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Simple Grain Drier

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A Simple Grain Drier Using Conducted Heat

William J. Chancellor

MEMBER ASAE

SPEAKING to a group of scientists in 1965 (1)* C. J. Moss, director of Britain's National Institute of Agricultural Engineering, made these comments: (a) "More than two-thirds of the population of the world depend on rice for food"; (b) "One-third of the rice crop harvested is wasted because of inadequate treatment and storage," and, (c) "It is clearly imperative that simple equipment for drying the rice, etc., be evolved so as to prevent this loss of food."

Inadequate drying is only one of several reasons for food grain losses (2). However, local availability of drying facilities not only can reduce spoilage losses in storage but also can promote increased production through strengthening the practicality of double cropping in irrigated areas where the off-season crop is harvested in humid weather. In addition, planned drying of the grain can permit an earlier date for the initial harvest. This (a) reduces the opportunity for field pests to attack the crop, (b) reduces the tendency for grain to shatter from the plant while standing in the field or while being harvested and transported, (c) extends the harvest season so that the peak labor requirement per acre need not be so high, and (d) makes possible earlier completion of harvest so that more time is available for land preparation for the ensuing crop in double-cropping areas.

In many tropical areas, particularly in humid weather, the transportation of grain to large centralized driers is difficult, because road facilities for bringing motorized transport to the harvest site frequently are not available. Furthermore, transport to and from the drier of the grain utilized by the farm family represents added effort and cost. For these reasons it seems advisable to conduct the drying operation with smaller facilities located near the harvest or immediate storage areas†.

In many tropical areas, the acreages



FIG. 1 Proposed drier design. Diameter of drying surface is approximately 16 ft or 5 m.

operated by individual farmers are frequently small and much of the food grain produced represents a large part of each family's food requirements. Under these circumstances it is essential that any process to which the entire crop is submitted by completely reliable and within the control of those immediately concerned.

The most common traditional method of grain drying is sun drying. It is effective only during seasons of relatively warm, clear, dry weather, and, therefore, farmers try to avoid the production of grain crops which will require sun drying during moist weather. Under humid conditions, it is necessary that some source of added heat energy be provided to supply the heat of vaporization for the water to be evaporated from the grain. One small-scale method for drying grain with added heat utilizes an engine-driven fan to force air through the storage bin, the heat energy coming principally from that rejected by the engine (4). However, this method is subject to questionable reliability, particularly when small petrol engines are used. The constant speed and load conditions involved in driving a fan

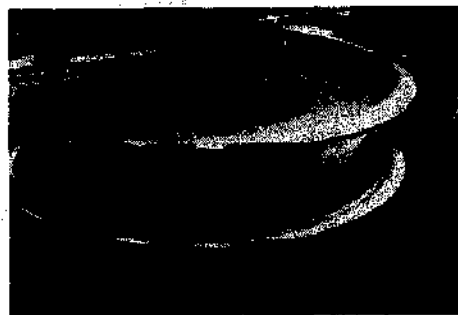


FIG. 2 Apparatus used in laboratory tests to determine thermal parameters. A blade which scrapes the bottom is fitted to two right-hand prongs of the stirring apparatus. The blade is only one radius long, so the complete stirring effect is produced only once per revolution of the stirring frame turning at 1 rpm.

24 hr a day impose severe requirements on an engine. Tests have indicated that under these conditions engine stoppages are likely within 60 to 80 hr of operation and that major repairs requiring spare parts are likely within 200 hr of operation (5). In addition, expenditures are required for fuel, lubricants, and maintenance materials.

It is with this background that the design of a grain drier was undertaken to meet the following conditions:

1 Heat from fuel will be used to permit drying of grain in wet weather, but fumes from the fuel will be prevented from coming in contact with the food grains.

2 The drier will incorporate only elements which are completely reliable and are available to, as well as within the control of, the tropical farmer.

3 Capacity will be sufficient to meet the needs of areas up to 50 acres.

4 Operating costs will be minimized by use of crop residues or other local materials as fuel.

5 Construction will avoid elaborate components and processes in order that initial costs may be low and that production may be carried out without highly industrialized facilities.

Driers which meet these conditions have been constructed and used in the past (2, p. 96). Their designs, however, have been such that their fuel requirements per pound of grain dried would have been in excess of the amount of residue associated with one pound of grain (6).

Fig. 1 illustrates one form of the proposed design, the principal elements of which are:

- (a) A horizontal metal surface placed over a fire pit
- (b) Use of animal power to stir the shallow layer of grain placed on the metal surface
- (c) Grain temperature, and thus the rate of moisture evaporation, controlled by adjusting the rate of fuel use.

