multistage drier with a capacity of 2000 kg is found to be the most effective and economic.

Table 21. Cost of drying one kilogram of permented beans in different types of driers

Sl.No.	Name of drier	Cost of drying per kg. (Re)
1	Bulb heated drier	0.50
2	Modified bulb heated drier with 500 watts electric coil	0.47
3	C.P.C.R.I. model	0.53
4	Modified C.P.C.R.I. model	0.36
5	Modified C.P.C.R.I. model with blower	0.56
6	Agitation type multistage drier capacity 90 kg	0.45
7	Agitation type multistage drier capacity 2000 kg	0.22

GRAPH No. 14



EXPENSE FOR DRYING ONE KG OF FERMENTED BEANS IN DIFFERENT TYPES OF DRIERS

FIG. No. 26

Summary

SUMMARY

Cocoa is one of the important beverage crops grown in Kerala. It is mainly grown as a mixed crop in coconut and arecanut gardens. The present area under cultivation of cocoa in Kerala is estimated to be 25,000 hectares and the annual production is about 4000 connes.

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 taste and flavour. Though large scale planting of the crop was taken up in this country during the seventies no serious attention was paid to its processing aspect.

The cocoa farmers of Kerala sell their cocoa pods to the nearest cocoa collecting centres or societies. The preliminary processing of fermentation and drying are done at the collection centres and subsequently these dried beans are sent to the secondary processing centres or factories.

Fermentation involves keeping a mass of cocoa beans well insulated so that the 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 up to seven days and is followed immediately by drying.

Drying constitutes the second part of curing. The objective of 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 7 to 8 per cent for safe storage. 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 outer side and may even penetrate the shell. There is a further danger that unpleasant flavours may also develop by slow drying. Where climate is favourable , drying is done in the sun.

For satisfactory drying and for large quantities of cocoa beans to be dried sun drying cannot be adopted under unfavourable weather conditions. The problem is especially severe in regions with heavy rain during the harvest period. In Kerala the rainy season concides with peak harvest and make sun drying difficult. To overcome this, artificial methods of drying becomes necessary.

Most of the existing driers utilise firewood or oil as heating source for air heating. The main drawbacks of these driers are the high cost of firewood and fuel oil as well as inadequacy in their availability. Sun drying is the most popular method followed in Kerala, though the peak harvest period coincides with the rainy season. This results in improper drying and deterioration in the quality of the cocoa product to a great extent. Artificial driers are not readily available in the market. Attempts were made in K.A.U. and C.P.C.R.I., for developing suitable driers for cocoa. K.A.U. developed a bulb heated drier, which has a capacity of 30 kg/loading. The C.P.C.R.I. developed an electric coil heated drier with a capacity of 50 kg/loading. Both these driers are suitable only for small scale processing.

It was decided to test the existing driers. It was also decided to modify the existing model to improve their efficiencies. The quality of the beans dried in the sun and different models were tested. The details are given below.

The cocoa beans after fermentation was dried in the sun. The process of drying continued upto seven days, before the desired dryness was obtained. pH of the dried bean was 5.2.

The rate of drying affects the pH of the dried beans. Quick drying decreases the pH of the beans or in other words increases the acidity of the beans. According to international standards pH varies from 5.3 to 5.6. The above value of pH (5.2) is close to it. Hence the quality of the bean was satisfactory.

A bulb heated drier developed earlier in K.A.U. was tested. The capacity of the drier was 30 kg of fermented beans. The bean could be dried to the desired moisture content in 38 hours. The moisture contents of the dried beans was about eight per cent. From the results it was seen that for drying one kg of fermented beans approximately 0.760 K.W.H. of electrical energy was required. pH of the dried beans was 5.00. The bulb heated drier fitted with a 500 watts electric coil heater was also tested. Beans could be dried to the desired moisture content in 34 hours. Moisture content of the dried beans was about eight per cent. Approximately 0.570 K.W.H. of electrical energy was required for drying, one kg of fermented beans. pH of the dried beans was 5.00. The cost of drying per kg of fermented beans was Re.0.47.

A modified C.P.C.R.I. model cocoa drier was fabricated and tested. The capacity of the drier was

60 kg of fermented beans. Beans could be dried to the required moisture content in 64 hours. Final moisture content of the dried beans was about eight per cent. The result revealed that approximately 0.530 K.W.H. of electrical energy was required for drying one kg of cocoa. Cost of drying per kg of fermented cocoa beans was Re. 0.36. Quality of the dried beans was satisfactory, because pH was 5.10.

The modified C.P.C.R.I. model fitted with a 0.5 h.p. electric motor and blower was also tested. Beans could be dried to the desired moisture content in 42 hours. Energy required for drying one kg of fermented beans was approximately 0.610 K.W.H. and the cost of drying per kg of fermented beans was Re. 0.56. pH of the dried beans was 5.2.

The primary aim of this project was to develop a low cost medium size drier for drying of cocoa without impairing its quality. With this in view an agitation type electrically heated multistage drier of 90 kg capacity was designed, fabricated, tested and its economics worked out. Prime mover of the blower was 0.5 h.p. variable speed motor. Rate of air flow was varied with the help of the variable speed motor coupled to the blower. In this drier tests were carried out with two quantities of cocoa (90 kg and 60 kg) two different rates of air flow (0.4 m^3/second, 0.2 m^3/second) and three different temperatures (56°C, 47°C and 42°C). Air temperature and humidity at various sections of the drier were noted. Also the weight loss of the bean at hourly interval was assessed using an infrared moisture meter. The pH of the dried beans was tested by using a digital pH meter. From the experiment conducted, using various quantities of beans, with different temperature and air flow, it was found that for drying 90 kg of cocoa beans, a temperature of 47°C and an air flow rate of 0.4 m^3/second were ideal for this type of drier. The energy consumed for drying was approximately 0.69 K.W.H. per kg of beans. The pH of the dried beans was 5.3 which was within safe limit. Cost of drying was Re.0.45.

Results of the above experiments revealed that uniformity in drying of cocoa beans could be achieved only with proper agitation and air flow. This could be achieved with the agitation type multistage drier.

