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DRYING AND PROCESSING RESEARCH AT IRRI

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The development of a low-cost farm drying and processing equipment that would be suitable for use and manufacture in the developing countries is of urgent neccessity. Such equipment could be used by the medium-size farm holdings of 2 to 10 hectares which constitute a large portion of the land under paddy cultivation in Southeast Asia. Very few attempts have been made by private manufacturers on the development of small drying and processing equipment. Research and development on low-cost drying and processing equipment for small-scale operation is one of the important areas of activities at the Agricultural Engineering department of the Institute. ~~The programs achieved so far in this area is discussed.~~

~~To produce a low-cost, functional and durable grain drier, the following design criteria were considered:~~

1. The drier should use a low-cost burner and fuel.
2. The blower should be driven by either an electric motor or an engine. If engine -driven, the excess engine heat should be utilized.
3. The burner unit should be interchangeable to use other low-cost fuel burner.
4. The fuel safety control valve should be mechanically actuated.
5. The grain bin should be portable.

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DRYING AND PROCESSING RESEARCH AT IRRI

by

A. S. Manalo, J. R. Arboleda and A. U. Khan [1]

Rice must be harvested as it matures or when the moisture content is between 20 and 30 percent (wet basis). The harvested paddy must be dried to 14 percent (w.b.) and processed before it is ready for consumption. Improper drying and processing procedures may result in a sizeable amount of grain loss.

Modern rice drying and processing plants for commercial scale operation are being established in the developing countries to cater primarily the urban population. In the countries of Southeast Asia, with about 50 to 70 percent of the population in the rural areas, much of the rice consumed is processed with the traditional methods and with obsolete equipment.[2] Sun drying of fresh paddy is the most common method. High grain losses are incurred due to sun checks which produce low head rice yields and result in high bran production in milling. The farmer has very little control in the sun drying operation and sprouting and other forms of spoilage are often common during the wet season.

Milling by hand-pounding with mortar and pestle is still practiced in the remote rural areas. The steel huller (Engleberg) or kiskisan, however, is the most popular milling equipment in the region. This type of rice mill removes the hull and bran in one operation by subjecting paddy to high friction under great pressure. It is characterized by a large amount of brokens, excessive bran production, and high power requirement. Compared with the modern rice mills, the average reduction in milling is 6.6 percent in total yield and 15.4 percent in head yield.[3] Some governments in Southeast Asian countries are banning further installation of steel huller mills.

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[1]/Assistant Agricultural Engineer, Research Assistant, and Head, respectively, Agricultural Engineering Dept., IRRI.

[2]/Khan, A. U. Rice drying and processing equipment for Southeast Asia. Paper presented at the 1972 Annual Meeting of the American Society of Agricultural Engineers, Hot Springs, Arkansas, June 27-30.

[3]/Wimberly, J. Review of storage and processing of rice in Asia. Paper No. 72-01. Prepared for the Agricultural Engineering Dept., IRRI. January 1972. (Mimeo.)

Parboiling of paddy is popular in some countries like India, Pakistan, Ceylon, and Bangladesh. It is a process in which paddy is soaked in cold or hot water and then followed by a steaming and drying operation. Parboiling gelatinizes starch granules and welds fissures in the grain. The process results in an increase of 5 to 10 percent in head rice yield and 1 percent in total grain recovery. The traditional method consists of soaking paddy for 2 to 4 days, steaming for a short time, and drying. It is a high-labor, time-consuming operation. The traditional method of parboiling is often unhygienic and the rice acquires a peculiar flavor.

The development of a low-cost farm drying and processing equipment that would be suitable for use and manufacture in the developing countries is, therefore, of urgent necessity. Such equipment could be used by the medium-size farm holdings of 2 to 10 hectares which constitute a large portion of the land under paddy cultivation in Southeast Asia.[4] Very few attempts have been made by private manufacturers on the development of small drying and processing equipment. Research and development on low-cost drying and processing equipment for small-scale operation is one of the important areas of activities at the Agricultural Engineering department of the Institute. The progress achieved so far in this area is discussed below.

Batch type drier

To adapt the design of available batch driers to the local production methods and facilities, and to utilize local materials, readily available standard parts and a minimum of imported components would tend to reduce the cost and, hence, avail the tropical farmer of a simple drier.

To produce a low-cost, functional and durable grain drier, the following design criteria were considered:

1. The drier should use a low-cost burner and fuel.
2. The blower should be driven by either an electric motor or an engine. If engine-driven, the excess engine heat should be utilized.
3. The burner unit should be interchangeable to use other low-cost fuel burner.
4. The fuel safety control valve should be mechanically actuated.
5. The grain bin should be portable.

Working within these specifications, a batch drier was designed (fig. 1). It consists of a kerosene burner, vane axial blower, and a rectangular grain bin.

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[4] Asian Productivity Organization. Proceedings of an expert group meeting in agricultural mechanization. Tokyo, Japan, December 12-18, 1967.

The burner is a gravity-flow type adapted from an imported drier. Casting of the pot-type kerosene burner in a local foundry shop costs only ₱15. Unlike diesel oil which needs a pressurized burner for combustion, kerosene can readily burn in an open pot-type burner. The fuel cost per 100,000 BTU is about ₱0.97 for diesel oil, ₱1.00 for kerosene, and ₱2.10 for LPG.[5] Furthermore, kerosene is available in most rural areas.

A safety control automatically turns off the fuel flow whenever the blower stops. A vane in the blower's air passage actuates the fuel valve. If the flame does not reignite after a brief blower interruption, the kerosene flows to a container. In addition to this automatic cut-off valve is an ordinary stove needle valve to limit the drying air temperature. These standard valves are readily available in the Philippines. An airduct under the burner cylinder recovers the heat dissipated from the engine.

The blower is driven by a 3 hp engine or it could be operated by a 2 hp electric motor. The 18-in. diameter vane axial blower was adapted from an imported drier. It rotates at 2200 rpm and delivers a total airflow of 1750 cfm against a static pressure of 0.8 in. water. The blower was made of gauge 16 galvanized iron sheet and balanced to minimize vibration. The blower supports were padded with four layers of rubber tire interior to absorb vibration. The cover which protects the belt and bearing from excessive heat was made to coincide with the base of the burner to maintain the same airflow. This necessitates the engine to be located below the blower otherwise the airflow is reduced by about one-third. The 1-in. diameter shafting and flange of the blower are about the only machined parts of the drier. Two 3/4-in. diameter self-aligning flange bearings support the blower at both ends. Grease fittings of bearings are extended to the surface of the cylinder for easy servicing.

A canvas duct connects the blower to the plenum chamber. The area of the air entry is 1.5 times the area of the blower casing to make correction for the bend.

The 54 sq ft grain bed can hold a ton or 23 cavans of dried paddy at a grain depth of 13 in. The floor was made of three pieces of individually framed 3 x 6 ft perforated sheet. Metal sheets and angle bars constituted the sides and bottom of the bed. The two doors on the sides of the bin are for manual unloading of paddy. The bin was made into sections of four sides, bottom, and three individually framed perforated sheet for easy transport and assembly.

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[5] Assumed values: kerosene, 26,870 BTU/liter; diesel oil, 30,788 BTU/liter; LPG, 43,400 BTU/kg; and kerosene, ₱0.27/liter; diesel oil, ₱0.28/liter; LPG, ₱0.90/kg.

Tests showed that the burner consumed an average of 1.8 liters of kerosene per hour to maintain a drying air temperature of 110 F (from an ambient temperature of 85 F) at an airflow rate of 1750 cfm. The maximum burner consumption was 3 liters of kerosene per hour.

At an airflow rate of 1750 cfm, the drying air temperature increased by 8 F when the waste and exhaust heat of the engine was directed into the air stream. This is equivalent to about 13,400 BTU/hr or 45 percent of the gasoline consumed by the engine or 0.5 liter of kerosene per hour or 28 percent of the kerosene consumption of the burner.

Drying tests (fig. 2) showed that 1 ton of wet paddy (equivalent to 900 kg of paddy at 14 percent (w.b.) or 12 in. grain bed depth) was dried from 22.5 to 14 ± 1.5 percent (w.b.) in 4 hours, which is equivalent to a drying rate of 2 percentage points per hour. The drying air temperature was 110 F (43 C) and airflow rate was 32 cfm/cu ft of grain.

The theoretical drying rate which approximates the average moisture content in the grain mass is expressed by the equation below:[6]

$$\frac{M - M_e}{M_o - M_e} = 0.735\left(e^{-G\theta} + \tfrac{1}{4}e^{-G\theta} + \tfrac{1}{9}e^{-9G\theta}\right)$$

where:

M_o = moisture content, % d.b. at the beginning of the drying period, at time zero.

M_e = equilibrium moisture content, % dry basis.

M = moisture content, % d. b. after a period of time θ.

θ = time in hours.

G = a constant = 0.19 at 110 F or 0.224 at 120 F.

Drying air temperature of 120 F (fig. 3) resulted in a bigger moisture gradient between the top and bottom of the grain mass. The bottom grain overdried before the top grain reached a safe level. This is one of the basic limitations of the batch type drier. The grain dried faster at the bottom

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[6] Chancellor, W. J. Characteristics of conducted-heat drying and their comparison with those of other drying methods. ASAE Transactions 11(6): 863-867. 1968.

of the grain layer where the drying air enters than the paddy on top where the air leaves the grain. The same result was noted with an airflow rate of 15 cfm/cu ft and drying air temperature of 110 F.[7]

This limitation can be minimized by using optimum drying condition. A drying air temperature of 110 F at 30 to 35 cfm/cu ft of grain is considered optimum for the given drier conditions.

The computed theoretical drying rate shown in fig. 4 will approximate the number of drying hours with air temperature of 110 F and airflow rate of 32 cfm/cu ft of grain. The curves approximate the drying time of paddy at different initial moisture contents.

Design drawings of the drier have been released for limited production to a manufacturer in the Philippines. The estimated selling price of the manufacturer is about one-half of the comparable imported batch type drier.

Rice hull furnace

Paddy is about 20 to 22 percent hulls. The hulls are a by-product of milling. Rice hull which contains 11,000 to 13,000 BTU/kg is freely available to farmers as a heat source. A suitable design of a rice hull furnace is needed as an alternative heat source for the batch drier.

Two designs of the hull furnace (fig. 5 and 6) are being tested for the batch drier. Figure 5 has a rectangular combustion box made of metal plate. A square column containing the hulls from the hopper passes through the top of the box at one end. This metal plate column has louvered openings in the combustion chamber. A tilting grate at the bottom holds the hull and controls the ash discharge as it vibrates. Air is drawn by the blower from the grate opening through the hull mass. An open flame comes out of the louvered openings as hulls burn inside the column. The ash with the air settles at the trap. An outer wall made of sheetmetal recovers the heat conducted and radiated by the combustion box. Rate of combustion is controlled by the airflow through the hull mass and rate of ash discharge through the vibrating grate.

Figure 6 is a rectangular box made of fire bricks and mounted on wheels with angle bar framings at the edges. Open walls of fire bricks divide the inside of the box into combustion and settling chambers. Continuous

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7/Manalo, A. S. Rice hulls as fuel for drying paddy. IRRI Saturday Seminar, September 11, 1971.

burning of hulls and feeding is made possible by the vibrating feeder at the hopper. Air enters the grate opening at the bottom of the combustion chamber and passes through the burning hulls. Hot air is drawn by the blower through an opening at the other end of the box. Rate of combustion is controlled by the airflow through the hull mass and hull feeding rate. Ash that goes with the hot air is trapped at the settling chamber. An air stream on top and sides of the box is maintained by the blower to recover heat losses from the walls.

Preliminary tests indicated that both designs are compatible with the batch drier designed at the Institute. Hull consumption of 5 to 6 kg/hr was obtained for a drying air temperature of 110 F at 1750 cfm air flow rate.

An eccentric idler pulley placed on the slack side of the blower belt produced the vibration which is transmitted to the feeder and grate by a piece of wire.

Both designs will undergo more tests and evaluation.

Heated-sand conduction drying and parboiling

Laboratory conduction-drying experiments were conducted with sand as the heat transfer medium. These experiments indicated that paddy can be dried from about 32 percent to 18 percent moisture content (dry basis) [8] in 15 to 20 seconds exposure to sand heated to about 200 C. When sufficient moisture (about 27 to 30%) was initially available in the grain, increased head yields were obtained due to the gelatinization of starch granules. Results also indicated that dry paddy could be soaked for about 6 to 12 hours in water at ambient temperature to introduce sufficient moisture so that higher head and milling yields are obtained. The process imparted an effect somewhat similar to parboiling of rice. The grains had a slightly darker and translucent appearance.

The development of a continuous-flow, heated-sand conduction drying and parboiling equipment is currently underway. The machine has a cylindrical sand-grain mixture chamber mounted in a sandpan on two bearings. Sand is heated by LPG burners located under the sandpan. The mixing chamber has a partially perforated section, internal spiral baffles and externally mounted sand sweepers and scoops. As the mixing chamber rotates, the s c o o p s pick up and introduce hot sand from the pan while an auger delivers wet grain from the hopper into the mixing chamber. While the chamber rotates, the mixture of hot sand and grain is moved axially by the internally mounted spiral

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[8] Unless specified, henceforth all moisture contents used in this paper are expressed in dry basis.

baffles. Finally the sand falls back into the pan through the screen portion and dry grain is discharged at the end of the cylinder. The sand in the pan is gradually moved towards the scoops by the externally mounted sand sweepers for recycling through the mixing chamber.

The machine has undergone a series of modifications from its original design to improve its performance. With the semicircular sandpan used, modifications were made with the machine. The burners were increased from two to three and the orifice changed from circular to slotted to increase heating; fins were welded along the length of the pan bottom; a grain agitator was installed to prevent wet paddy from bridging at the hopper; the sand screening area was lengthened from 8 to 16 in. to improve sand separation; an auger feeding mechanism was installed to insure uniform paddy feeding; the sandpan was lengthened to increase content and the two sides of the firebox were insulated to prevent too much heat loss.

Initial tests on the modified machine indicated that the sand temperature stabilized at 154 C when feeding paddy with 32 percent initial moisture content at the rate of 54 kg dry matter per hour. Heat utilization efficiency obtained was 35 percent.

Additional test was made on the machine with paddy initial moisture content and sand temperature as the variables. IR20 paddy with initial moisture contents of 17, 23, 25, 27 and 30 percent were subjected to sand temperatures of 127-132, 138-143, 149-154, 160-166, 171-177, 182-188, 193-199, and 204 C. Paddy was fed into the machine when the sand temperature reached the desired level. Samples were immediately sealed in bottles after determining the grain temperature and spread on the floor prior to milling until the moisture content was reduced to 16 percent.

Results of the test showed the following:

1. Paddy with initial moisture content of more than 25 percent had a head rice increase of 5 percentage points over the control when treated with heated sand.

2. The color change to darker shade in the processed rice became more pronounced with increasing initial moisture content.

3. Based on head rice yields and the change in color of paddy processed at different initial moisture contents, the following safe sand temperatures were found:

Initial paddy moisture content, % d.b.	Safe sand temperature, °C
25 - 30	138 - 203
23	149 - 203
21	160 - 203

In an attempt to further improve the drier performance, additional insulation on the sides of the firebox was made. the sidewalls of the sandpan were raised to prevent spillage and increase its content, and the burners were relocated in an off-center position to concentrate the heat under the sand mass. Tests on the machine resulted to 38 percent heat utilization efficiency.

Further tests made on the machine indicated the following results:

1. Sealing in bottles or spreading the hot-sand dried grain for 30 minutes or until it has cooled off as a post-treatment of paddy yielded negligible difference in head and broken grain when the initial moisture content was above 28 percent. At initial moisture content of 23 percent, a significant reduction in head grain recovery was observed on the spread grain although the total recovery was not affected. This result indicates the need for presoaking the paddy before the heated-sand treatment to take advantage of the process.

2. White bellies were not removed when paddy was soaked for 24 hours and exposed to heated sand for 20, 30, and 40 seconds. The presence of white bellies in the milled rice was probably due to incomplete gelatinization of the wet paddy.

3. Comparing the presoaked sand-treated samples with the regular parboiled rice showed that sand temperature range of 150-180 C produced the desirable qualities of milled parboiled rice. The differences in the total and head rice recoveries of samples treated at this sand temperature range were negligible and the average moisture reduction was 21 percentage points. Higher moisture reduction but darker and non-uniform milled rice was observed at higher sand temperatures. Low moisture reduction was observed at lower temperatures.

In an attempt to improve further the capacity and efficiency, the machine was again modified with the following changes (fig. 7):

1. The sandpan was enlarged using ¼-in. thick plate and the shape changed from semicircular to 45° angle from the bottom end on the front side of the drier. Fins outside and along the curvature of the pan were welded to improve heat transfer.

2. Insulation of the four sides of the firebox.

3. Corresponding enlargements of the frame, cover, sand sweeper and scoop.

Tests on the machine indicated that feeding presoaked paddy (with initial moisture content of 48.8%) at the rate of 146 kg dry matter per hour

and paddy-sand ratio of 1:10.3 stabilized the sand temperature at 104 C. Moisture extraction was 9.72 percent. The heat utilization efficiency was increased to 55 percent and further increased to 65 percent if the moisture removal during the cooling of the grain was also considered.

The machine is still in the experimental stage and further modifications are expected in its design. Additional tests will be conducted to study in more detail the effects of various variables on the machine's performance. Increasing the capacity, utilizing the exhaust heat in preheating the ingoing wet paddy or further drying of the outgoing high-moisture hot grain from the drier will be investigated. Investigation to utilize rice hulls as possible source of fuel is also planned.