One of the objectives of this project was to evolve suitable design of equipment for drying large quantities of cocoa beans. With this in view an agitation type multistage drier of 2000 kg capacity was designed. From the cost analysis it was found that the cost of drying one kg of beans was only Re. 0.22. The cost of drier was about Rs.23,000/-.

The advantage of agitation type multistage drier are as follows:

a) Due to the stage by stage drying the loss of heat is reduced and hence the thermal efficiency is high

b) Cost of drying was only 50 per cent of the other type of driers

c) Energy consumption was less compared to other type of driers

d) Drying time was reduced considerably

e) Uniformity in drying was achieved in this drier

f) As the beans were moving in the drier they were not exposed to high temperature, continuously, which helped in maintaining the quality of the beans.

References

REFERENCES

Anon. (1980). A knife for harvesting Cocoa and a small drier for cocoa beans. Central Plantation crops Res. Inst., Kasaragod, Pamphlet No. 15. 2-6.

Anon. (1981) Cocoa Drying - A Review. Cocoa growers bull., Cadbury Schweppes Ltd., England. 5-36.

*Ehsanullah, L. (1973). Mechanical Drying of Cocoa. World Crops 25 : 5-7.

Ganesan, V. (1982). Development of small scale equipment for Extraction of Cocoa Butter and Production of Cocoa Powder. M.Sc Thesis. Kerala Agrl. University, Vellanikkara.

Gosh, B.N. (1973). Drying cocoa beans by Gas: World Crops 25 : 232-237.

*Haynes, D.W.M. (1958). Cocoa Drying. Malaya Agric. J. 41 : 88-96.

Henderson, S.M. and Perry, R.L. (1954). Agricultural Process Engineering. The Avi Publishing Company, INC. pp. 302-339.

Jacob, Ralaiselvam and Annamalai. (1977). Optimising Air Flow Rate for Drying Paddy Grains with the allied Air. Pjt. work. Tamil Nadu Agric. University, Coimbatore. 1-26.

Jain, R.K. (1978). Machine Design (Mechanical Engineering Design). Khanna Publishers, Delhi 828-903.

Janardhanan, M.N., John, Nelson and Indirajith. (1978). Design and Development of a Test Ring for Studying the Drying Characteristics of Different Agricultural Products Project work. Tamil Nadu Agric. University, Coimbatore 10-25.

John, E., Zachariah, G. and Giridhar, R. (1981). Design and Development of a Small Scale Cocoa Processing Plant. Project Work Engg. College, Trichur, pp. 1-36.

Khurmi, R.S. and Gupta, J.K. (1979). A text book of machine design. Eurasia Publishing House (Pvt) Ltd., New Delhi, pp. 59-220.

Kumaran, K., Nair, P.C.S. and Nair, R.V. (1980). Studies on the methods of curing for small quantities of cocoa beans. Indian Cocoa Arecanut and Spices 4 : 42-44.

Kumaran, K. Nair, P.C.S. and Nair, R.V. (1980). Paper presented in the 1st Ann. workshop on Agric. Engg. and Tech. in Kerala at the College of Horticulture, Vellanikkara.

*Lawand, T.A. (1966). A Solar - Cabinet drier. Solar energy 10(4) : 158.

Lees, R. and Jackson, E.B. (1975). Sugar confectionary and Chocolate Manufacture. Chemical Publishing Co. Inc, New York. pp. 47-68.

Madavan, K. and Reddy, B. (1978). Design Data Hand Book for Mechanical Engineers. Sarala Press, Mangalore. pp. 160-207.

Michael, A.M. and Ojha, T.P. (1981). Principles of Agricultural Engineering Vol. I. Jain Brothers. New Delhi. p. 511-589.

Mohamed, S. (1977). Planning and Design of a Test Ring for Measuring Wear on Agricultural tools. Project work. Tamil Nadu Agric. University, Coimbatore.

Murugesan, V. (1982). Study on some Aspects of Heat and Mass Transfer Phenomena in Ground nut Dehydration. M.Sc Thesis. Tamil Nadu Agric. University, Coimbatore. pp.112.

Ongkhenghol. (1977). Cocoa bean processing a review. Division of Agriculture Abstr. pp. 509-530.

Pandya and Shah (1978). Machine Design. Charotar Book Stall. Anand pp. 707-795.

Perry, J.H. (1963). Chemical Engineering Hand Book. McGraw Hill, New York. pp. 249-333.

Premalatha, T. (1983). Studies on the fermentation and curing of cocoa beans. M.Sc (Hort) Thesis, Kerala Agric. University, Vellanikkara pp. 1-35.

Radheylal and Agrawal, K.K. (1968). Principles and Practice of Rice drying Indian Inst. Tech. Kharagpur. pp. 54-175.

Radeylal., Datta, A.C. (1979). Agricultural Engineering. Saroj Prakashan, Allahabad. pp. 342-418.

Rohan, T.A. (1963). Processing of Raw Cocoa for the Market. Agricultural Studies, Food and Agricultural Organisation of the United Nations, Rome. pp. 1-153.

Trikha. (1978). Machine Design Excercises. Khanna Publishers, Delhi. pp. 125-142 & 417-422.

Wood, G.A.R. (1957). Cocoa. Tropical Agriculture Series Longmans green Ltd., London. pp. 1-220.

Appendices

Appendix-I Agitation type Multistage drier of capacity 2000 kg - Design

a) Screw conveyer

The conveyer discharge capacity is 50 kg for one revolution of the scraper (Assume). As per the data available for rotary type cocoa driers rpm of the drier is below one rpm. Hence assume rpm of the drier is 0.9. That is one revolution takes 1.1 minutes.

Hence the discharge capacity is

$$\frac{50 \text{ kg}}{1.1 \text{ minutes}} = 45.45 \text{ kg}$$

It is found that 700 kg of cocoa beans taken for this study has a volume of 1 m^3.

$\therefore$ Volume of 45.45 kg $= \frac{45.45}{700}$

$= 0.0649285 \text{ m}^3/\text{minute}$

i.e. 6492.285 cm^3/minute

Giving space for two cocoa beans, take

pitch of the screw = 3.6 cm

Preliminary studies on the conveyer speed revealed that a speed between 70 to 75 rpm is optimum. Hence assume the screw rotates at 72 rpm.