Direct-flame drying

Laboratory experiments were conducted to investigate drying of freshly harvested paddy by exposing it to a flame. Initial results indicated a higher rate of moisture removal at the early stages of exposure. A parboiling effect, the same as the heated-sand drying process, was observed and milling results showed an increase in head rice recovery with increase in paddy initial moisture content. Taste tests indicated no difference between the direct-flame treated and the control samples.

A continuous-flow, direct-flame laboratory drier was fabricated (fig. 8). The machine has a perforated cylinder mounted on bearings with an internal spiral baffle. An LPG burner is mounted under the perforated cylinder. Wet paddy from a hopper is fed into the rotating cylinder at one end by an auger and the grain is moved axially by the spiral baffles as the flame impinges on the grain through the perforations.

Tests on the machine showed that the total drying time of continuous heated-air drying was reduced by 50 percent when wet paddy was subjected to direct flame for 40 seconds and dried with heated air (fig. 9). Flame exposure coupled with shade or heated-air drying resulted to increased head rice compared with the shade-dried control and continuously heated dried grain (fig. 10).

A hopper which would utilize the excess heat from the drying chamber to increase the efficiency and capacity has been added to the experimental direct-flame drier. An air channel constructed at the hopper introduces the hot air to the wet paddy before flame exposure.

Preliminary results indicated that the paddy temperature increased from 80 F to 160 F before it was exposed to the flame. The thermal efficiency increased from 35 to 60 percent with the addition of this pre-heater. Tests are underway to pursue this encouraging trend and evaluate the effect of the process on the quality of the milled rice.

Further modification in the design is expected and additional tests will be made to study the various factors affecting machine performance. Work will be directed in determining and controlling the variables involved in producing a machine that could be used as a drier and a parboiler.

Rice milling

Investigation has been started to explore the possibility of developing a rice milling machine that could be simple in operation, more efficient, require less power and easy to fabricate using readily available material. Investigations are planned to study the performance of different rice milling machines and to evaluate new concepts.

The possibility of using readily available, low-cost, flat rubber belting instead of the special plastic impact lining that is marketed by the manufacturer was explored. It was also felt that the centrifugal huller may be used for milling paddy by using an abrasive impact surface.

A laboratory centrifugal huller was fabricated for test purposes. The machine consists of a standard 32-blade plastic impeller from a Japanese centrifugal mill; electric motor drive through a variable speed pulley; sheetmetal housing with provision for changing impact lining; transparent front face for hulling observation; hopper to feed paddy through a hole at the center with a slide gate to regulate feeding.

Initial test results using different impact linings indicated good performance of the ordinary rubber belt in hulling and of the rough surface "Safety Walk" in polishing. The life of plywood lining for hulling and sandpaper for polishing was too short for practical application. Also, increasing the impeller speed and number of passes through the machine reduced the number of unhulled paddy but increased broken rice.

Since the feeding rate can affect hulling efficiency and grain breakage, further study was done to verify the preliminary results. The impact lining of the laboratory centrifugal huller was changed with a new 4-ply flat belt and the 32-blade impeller was changed with a 60-blade impeller currently used by the commercial machine. Test was made using IR24 rice variety with 15 percent moisture content. Impeller speeds of 850, 1050, 1250, 1470 and 1650 rpm and feeding rates of 470, 720, 880, 970, 1230, and 1380 kg/hr were used. A laboratory grain cleaner was used to remove the hull-bran from the processed sample. Tests were also conducted to determine the effect of the number of passes through the centrifugal huller at 470, 720 and 970 kg/hr feeding rates. These feed rates were selected because they are within the range of the steel huller and the commercial centrifugal rice mill.

The effect of the impeller speed and feeding rate on unhulled paddy and broken rice is indicated in fig. 11 and 12. The figures show the following results:

1. The amount of unhulled grain increased with feeding rate.

2. A decrease in broken rice was observed with increased feeding rate.

3. Unhulled grain decreased while broken rice increased with increase in impeller speed.

4. The optimal impeller speeds for the 470 and 720 kg/hr feeding rates were 1330 and 1500 rpm, respectively, as shown by the intersecting lines. The unhulled and broken grain lines did not intersect within the range of impeller speed used at feeding rates above 880 kg/hr.

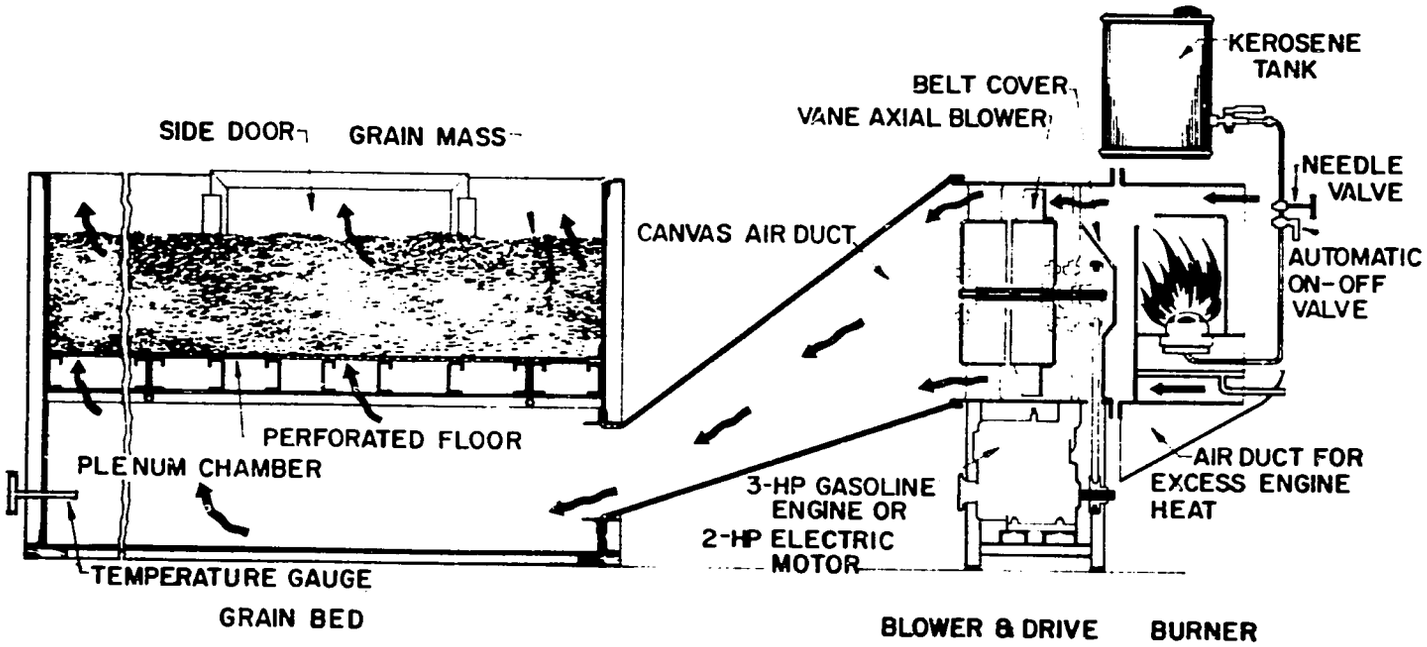
Performance results on multipass hulling from the laboratory centrifugal machine are indicated in fig. 13, 14 and 15 for the 470, 720, and 970 kg/hr feeding rates, respectively. The figures indicate an increase in broken grain for each additional pass and increasing impeller speed. The decrease in the amount of unhulled grain was greatest on the second pass compared with the third and fourth. The intersecting lines for the second pass indicating the optimum impeller speeds for the 470, 720, and 970 kg/hr feeding rates were 950, 1030, and 1050 rpm, respectively.

Tests will be continued to further verify these results. A program is underway to test and study all small commercially available rice mills to find ways of improving them or developing more efficient mills that could be used to replace the steel huller machine.

Laboratory test tube miller

A laboratory test tube miller (fig. 16) which mills brown rice samples by shaking a mixture of brown rice and fused aluminum oxide in small test tubes was developed. This machine is intended for plant breeders and other scientists who frequently require small milled rice samples for visual, physical and chemical testing. The shaking mass has been kept at a minimum of 1-in. stroke to permit 1000 to 1500 cpm oscillation. Two boxes to hold 24 test tubes each were mounted on frames of fibreglass strips. The two boxes are oscillating by the action of cams through two connecting fibreglass strips. Prelubricated sealed bearings were used throughout to minimize service problems. A ½ hp electric motor is sufficient to drive the miller. The 48 rice samples of 3 g each can be polished in 5 to 10 minutes.

The laboratory test tube miller is being used by the Rice Quality Laboratory of the Institute. It is now undergoing endurance test and a unit has been tested for more than 100 hours operation.



BATCH TYPE GRAIN DRIER

Fig. 1. Schematic of batch type grain drier,

12.

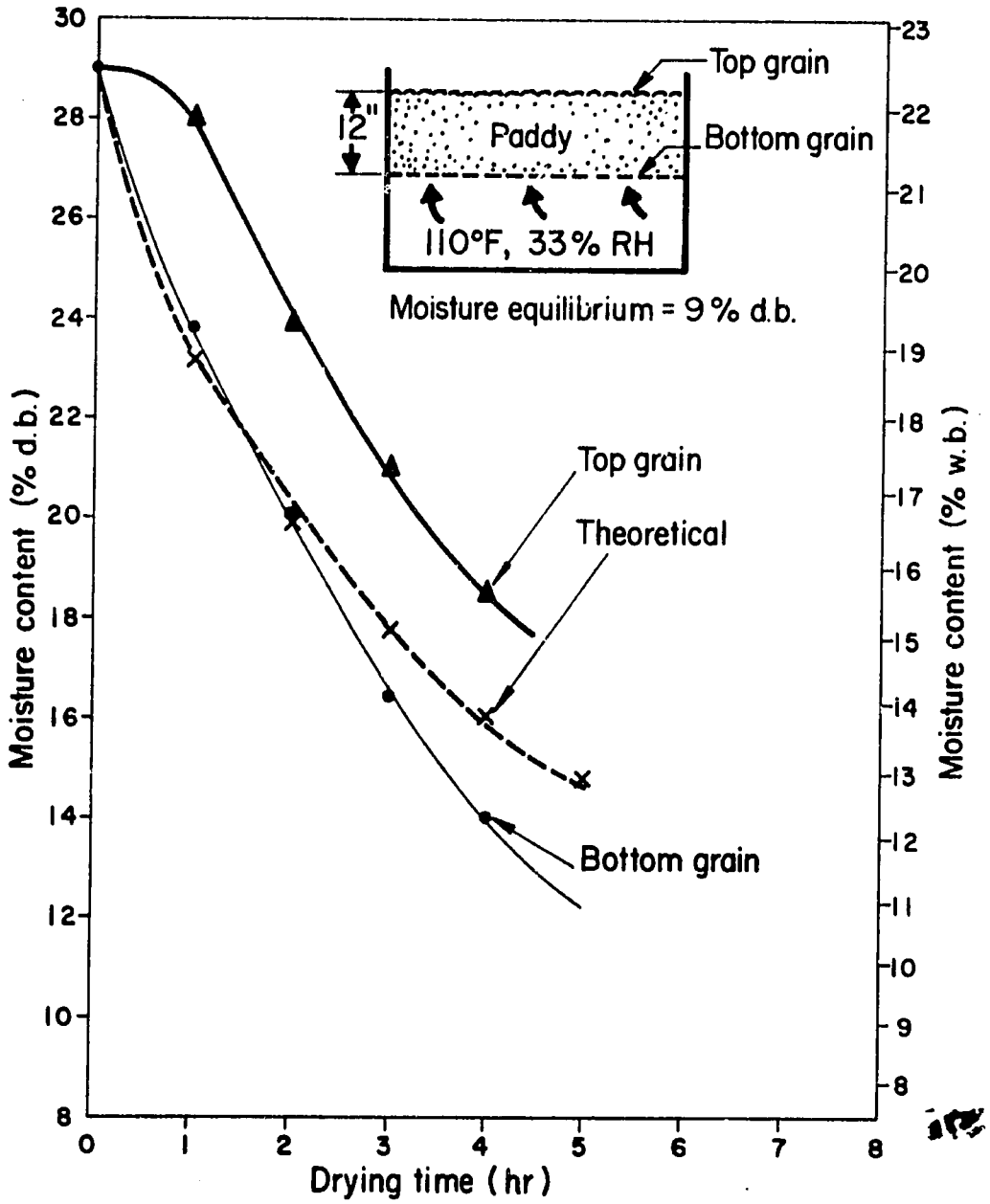


Fig. 2. Drying rate of paddy with drying air temperature of 110°F (or 43°C) at air flow rate of 32 cfm/cu. ft. of grain.

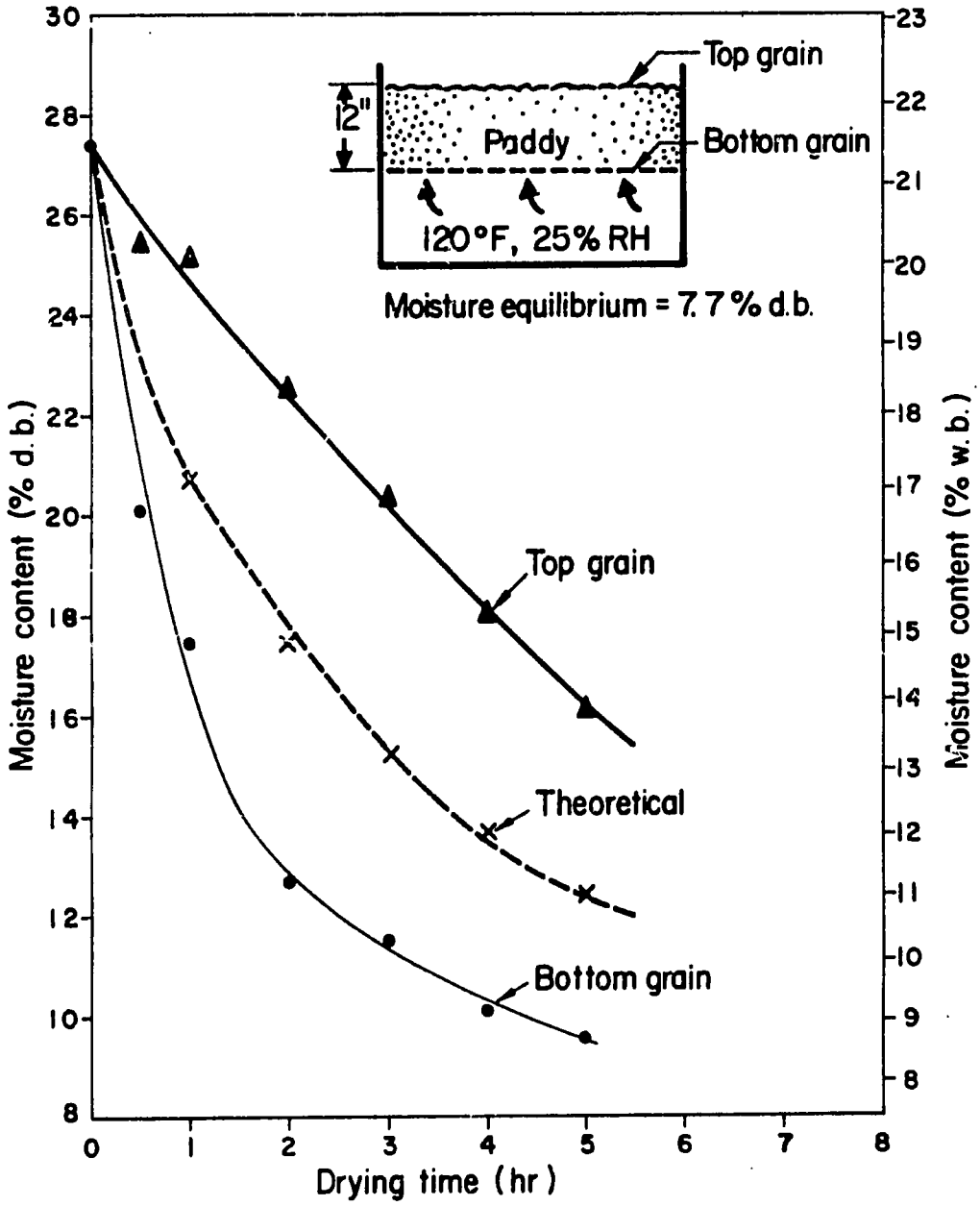


Fig. 3. Drying rate of paddy with drying air temperature of 120°F (or 49°C) at air flow rate of 32 cfm/cu. ft. of grain.