In a minute the axial displacement $= 3.6 \times 72$ cm

$= 259.2$ cm

Minimum diameter required may be calculated using the equation

$$\pi/4\ d^2 \times 259.2 = 6492.85$$

Diameter

$$= \sqrt{\frac{6492.85 \times 4}{\pi \times 259.2}}$$

$$= 17.85 \text{ cm}$$

For the space occupied by the spindle conveyer blade etc, given an allowance of 25 per cent on diameter.

Hence the diameter of the spiral $= 1.25 \times 17.85$

$= 22.32$ cm

Take 'D' $= 24$ cm

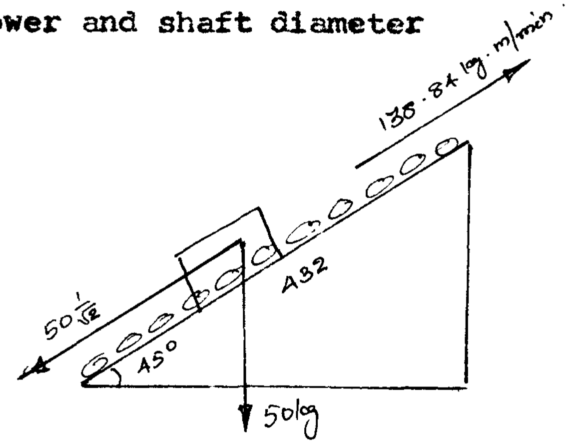
It is found that for uninterrupted fall of the cocoa beans from the drum through the chute and a smooth upward travel the conveyer should be set at 45° and should have a length of 4 to 4.5 metres. Hence for comparability assume 120 turns of the screw.

$\therefore$ Axial length $= 120 \times 3.6$

$= 432$ cm

Since the conveyer can have a maximum inclination of 45° in similar cases, the conveyer screw is set at an angle of 45° to the horizontal.

b) Spiral power and shaft diameter



In the ideal case the work done by the conveyer is the work required to lift 45.45 kg of cocoa per minute, through a distance of 432 cm x sin 45°. But major work has to be done in order to overcome the resistance. For the ideal case work done

$$= 45.45 \times 4.32 \times \frac{1}{\sqrt{2}}$$

$$= 138.84 \text{ kg,m/minute}$$

$$\therefore \text{ h.p.} = \frac{138.84}{4500}$$

$$= 0.0309$$

However, taking the friction into consideration assume that

$$\text{h.p.} = 0.5$$

$$\text{Torque on the conveyer shaft} = \frac{0.5 \times 4500}{2 \times \pi \times 72}$$

$$= 4.97$$

$$= 2.99 \times 100$$

$$= 497 \text{ kg cm}$$

497 kg cm

$$\frac{\pi d^3}{16} \times 350 = 497$$

$$d = \left[\frac{16 \times 497}{\pi \times 350}\right]^{1/3}$$

$$= 1.934 \text{ cm}$$

Assume a shaft size of 25 mm to account for weakening of the shaft due to spiral groove to accommodate the conveyer blades.

c) **Support of the drier**

From actual measurement weight of the motor unit was 125 kg, weight of the reduction geat unit was 155 kg and the weight of the drying unit, 3000 kg (including 2000 kg of cocoa beans).

Effect of eccentric load $= \frac{125}{3}$ on one column

Load due to resisting moment, let it be F_1. Thus

$$F_1 r_1 + F_1 r_2 + F_1 r_3 = 125 \times 82.7$$

$$\therefore F_1 = \frac{125 \times 82.}{(104+62+86)}$$

$$= 40.67 \text{ kg}$$

Load due to driving gears $= \frac{160}{3} = 53.3$

Load due to drum and contents $= \frac{3000}{3} = 1000$ kg

Total $= \frac{125}{3} + 40.67 + 1000 + 53.3$

$= 1136.64$ kg

Assume that 'C' section supported the set up. Treating the support as long column

Rankain's formula

$$P = \frac{f_c \cdot A.}{1 + a \left(\frac{l}{K}\right)^2}$$

$$1136.64 = \frac{f_c \times 6}{1 + \frac{1}{7500}\left(\frac{300}{2.54}\right)^2}$$

$$f_c = 541.3 \text{ kg/cm}^2$$

Steel can safely take a compressive stress of more than 1000 kg/cm^2.

Hence, factor of safety $= \frac{1000}{541.3} = 1.85$ Hence

This is Safe

d) Fixed tray

The plate may be considered as a circular plate supported at the ends and subjected to a uniformly distributed pressure over the entire area.

Circular plate uniformly loaded, the thickness of the plate with a diameter, 'D', supported at the circumference and subjected to a uniformly distributed pressure 'p' over total area, is given by

$t = C_1 \; D \sqrt{P/f}$

Where C_1 = Coefficient which may be taken as 0.42 for M.S.

$f = 800 \; kg/cm^2$ for M.S.

$A = \pi/4 \; (D^2 - d^2)$

$A = \pi/4 \; (100^2 - 5^2)$

$= 7834.34 \; cm^2$

$P = \frac{50}{7834.34}$

$= 6.382 \times 10^{-3} \; kg/cm^2$

$t = 0.42 \times 100 \times \sqrt{\frac{0.006382}{800}}$

$= 0.118 \; cm$

For rigidity take, $t = 3$ mm

e) Scraper

Torque on the scraper spindle may be calculated from the following facts.

As the scraper has to distribute the cocoa beans over the plate, assume

Horse power = 2

As per the data available, for rotary type cocoa driers rpm is below one. Hence assume rpm of the drier is 0.9

Torque T $= \frac{h.p. \times 4500 \times 100}{2 \times \pi \times N}$

$= \frac{2 \times 4500 \times 100}{2 \times 0.9 \times \pi}$

$= 159154.94$ kg cm

This torque is shared by 20 scrapers.