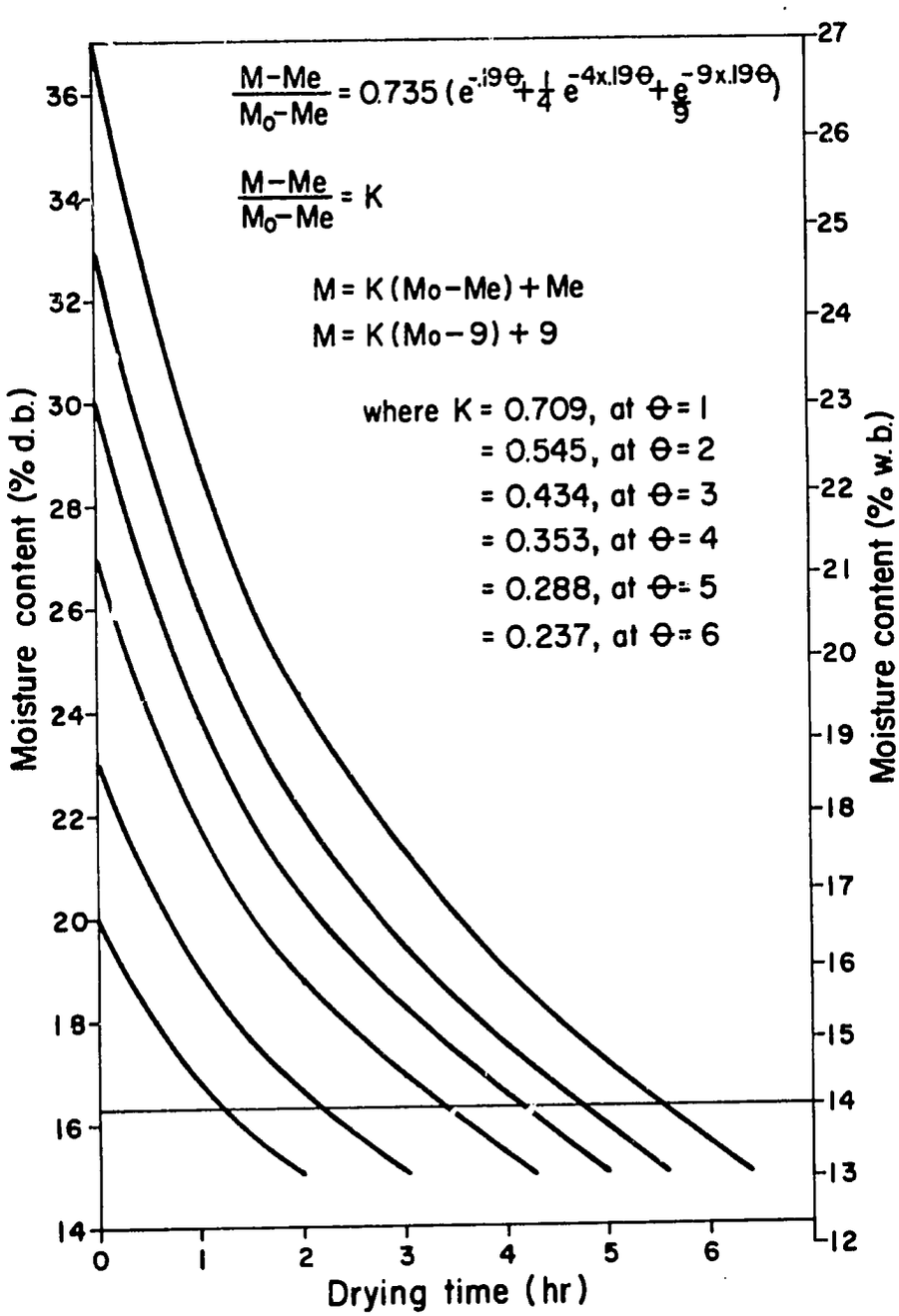
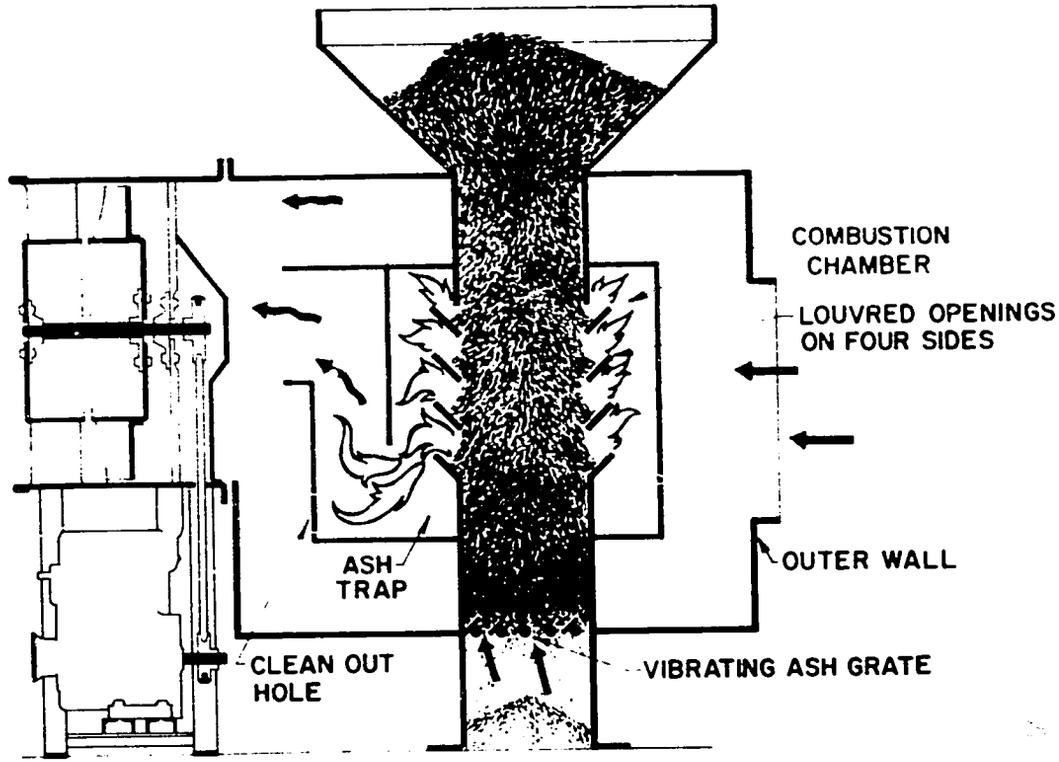
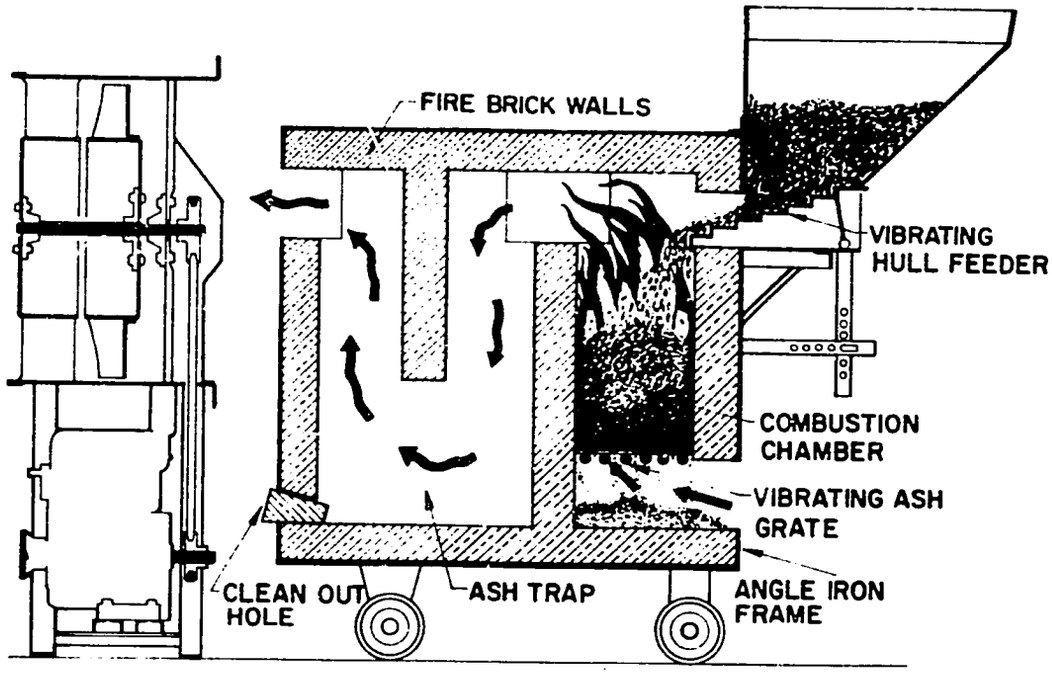


Fig. 4. Theoretical drying rate at drying air temperature of 110°F and 33% RH.



RICE HULL FURNACE

Fig, 5. Louvered rice hull furnace.



RICE HULL FURNACE

Fig. 6. Rice hull furnace made of fire bricks.

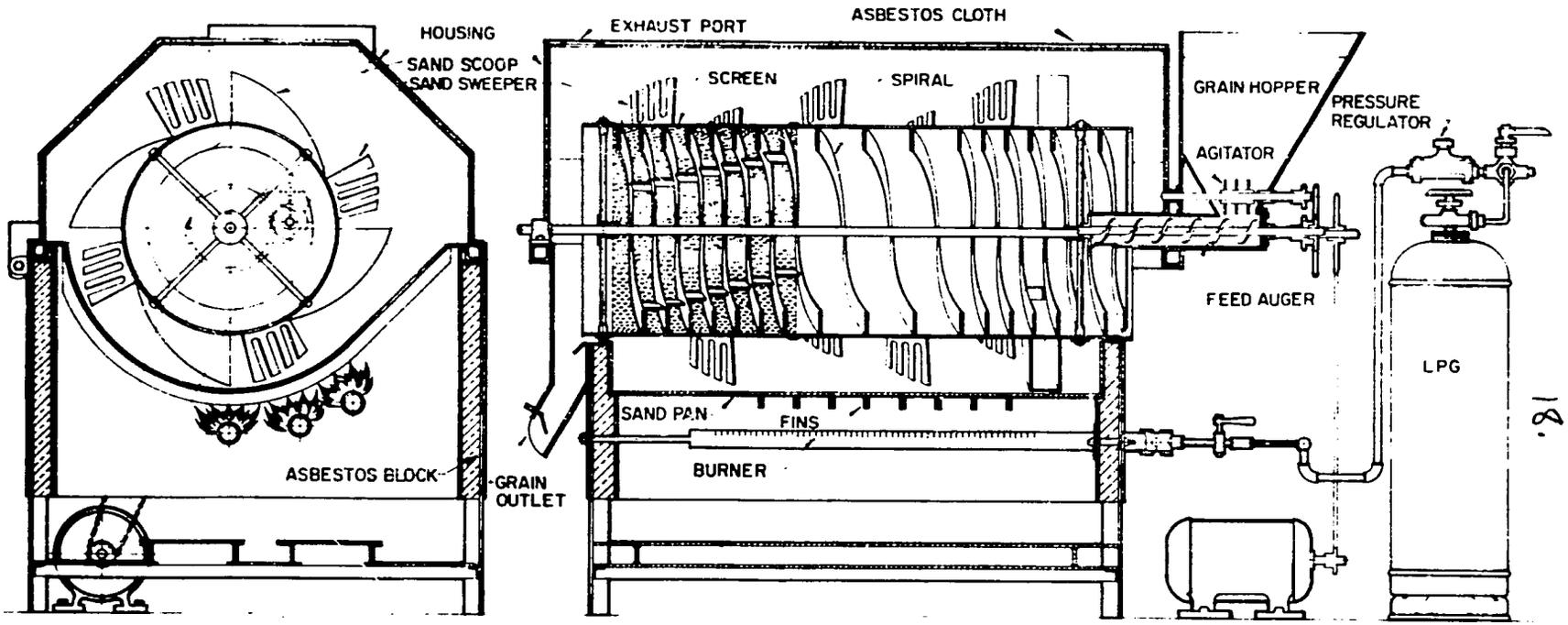


Fig. 7. SCHEMATIC DRAWING OF THE CONTINOUS FLOW HEATED-SAND DRYING AND PARBOILING EQUIPMENT

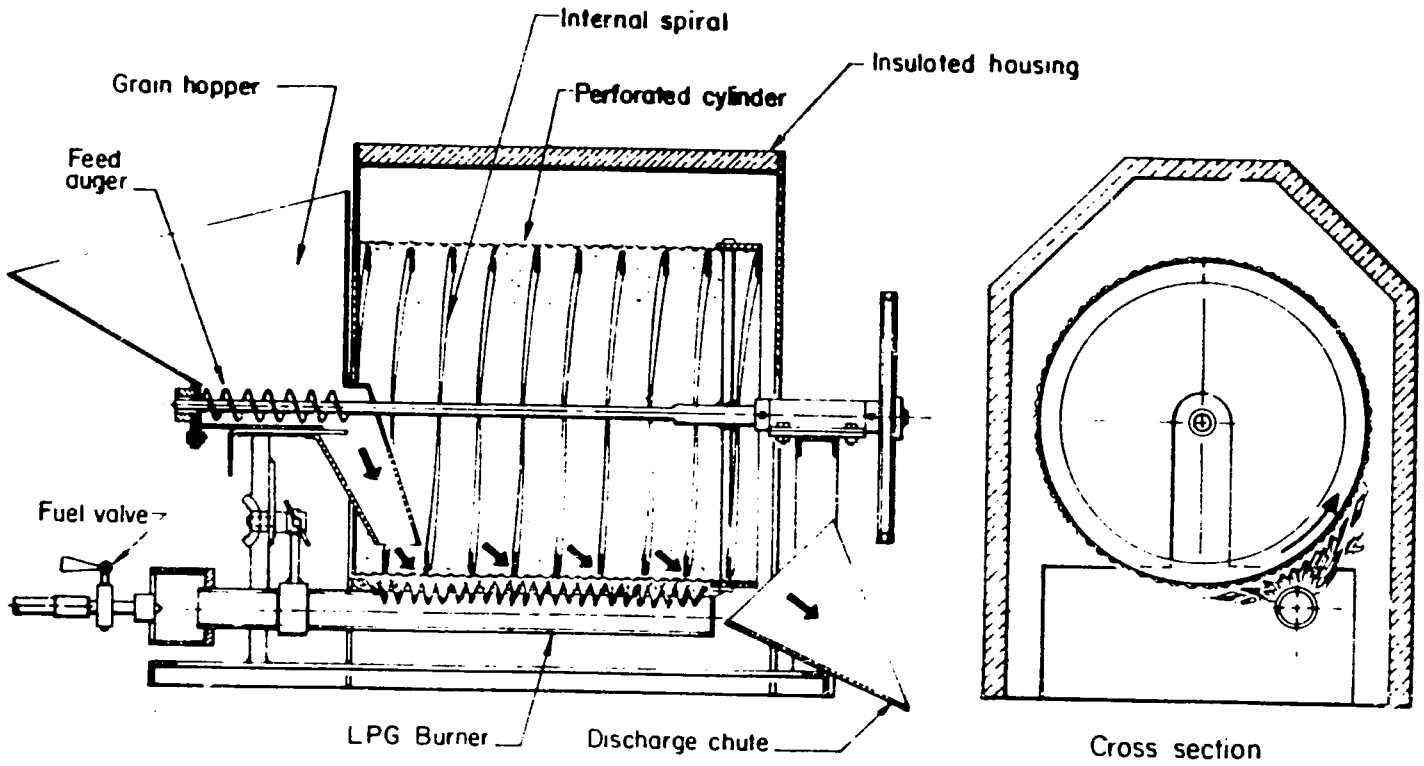


Fig. 8. Schematic drawing of a direct flame laboratory grain dryer.

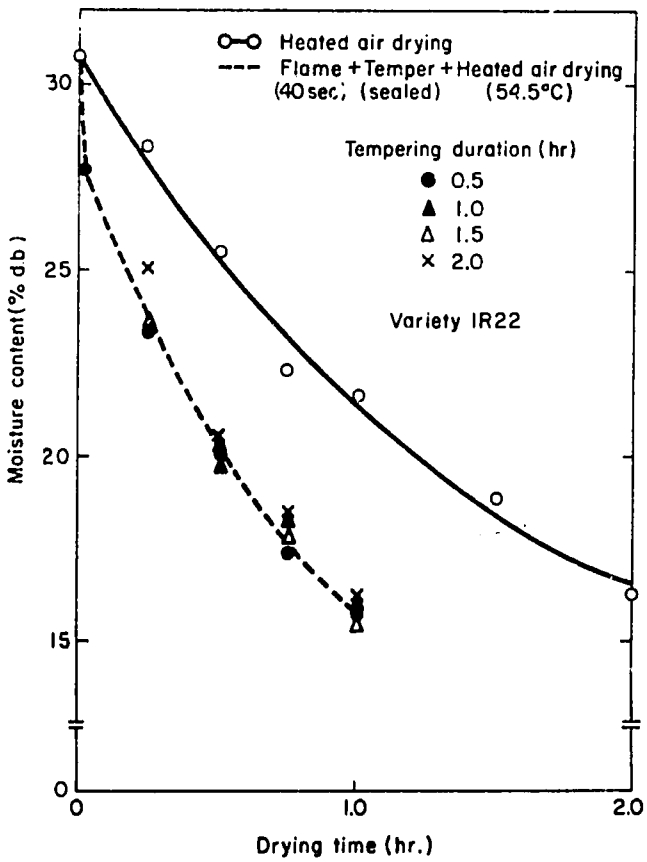


Fig. 9. Flame exposure effect on drying time.