Torque of each scraper $= \frac{159154.94}{20}$

$= 7957.75$ kg cm

Length of each scraper $= 49$ cm

Assume 2.5% of this amount as a resistance moment offered by the cocoa beans. This creates bending moment on the scraper.

Bending moment on each scraper $= \frac{2.5}{100} \times 7957.75$

$= 198.94$

Bending moment $= \frac{6 \times b^2 \times f}{6}$

Assume a width of 2 cm,

$\frac{t \times 2^2 \times 800}{6} = 198.94$

t $= \frac{198.94 \times 6}{2^2 \times 800}$

$= 0.373$ cm

Take thickness t $= 1$ cm

f) Coupling

The diameter of the output shaft is 5 cm. The hub diameter 1.6 x the diameter of the shaft

∴ Hub diameter = 1.6 x 5 = 8 cm

Let the thickness of the flange = ½ x D = ½ x 5
= 2.5 cm

Let there be 3 pins arranged in the periphery of a circle of diameter 1.9 D

Say 95 mm

Let the pin diameter be 10 mm

The overall diameter of the flange will be

2.5 x diameter = 2.5 x 5 = 12.5 cm

The coupling on the drier shaft will be similar in dimensions but instead of the projecting pins, the flange will carry holes, to house the projecting pins. This is shown in the diagram. The overall length of each flange including the hub will be taken as

1.5 d = 1.5 x 5 = 7.5 cm

g) Gear drive

Horse power = 2
Input speed = 1440 rpm (motor speed)

At the first stage, this is reduced with the help of a worm to a speed ratio of 1:40. The wheel shaft at the first reduction has a spur gear, which drive another counter shaft, that carries another step, the speed ratio being again 1:40, thus the output shaft speed is

$$1/4 \times 1/40 \times 1440 = 0.9 \text{ rpm}$$

The two worm drives are identical. The worm and gear design and the spur gear design are as follows:

i) Worm gear

The centre distance equation is

$$\frac{C}{\alpha n} = \frac{1}{2\pi}\left[\frac{1}{\sin\alpha} + \frac{VR}{\cos\lambda}\right]$$

Where 'C' is the centre distance between shaft n is the normal lead

λ is the lead angle

VR is the velocity ratio

The value of $\frac{C}{\alpha n}$ will be least, corresponding to the condition that the velocity ratio

$$VR = \cot^3\lambda$$

$$40 = \cot^3\lambda$$

$$\cot\lambda = 3.42$$

$$\lambda = 16.29^\circ = 16^\circ$$

The centre distance between the shaft will be assumed as 80 mm

$$\frac{C}{\lambda n} = \frac{1}{2\pi}\left[\frac{1}{\sin\lambda} + \frac{VR}{\cos\lambda}\right]$$

$$\frac{8}{\lambda n} = \frac{1}{2\pi}\left[\frac{1}{\sin 16} + \frac{40}{\cos 16}\right]$$

λn (Normal lead)

$$= \frac{16\pi}{\left[\frac{1}{\sin 16} + \frac{40}{\cos 16}\right]}$$

$= 1.11$

Axial lead $\frac{n}{\cos}$ $= \frac{1.11}{\cos 16} = 1.15$

Number of starts on the worm will be 1 (single start)

Axial pitch $= 1.15$ cm

Module m $= \frac{p}{\pi} = \frac{1.15}{\pi}$

$= 0.366$

Choose a module of 4 mm

Axial pitch $= \pi \times m = \pi \times 0.4$

$= 1.26$ cm

Normal pitch $= 1.26 \times \cos 16$

$= 1.21$ cm

Centre distance 'C'

$$\frac{C}{\lambda n} = \frac{1}{2\pi}\left[\frac{1}{\sin\lambda} + \frac{VR}{\cos\lambda}\right]$$

$$= \frac{1}{2\pi}\left[\frac{1}{\sin 16} + \frac{40}{\cos 16}\right]$$

$\frac{C}{\lambda n}$ = 7.2

C = 7.2 x 1.11 = 7.992 cm

C = 8 cm

Number of teeth on gear = Number of threads on worm x velocity ratio

= 1 x 40 = 40

Pitch diameter of worm 'd' = $\frac{p}{\pi \tan \lambda}$ = $\frac{1.26}{\pi \tan 16}$

= 1.4 cm

Addendum circle diameter = d + 2 m

= 1.4 + 2 x .4

= 2.2 cm

Didendum circle diameter = 2 - 2 m

= 1.4 - 2 x 0.4

= 0.6 cm

Length of threaded portion = l

l = (1.25 + 0.09 + ng) m

ng = No. of teeth on gear

l = (12.5 + 0.09 x 40) 0.4

l = 6.44 cm

Allowing for the feed marks for the grinding wheel the the length will be taken as 8 cm

Pitch diameter of the worm wheel D	= 40 x 0.4	= 16 cm
Addendum circle diameter	= D + 2 m	
	= 16 + 0.4 x 2	
	= 16.8 cm	
Didendum circle diameter 'D_d'	= 16 - 0.4 x 2	
	= 15.2 cm	
Out side diameter	= Da + 1.5	
	= 16.8 - 1.5	
	= 18.3 cm	
Rim width	= 0.67 Da	
	= 0.67 x 16.8	
	= 11.256 cm	

ii) Spur gear

Let D_g be the diameter of the gear and D_p be the diameter of the pinion assume the centre distance to be 9 cm.

$$\frac{D_g + D_p}{2} = 9 \text{ cm}$$

The gear ratio

$$\frac{D_g}{D_p} = 1$$

$$D_g = D_p$$

$$\therefore D_g = D_p = 9 \text{ cm}$$

The speed ratio of gears $= \frac{1440}{40}$ = 36 rpm

∴ Pitch line velocity $= \pi D_g \times N_g$ metres/minute

Where, N_g = rpm of the gear

Pitch line velocity $= \pi \times 0.09 \times 36$

= 10.18 metres/minute

The tangential load f_t $= \frac{h.p. \times 4500 \times C_s}{v}$

Where 'v' is the pitch line velocity

Where 'C_s' is the service factor

Assume C_s as 1.2

∴ f_t $= \frac{2 \times 4500 \times 1.2}{10.18}$

= 1060.90

Using the "Lewis" equation

f_t = s.b.y.p.

Where f_t = Tangential load

s = allowable dynamic stress

b = Face width

y = Lewis factor

p = Circular pitch

s $= \beta_d C_v$

Where β_d = Permissible static stress

Assume	$\mathscr{P}_d$	$= 1400\ kg/cm^2$
	C_v	$= \frac{4.58}{4.58 + v}$
Where	v	= Pitch line velocity
	C_v	$= \frac{4.58}{4.58 + 10.18}$
		= 0.310 metres/second
	s	$= 1400 \times 0.31 \quad = 434\ kg/cm^2$
	b	= Face width = 10 module
		= 10 m
	y	$= 0.124 - \frac{0.684}{z}$
Where	z	= Number of teeth
	y	$= 0.124 - \frac{0.684}{z}$
Assume	'm'	= 6
∴	6	$= \frac{90}{z}$
	z	$= \frac{90}{6} \quad = 15$ teeth
	y	$= 0.124 - \frac{0.684}{15} = 0.0$
		= 0.0784
	p	$= \pi \times m$
	f_t	= s.b.y.p.
	1060.9	$= 434 \times 10\ m \times 0.0984 \times \pi \times m$
	$\frac{1060.9}{434 \times 10 \times 0.784 \times \pi}$	$= m^2$
	m	$= \sqrt{\frac{1060.9}{434 \times 10 \times 0.0784 \times \pi}}$
		= 0.996

Take a module as 10

Number of teeth on gear	$= \frac{90}{10}$	= 9 teeth
Addendum	= m	= 10
Didendum	= 1.25 m	
	= 12.5 mm	
Tooth thickness	= 1.5708 m	
	= 15.708 mm	
Tooth space	= 1.5708 m	
	= 15.708 mm	
Working depth	= 2 m	
	= 20 mm	
Whole depth	= 2.25 m	
	= 22.5 mm	
Clearance	= 0.25 m	
	= 2.5 mm	
Pitch diameter	= zn	
	= 9 x 10	= 90 mm
Outside diameter	= (Z + 2)m	
	= 110 mm	
Root diameter	= (z - 2.5 m)	
	= 65 mm	
Fillet radius	= 0.4 m	
	= 4 mm	

h) **Screw conveyer gear**

Velocity ratio = 10 (Assume)

Centre distance = 5 cm (Assume)

$$\frac{C}{\alpha n} = \frac{1}{2\pi}\left[\frac{1}{\sin \lambda} + \frac{VR}{\cos \lambda}\right]$$

Where, 'C' is the centre distance between the shaft

n is the normal lead

$$VR = \cot^3$$

$$10 = \cot^3 \lambda$$

$$\cot \lambda = 2.15$$

$$\lambda = 25°$$

The centre distance between the shaft will be assumed as 5

$$\frac{5}{\alpha n} = \frac{1}{2\pi}\left[\frac{1}{\sin 25°} + \frac{10}{\cos 25°}\right]$$

αn (Normal lead)

$$= \frac{10\pi}{\left[\frac{1}{\sin 25} + \frac{10}{\cos 25}\right]}$$

$$= 2.34 \text{ cm}$$

Axial lead $= \frac{\alpha n}{\cot} = \frac{2.34}{\cos 25}$

$$= 2.58 \text{ cm}$$

Number of starts on the worm will be 2 (Double start)

Axial pitch $= \frac{2.58}{2} = 1.29$ cm

Module m $= \frac{p}{\pi} = \frac{1.29}{\pi}$

$$= 0.41$$

Choos a module of 4 mm

Axial pitch $= \pi \times 0.4 = 1.26$ cm

Normal pitch $= 1.26 \times \text{Cos } 25$

$= 1.14$ cm

$$\frac{C}{\alpha n} = \frac{1}{2\pi}\left[\frac{1}{\text{Sin } 25} + \frac{10}{\text{Cos } 25}\right]$$

$$C = \frac{\alpha n}{2}\left[\frac{1}{\text{Sin } 25} + \frac{10}{\text{Cos } 25}\right]$$

C= $= 4.99 = 5$ cm

Number of teeth on gear = Number of threads on worm x velocity ratio

$= 2 \times 10 = 20$

Pitch of worm 'd' $= \frac{\text{Lead}}{\pi \tan \lambda} = \frac{2.34}{\pi \times \tan \lambda}$

d $= 1.6$ cm

Addendum circle diameter $= d + 2 \times m$

$= 1.6 + 2 \times 0.4$

$= 2.4$ cm

Didendum circle diameter $= d - 2\,m$

$= 1.6 - 2 \times 0.4$

$= 0.8$ cm

Length of the threaded portion= 1

$$1 \geq (12.5 + 0.09 \times n_g)\ m$$

$$1 \geq (1.25 + 0.09 \times 10)\ 0.4$$

$$1 = 5.36 \text{ cm}$$

Allowing for the feed mark for the grinding wheel the length will be taken as 6 cm

Pitch diameter of the worm wheel

	D	= No. of thread x m
		= 20 x 0.4 = 8 cm
Didendum diameter	Dd	= 8 - 0.4 x 2
		= 7.2 cm
Addendum diameter	Da	= D + 2 m
		= 8 + 0.4 x 2
		= 8.8 cm
Outside diameter	Do	= Da + 1.5
		= 8 + 1.5 = 9.5 cm
Rim width		= 0.67 x 8
		= 5.36 cm

i) Heating coil

Heating coil is designed based on the result obtained from the prototype studies. The moisture content of freshly fermented beans was found to be 55%. The recommended moisture content for safe storage is 6%. The moisture content of the freshly fermented beans used for the prototype studies was 55%. This was brought down to 6%, after 15 hours of drying, in the prototype model.
(90 kg, 0.4 m^3/second, 47°C).

Energy required $= 3 \times 15 = 45$ K.W.H.