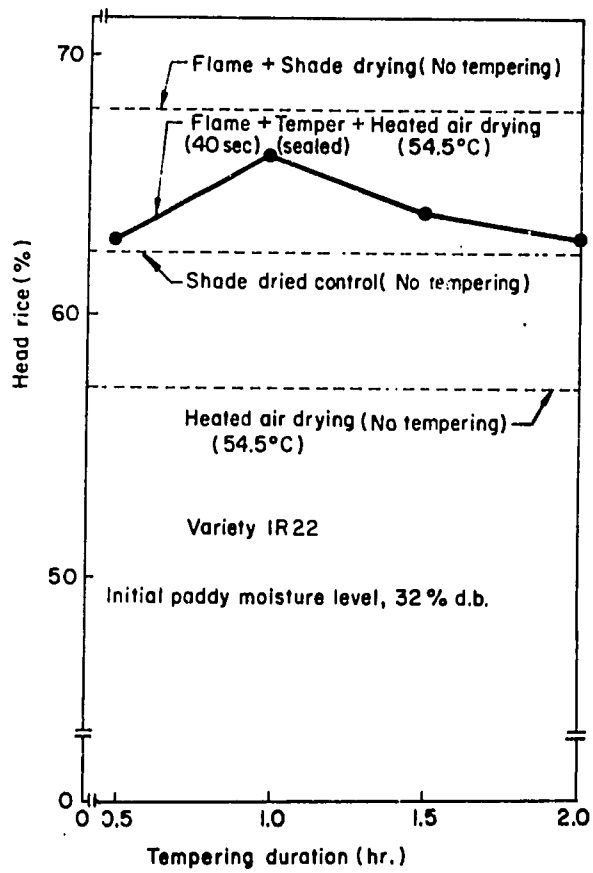


Fig. 10. Head rice yields for different drying treatments.

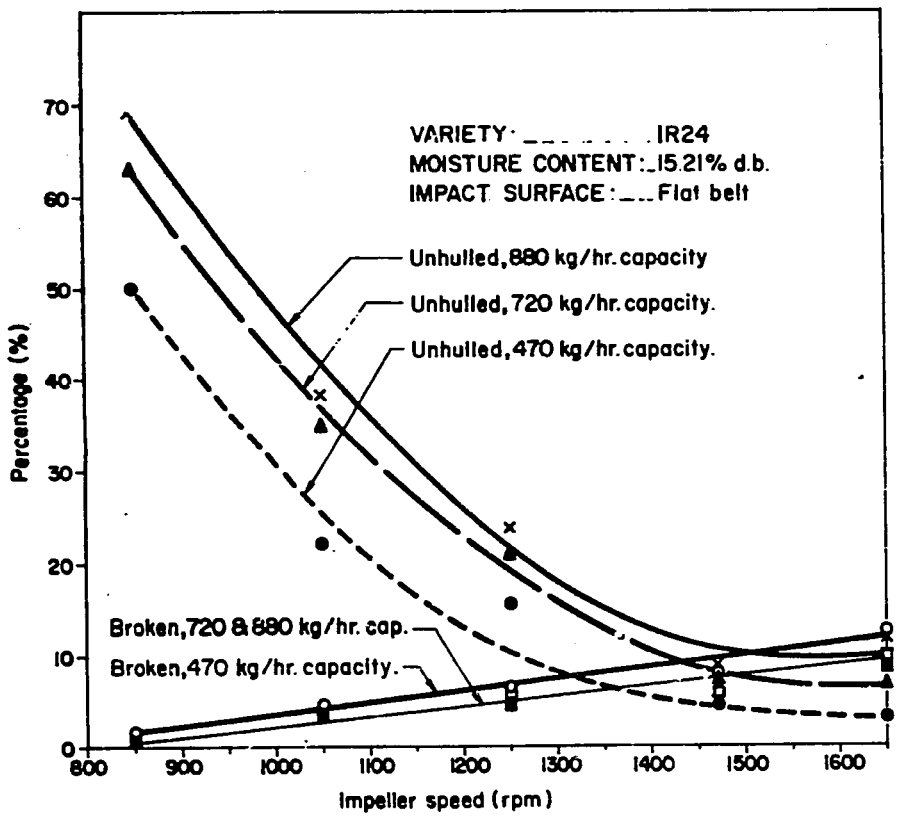


Fig. 11. Effect of impeller speed and feeding rates of 470, 720 and 880 kg/hr on unhulled paddy and broken rice.

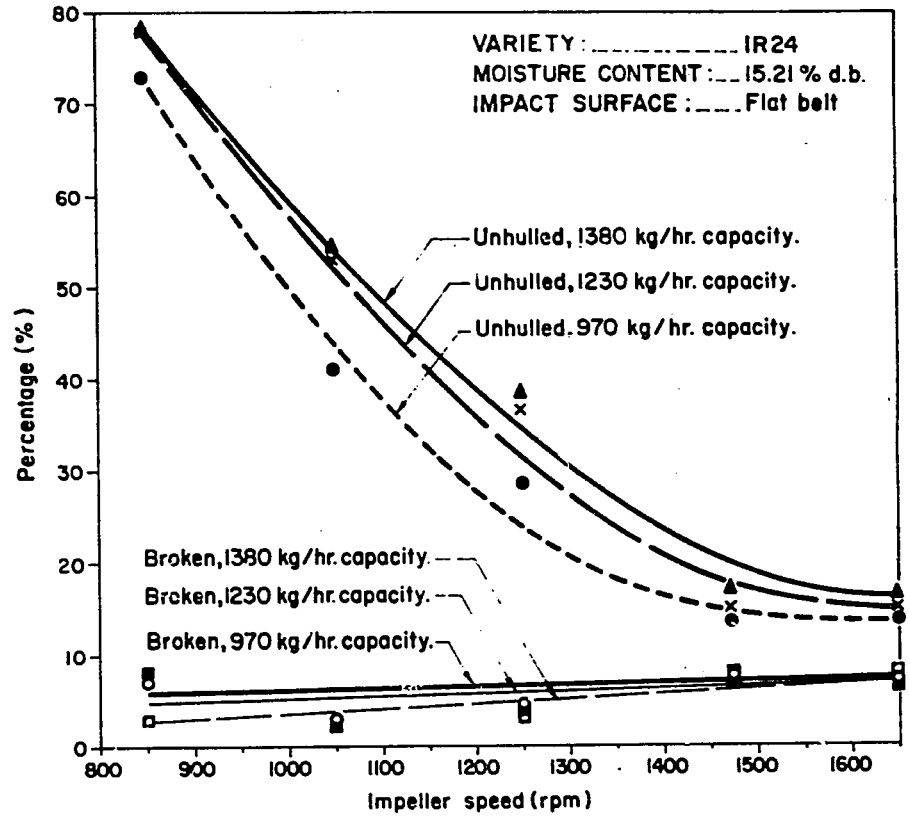


Fig. 12. Effect of impeller speed and feeding rates of 970, 1230 and 1380 kg/hr on unhulled paddy and broken rice.

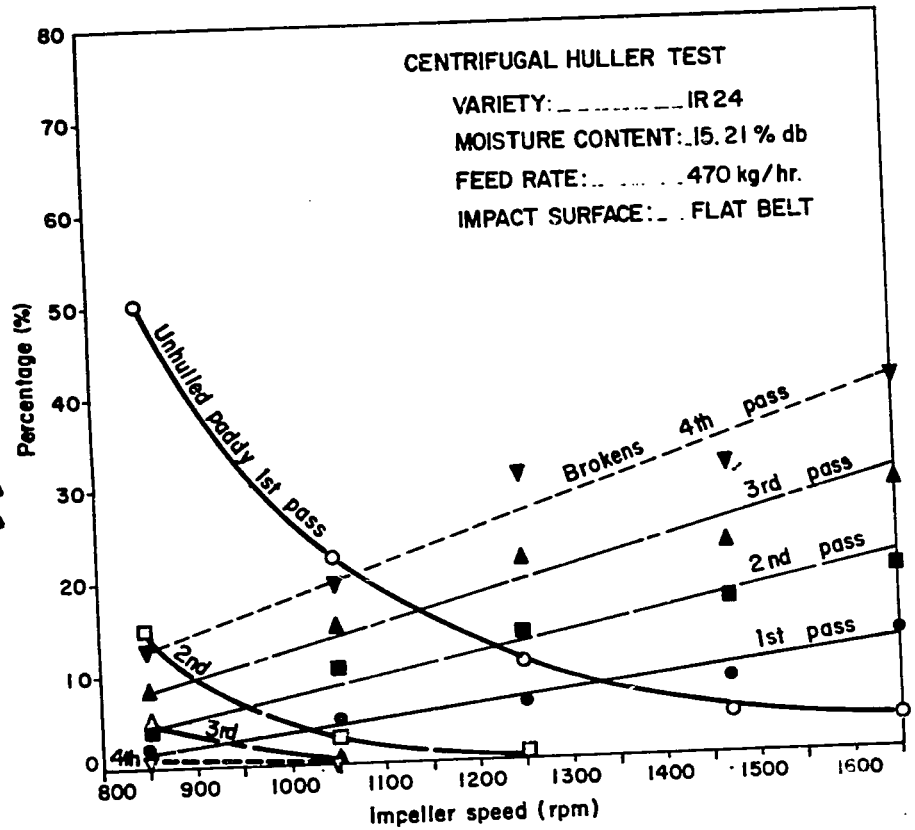


Fig. 13. Effect of impeller speed and number of passes on unhulled paddy and broken rice at 470 kg/hr feeding rate.