The heat energy required to dry 90 kg of beans $= \dfrac{m \times L.H.V.}{\eta_t}$

Where m = Amount of moisture removed in kg

$$m = \frac{Q_1\ (Mwb_1 - Mwb_2)}{(1 - Mwb_2)}$$

$$= \frac{90\ (0.55 - 0.06)}{(1-0.6)}$$

$$= 46.91 \text{ kg}$$

$$45 \times 860 \text{ kilocalories} = \frac{m \times L.H.V.}{\eta_t}$$

$$\eta_t = \frac{m \times L.H.V.}{45 \times 860}$$

$$= \frac{46.91 \times 600}{45 \times 860}$$

$$\eta_t = 0.727$$

Take $\eta_t = 73\%$

Heating coil capacity of 2000 kg drier = ?

The heat energy required to dry 2000 kg of cocoa beans from an initial moisture content of 55% to a final moisture content of 6%

$$= \frac{m \times L.H.V.}{\eta_t}$$

$$m = \frac{Q_1\ (Mwb_1 - Mwb_2)}{(1 - Mwb_2)}$$

$$= \frac{2000\ (0.55 - 0.06)}{(1 - 0.06)}$$

$= 1042.55$ kg

∴ Heat energy required $= \frac{1042.55 \times 600}{0.73}$

$= 856890.4$ kilocalories

But 860 kilocalories $= 1$ K.W.H.

∴ Electric energy required $= \frac{856890.4}{860}$

$= 996.38$ K.W.H.

From the result obtained from prototype model, total drying time = 15 hours

∴ The heating coil capacity $= \frac{996.38}{15}$

$= 66.42$ K.W.H.

Take 67 K.W.H.

Appendix-II Economic analysis of different types of driers

i) Bulb heated drier

Cost of drying of one kg of fermented beans = Re. 0.50
(from literature review)

ii) Modified bulb heated drier with 500 watts electrical coil heater

Manufacturing cost of the structure of the drier	= Rs. 500.00
Electrical coil heater	= Rs. 250.00
Total manufacturing cost	= Rs. 750.00

Running cost for one year $\frac{365}{3}$ = 121 loadings

After deducting repair and maintenance time etc. take 100 loading

For each loading quantity of fermented cocoa beans = 30 kg

For 100 loading total quantity of fermented beans dried = 30 x 100
= 3000 kg

For each kg of fermented beans, energy required = 0.56666 K.W.H.

$$\left(\frac{0.500 \times 34}{30} = 0.56666 \right)$$

Labour charges for each loading = Rs.8/- (Approximate)

Total labour charges for 100 loading = Rs.800/-

For 3000 kg of fermented beans energy required = 0.56666 x 3000

= 1700 K.W.H.

Total energy charges for 3000 kg of fermented beans @ Re.0.30/K.W.H. = Rs.510/-

Total running charges for 100 loading = Rs.510 + 800

= Rs.1,310/-

Considering maintenance and repairs

Maintenance and repairs (3% of fixed cost) = $\frac{3}{100}$ x 750

= Rs.22.50

Depreciation (10% of fixed cost) = $\frac{10}{100}$ x 750

= Rs.75/-

Total expense for drying 3000 kg of fermented cocoa beans = Rs.1,310 + 22.5 + 75

= Rs.1,407.50

Drying expense per kg of fermented cocoa beans = $\frac{1407.50}{3000}$

= Re. 0.469

Say Re. 0.47

iii) C.P.C.R.I. model drier

Manufacturing cost of the drier = Rs. 1,500.00

Running cost for one year $\frac{365}{4}$ = 91.5 loadings

After deducting repair and maintenance time etc. take 90 loadings for each loading, quantity of

Fermented cocoa beans dried	= 40 kg
For 90 loadings total quantity of fermented cocoa bean dried	= 3600 kg
For each kg of beans energy required	= 0.8125 K.W.H.
For 3600 kg of fermented beans energy required	= 0.8125 x 3600
	= 2925 K.W.H.
Total energy charges @ 0.30/K.W.H.	= 2925 x 0.30
	= Rs.877.50
Labour charges for each loading unloading, mixing etc.	= Rs. 9/-
Total labour charges	= 9 x 90 = Rs.810/-
Total running charges for 90 kg	= Rs.810 + 877.5
	= Rs.1,687.50

Consider maintenance and repair

Maintenance and repair (3% of fixed charges)	$= \frac{3}{100} \times 1500$
	= Rs. 45/-
Depreciation (10% of F.C.)	$= \frac{10}{100} \times 1500$
	= Rs.150/-
Total drying expense for 3600 kg of fermented cocoa	= 1687.5 + 45 + 150
	= Rs.1,882.50

Drying expense/kg of fermented cocoa beans $= \frac{1882.5}{3600}$

= Re. 0.53

iv) Modified C.P.C.R.I. model

Fixed cost

Sl.No.	Particulars	Cost
1	Single phase 230 volts, 50c/s, Electric heater 500 watts	= 250.00
2	Plain glass 1" x ¾" x 1/8" size, 2 Nos	= 28.00
3	Hard wood reaper 32 m	= 83.00
4	Reaper bundle 1" - 1 bundle	= 52.00
5	2" x 2" x ¼" M.S.flat 10 kg	= 60.00
6	1¼" x 1" angle iron 10 kg	= 60.00
7	Wiremesh 15' x 3' - 1 No.	= 152.00
8	Asbestos sheet 6' x 4'-2 Nos	= 166.00
9	Nut, bolt, nails, screws etc	= 50.00
10	Varnish, primer paints etc.	= 80.00
11	1½" x 1" angle iron 5 kg	= 30.00
12	Labour charges and miscellaneous items	= 239.00
		1250.00

Running cost

Time taken for completion of the drying = 64 hours

Electrical energy required for drying (each loading	= 0.500 x 64
	= 32 K.W.H.
Energy charges @ Re.0.30/K.W.H. for each loading	= Rs. 9.60
Labour charges for each loading	= Rs.10.00 (Approximately)
For one year $\frac{365}{4}$	= 91.25 loading

After deducting maintenance and repair, take 90 loadings

for 90 loadings, total quantital of fermented beans dried	= 90 x 60
	= 5400 kg
Electric energy required for drying 1 kg of fermented beans	= $\frac{32}{60}$
	= 0.5333 K.W.H.
Electric energy required for drying 5400 kg of cocoa beans	= 0.533 x 5400
	= 2879.98 K.W.H.
Total energy charges @ Re.0.30/K.W.H.	= 2879.98 x 0.3
	= Rs. 863.99
Labour charges for 90 loading	= 90 x 10
	= Rs. 900.00
Total running cost	= 863.99 + 900.00
	= Rs. 1,763.99

Consider maintenance and repair and depreciation

Maintenance and repair (3% of fixed charges)	$= \frac{3}{100} \times 1250$
	= Re. 37.50
Depreciation, 10% of fixed cost	$= \frac{10}{100} \times 1250$
	= Rs.125.00
Total expense for drying 5400 kg of fermented beans	= 1763.99 + 37.50 + 125.00
	= Rs. 1926.49
Drying expense/kg of fermented beans	$= \frac{1926.49}{5400}$
	= Re. 0.36

v) Modified C.P.C.R.I. model with ½ h.p. motor and blower

Manufacturing cost of the structure of the drier	= Rs. 1000.00
Electric coil heater	= Rs. 250.00
½ h.p. electric motor, blower and its' fittings	= 1500.00
	2750.00

Running cost (for one year)

For one year $\frac{365}{2}$ = 182.5 loadings

After reducing maintenance time etc., take 150 loadings.

Quantity of fermented beans dried for each loading	= 60 kg
For 150 loading	= 60 x 150
	= 9000 kg

Energy required for each kg of fermented beans	$= \frac{(500 + 373) \times 42}{60}$
	= 0.6111 K.W.H.
Energy required for 9000 kg of fermented beans	= 0.6111 x 900
	= 5499.9 K.W.H.
Total energy charges @ Re. 0.30/K.W.H.	= Rs. 1649.97
Labour charges for each loading	= Rs. 26.00 (Approximately)
Total labour charges for 150 loading	= 20 x 150
	= Rs. 3000.00
Total running charges	= 1649.97 + 3000.00
	= Rs. 4649.97

Consider maintenance and repair charges and depreciation

Maintenance charges (3% of fixed charges)	$= \frac{3}{100} \times 2750$
	= Rs. 82.50
Depreciation (10% of fixed charges)	$= \frac{10}{100} \times 2750$
	= Rs. 275.00
Total expenses for drying 9000 kg of fermented beans	= 4649.97 + 82.50 + 275.00
	= Rs. 5007.47
Drying expenses per kg of fermented beans	$= \frac{5007.47}{9000}$
	= 0.556
	= Re. 0.56

vi) Agitation type, multistage drier (capacity 90 kg)

Fixed cost (Manufacturing cost of the drier)

Sl.No.	Particulars	Cost (Rs)
1	Reduction gear box, horizontal to vertical drive, speed reduction 1:1600 using worm and spur gear for fitting a motor of rating 1 h.p.	2,000.00
2	1 h.p.electric motor	1,000.00
3	Axial type blower with 0.5 h.p. motor	1,000.00
4	Electric heater 4.5 K.W., suitable for operation from 440 V, three phase 50 cycle, A.C., complete with thermostat control	1,500.00
5	C. Channel 50 kg	350.00
6	Worm and pinion 1 set	100.00
7	Electric goods, including, starter etc.	700.00
8	100 mm thick M.S. sheet 50 kg	300.00
9	20 gauge M.S. sheet 1 no.	250.00
10	1¼" x 1" Angle iron ½ full length	70.00
11	M.S. rod for shaft 25 mm 15 kg	100.00
12	Flange coupling 1 set	50.00
13	Belt 3 Nos.	75.00
14	V pully 2 Nos.	50.00
15	Ball bearing 4 Nos.	100.00
16	Taper roller bearing	25.00

17	Paint and primer	50.00
18	Other materials	100.00
19	Fabrication charges	1,500.00
	Total =	9,320.00

Running cost

For one year $\frac{365}{2}$ = 182.5 load

After deducting maintenance and repair time, take 150 loadings

For each loading, quantity of fermented cocoa beans = 90 kg

For 150 loading, quantity = 90 x 150

= 13500 kg

For each loading electrical energy required

(Take 90 kg, 47°C, 0.4 m^3/second loading)

15 x (3 K.W.H. + ½ K.W.H. + 1 K.W.H.) = 67.5 K.W.H.

Energy charges @ Re. 0.30/K.W.H. for each loading = 67.5 x 0.3

= Rs. 20.25

Total energy charges for 150 loadings = 20.25 x 150

= Rs.3037.50

Labour charges for each loading = Rs. 12.00

Total labour charges of 150 loading = 150 x 12

= Rs. 1800.00

Total running cost for 150 loading = 3037.5 + 1800

= Rs.4837.50

Consider maintenance and repair and depreciation also

Maintenance and repair charges (3% of fixed charges) = $\frac{3}{100}$ x 9320

= Rs. 279.60

Depreciation (10% of fixed charges) = $\frac{10}{100}$ x 9320

= Rs. 932.00

Total expenses, for drying 13500 kg of fermented cocoa beans = 4837.5 + 279.60 + 932.00

= 6049.10

Drying expense per kg of fermented beans = $\frac{6049.10}{13500}$

= Re. 0.448

= Re. 0.45

vii) Agitation type multistage drier (capacity 2000 kg)

Cost analysis

A. Manufacturing cost of the drier

Sl.No.	Particulars	Cost (Rs)
1	Reduction gear box, horizontal to vertical drive, speed reduction 1600:1, using worm and spur gear for fitting a motor of rating 2 h.p. 1 No.	3,000.00

Sl.No.	Particulars	Cost (Rs)
2	2 h.p. electric motor - 1 No	2,000.00
3	Axial flow type blower with 1 h.p. motor	2,500.00
4	Electric heater 67 KW, suitable for operation from 440 V, three phase, 50 cycle, A.C. complete	5,000.00
5	'C' Channel - 100 kg	700.00
6	Worm and pinion - 1 set	250.00
7	Electrical goods including starter etc.	1,000.00
8	10 mm thick M.S. sheet - 200 kg	1,200.00
9	20 gauge M.S. sheet 2 Nos	500.00
10	$1\frac{1}{4}$" x 1" angle iron one full length	150.00
11	M.S. rod for shaft 75 mm, 50 kg	400.00
12	Flange coupling 1 set	100.00
13	Belt - 3 Nos	150.00
14	V - Pully - 2 Nos	100.00
15	Ball bearing 4 Nos	200.00
16	Taper roller bearing	50.00
17	Paint and primer	200.00
18	Other materials	1,000.00
19	Fabrication charges	2,500.00
20	Miscellaneous items	2,000.00
	Total	23,000.00