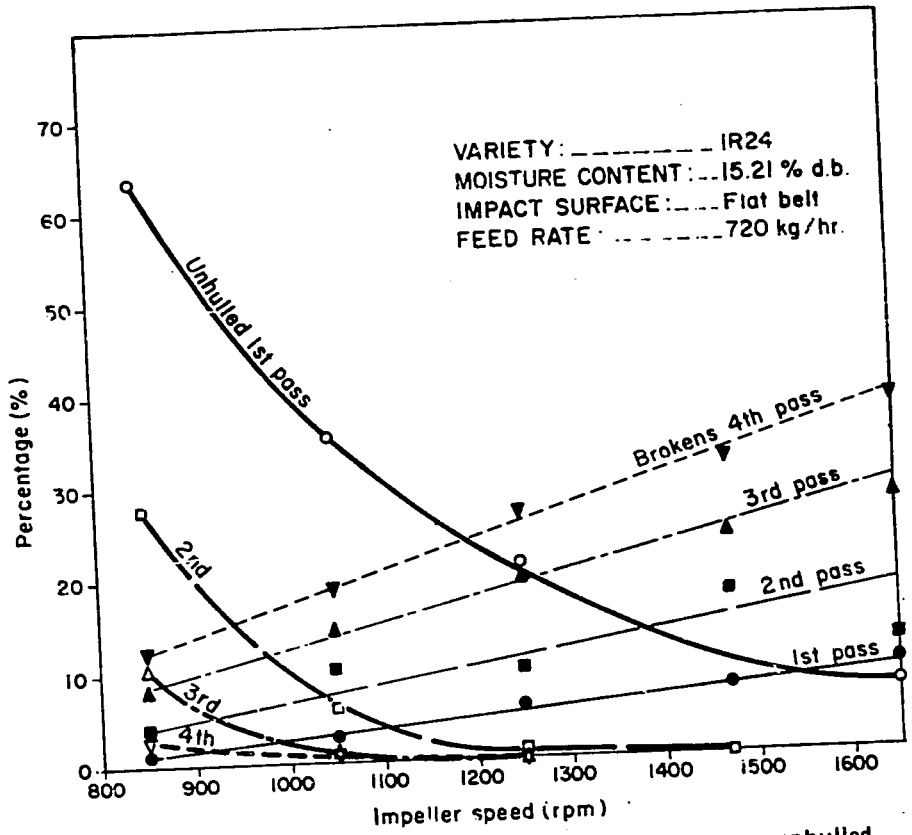


Fig. 14. Effect of impeller speed and number of passes on unhulled paddy and broken rice at 720 kg/hr feeding rate.

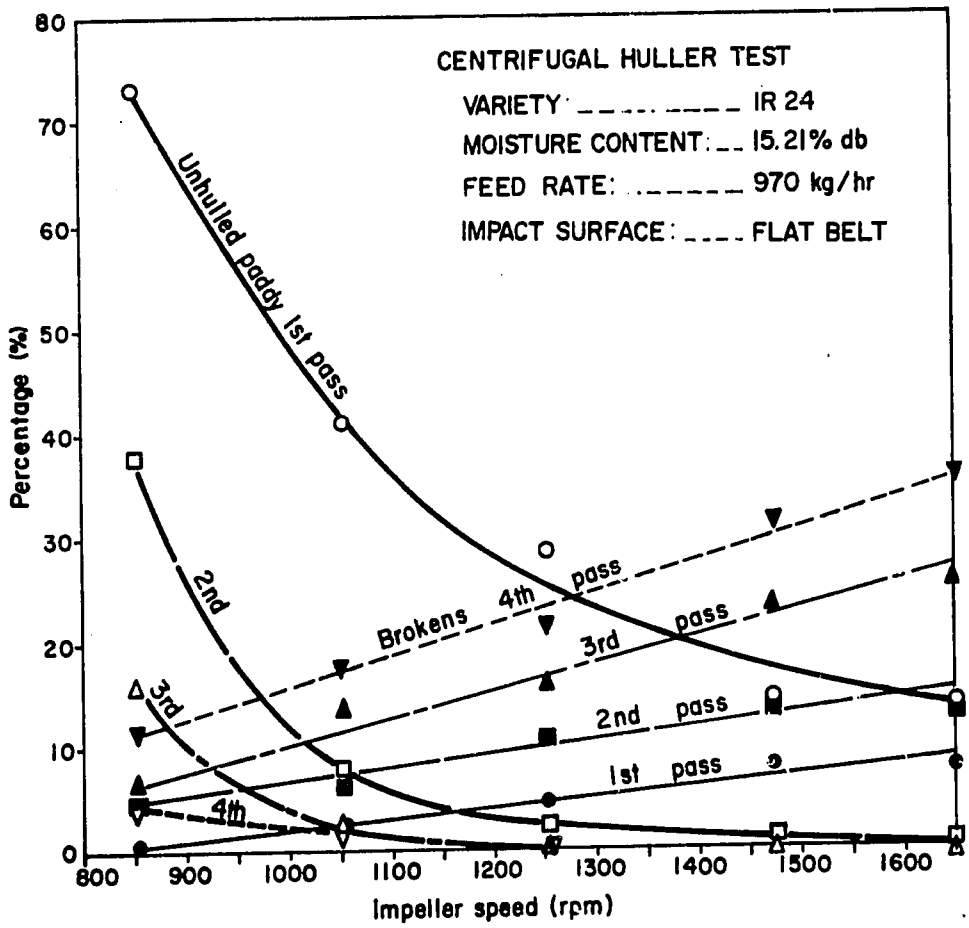


Fig. 15. Effect of impeller speed and number of passes on unhulled paddy and broken rice at 970 kg/hr feeding rate.

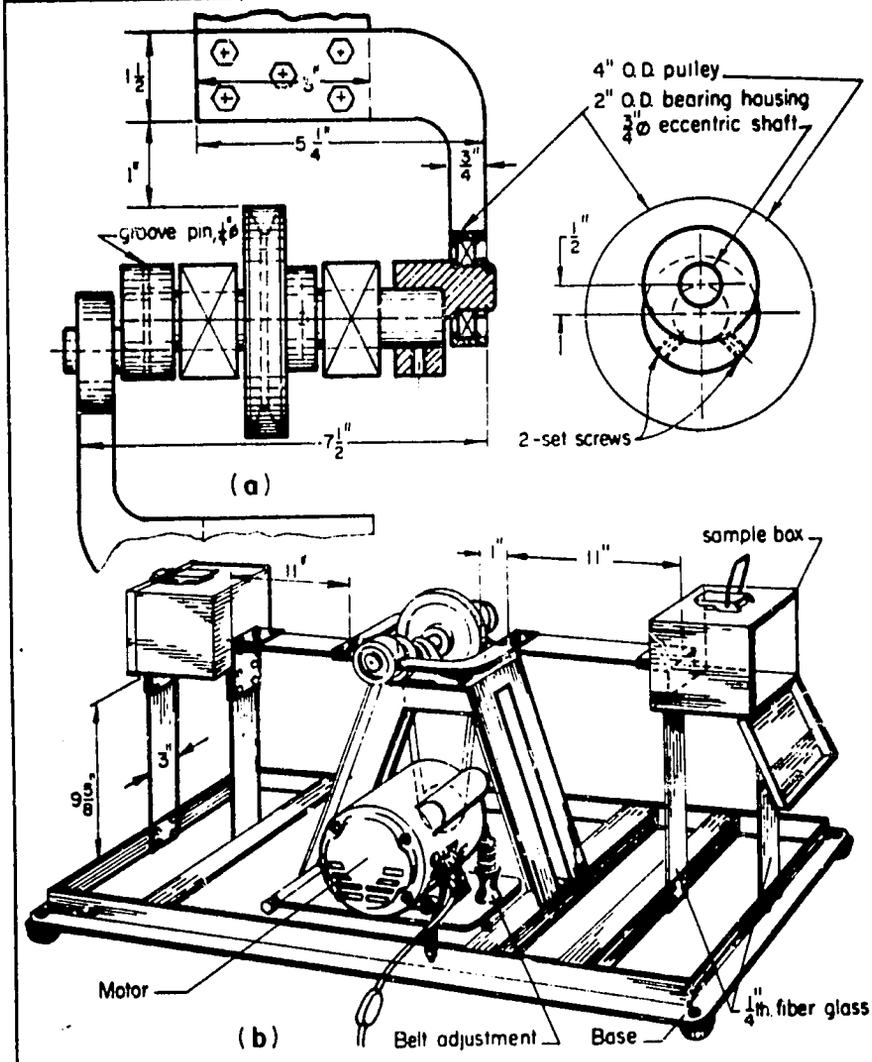


Fig. 16. The laboratory test-tube rice miller. (a) Detail of main shaft assembly. (b) General assembly.