B. Running cost (for one year)

For one year $\frac{365}{2}$ = 182.5 loading

After reducing maintenance time etc., take 150 loading

For each loading, quantity of loading	= 2000 kg
For 150 loading	= 150 x 2000
	= 300000 kg
For each loading electrical energy required	= (67 + = + 2) x15
	= 70 x 15
	= 1050 K.W.H.
Energy required for drying 1 kg of fermented beans	= $\frac{1050}{2000}$
	= 0.525 K.W.H.
Labour charges for each loading and unloading	= Rs. 100.00
Total energy charges for each loading, @ Re. 0.30/K.W.H.	= 1050 x 0.3
	= Rs. 315.00
Total running charges	= 315 + 100
	= Rs.415.00

Considering maintenance and repair and depreciation also, then

For each loading electrical energy required	= 1050 K.W.H.
For 150 loading, electrical energy required	= 1050 x 150
	= 157500 K.W.H.

Total energy charges @ Rs.0.30/K.W.H.	= 47250.00
Total quantity of cocoa dried	= 2000 x 150
	= 300000 kg
Total labour charges for 150 loading	= 150 x 100
	= Rs.15000.00
Maintenance and repairs (3% of fixed cost)	= $\frac{3}{100}$ x 23000
	= Rs. 690.00
Depreciation (10% of fixed cost)	= $\frac{10}{100}$ x 2300
	= Rs. 2300.00
Total expense for drying 300000 kg of cocoa beans	= 47250 + 15000 + 690 + 2300
	= Rs. 65240.00
Drying charges per kg of fermented beans	= $\frac{65240}{300000}$
	= Re. 0.217
i.e.	= 22 paise

DEVELOPMENT OF COCOA DRIER

By

M. ABDASSALAM

ABSTRACT OF THE THESIS

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ABSTRACT

An investigation for the development of an electrically heated, multistage, agitation type cocoa drier, suitable for the Kerala conditions for drying of cocoa beans without impairing the quality, was conducted in the Agricultural Engineering Department of the College of Horticulture under the Kerala Agricultural University.

The mini box fermentation method developed in Kerala Agricultural University was selected for fermentation of the beans. The fermented cocoa beans were dried in the sun. The process of sun drying continued upto seven days. The pH of dried beans was 5.2, which was very close to the pH range, 5.3 to 5.5 for good quality beans as per international standards. Hence, the quality of the beans was considered satisfactory.

A bulb heated drier developed earlier in K.A.U. was tested. The capacity of the drier tested was 30 kg of fermented beans. The bean could be dried to the desired moisture content in 38 hours. The moisture content of the dried beans was about eight per cent. From the result it was found that for drying one kg of

fermented beans approximately 0.760 K.W.H. of electrical energy was required. pH of the dried beans was 5.00.

The bulb heated drier was modified and fitted with a 500 watts electric coil heater was also tested. Beans were dried to the desired moisture content in 34 hours. Moisture content of the dried beans was about eight per cent. The result showed that approximately 0.57 K.W.H. of electrical energy was required for drying one kg of fermented beans. The quality of the dried bean was satisfactory because pH of the dried beans was 5.0. The cost of drying per kg of fermented beans was Re.0.47.

A modified C.P.C.R.I. model drier of capacity 60 kg of fermented beans was fabricated, tested and economics worked out. For attaining the required moisture content of about eight per cent, the time taken was 64 hours. The result revealed that approximately 0.533 K.W.H. of electrical energy and an amount of Re. 0.36, was required for drying one kg of fermented beans. pH of the dried bean was 5.1 and hence quality of the dried bean was also satisfactory.

The modified C.P.C.R.I. model drier fitted with an half h.p. electric motor and a blower was also tested. Beans were dried to the desired moisture content in 42 hours. The result showed that for drying one kg of fermented beans approximately 0.610 K.W.H. of electrical energy was required. Cost of drying per kg of fermented bean was Re. 0.56. Quality of the dried beam was satisfactory since pH was 5.2.

An agitation type electrically heated multistage drier of 90 kg capacity was designed, fabricated, tested and its economics was worked out. Tests were carried out with two quantities of cocoa (i.e. 90 kg, and 60 kg), different quantity of air (i.e. 0.4 m^3/second, 0.2 m^3/second) and varying temperatures (i.e. 56°C, 47°C and 42°C). Air temperature and humidity at various sections of the drier were noted. Also the weight loss of the bean at every hour of drying was noted by using an infrared moisture meter, and the final pH of the dried bean by using a pH meter. From the experiment, using various quantities of beans, with different temperature and air flow, it was found that for drying 90 kg of cocoa beans a temperature of 47°C and air flow rate of 0.4 m^3/sec was optimum, for this type of drier. The energy consumed/kg of bean was appromimately 0.69 K.W.H. The pH of the dried beans was found to be 5.3 and hence the quality of the dried bean was satisfactory. Cost of drying per kg of fermented bean was Re. 0.45.

One of the objectives of this project was to evolve suitable design of an equipment for drying large quantities of cocoa beans.

With this in view an agitation type multistage drier of 2000 kg capacity of fermented beans was designed. From the cost analysis it was seen that the cost of drying one kg of bean was only Re. 0.22. The cost of the drier was about Rs.23,000/-.

The advantage of agitation type multistage drier are as follows.

As the beans were moving in the drier better uniformity in drying was achieved and they were not exposed to high temperature continuously which helped in maintaining the quality of the beans. The drying time was reduced considerably. Energy consumption was less and cost of drying was only 50 per cent compared to other driers. Due to stage by stage drying the loss of heat is reduced and hence the thermal efficiency is high.