Drying Characteristics

Drying Rate Laboratory tests were made with a model drier 10 in. in diameter (Fig. 2).

Temperatures of the top and bottom of the grain layer were recorded, and the grain was weighed regularly to determine moisture loss. Tests were run at three depths of grain (approximately 1/2, 1 and 2 in.) with three surface temperatures, approximately 160, 212 and

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* Numbers in parentheses refer to the appended references.

† The average distance (in meters) of transport involved to and from the drier for the grain to be consumed by the farm family may be approximated as $0.8 \times (\text{area served by drier in square meter})^{1/2}$ when the drier is in the center of an approximately square area of service (3).

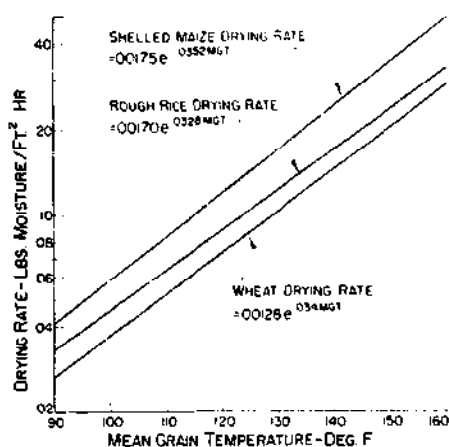


FIG. 3 Semilogarithmic relationship between drying rate per square foot and mean grain temperature for three grains. Drying rate approximately doubles with each 20-deg F increase in MGT.

260 F. Rough rice, wheat and shelled maize, all in a naturally moist condition, were each subjected to the complete series of laboratory tests. Fig. 3 shows the general drying-rate characteristics found. All three grains responded similarly with moisture loss rates per sq ft which approximately doubled with each 20 F increase in the mean grain temperature.

Effects of Grain Depth and Moisture Content The actual drying rate varied with both grain depth and moisture content. The values given in Fig. 3 are averages over all depths and moisture contents. The values in Fig. 3 may be modified to represent conditions at a specific depth and moisture content by multiplying the value from Fig. 3 by a factor X as determined from the following equations derived from the laboratory test results:

$$\text{For rice, } X = 0.4 + 0.0306 \frac{(MC - 9.8)}{(D)^{0.5}}$$

$$\text{For wheat, } X = 0.35 + 0.00547 \frac{(MC - 9)}{(D)^{0.9}}$$

$$\text{For maize, } X = 0.85 + .01 \frac{(MC - 17.2)}{(D)^{0.85}}$$

in which D is the grain depth in feet and MC is the moisture content (percent) on a wet-weight basis.

Field Tests of 8-ft Drier Figs. 4 and 5 show the experimental drier. A small engine was arranged to turn the stirring sweep one revolution per minute. The tests were made with naturally moist rice of approximately 20 percent moisture. Different depths of grain were tried, and some variation of grain temperature was attempted. Fig. 6 shows

‡ Varieties used where: Rice-Calrose (a medium grain), Wheat-Nimari-60 (a white spring wheat), and Maize-PAG-323 (a hybrid yellow dent).

§ A full discussion of the thermal characteristics of the grain found from these laboratory tests, as well as comparisons of drying rates using conducted heat with those from other drying processes appear in reference (7).

the results from a typical run and a comparison between actual and computed rates of drying. The computed values were approximately 40 percent of those measured. However, when a correction was added for solar and diffuse radiation received during the test, the theoretical and actual drying rates were in relatively close agreement. This does not imply that on a day such as this that sun drying would be faster than using the drier. Computations based on radiation and air temperatures (8) indicate that, even on such a warm day, sun drying could produce only 80 percent of the rate computed for the drier with no help from the sun. The reason that the computed sun-drying rate and the computed drier-drying rate are not additive is that such an addition would compensate twice for the radiant and convective losses from the top of the grain layer.

During most of the field tests, approximately 1 lb of fuel was burned for each pound of water evaporated. The results in Fig. 6 indicate that under conditions of overcast skies and temperatures in the 80s, approximately 2½ lb of straw (10 percent moisture) would be required to evaporate 1 lb of water. This represents a thermal efficiency of approximately 6.7 percent. Each pound of grain at 24 percent moisture must lose 0.117 lb of water to reach a storable moisture content of 14 percent. For drying purposes, this

¶ It seems to be the author's misfortune that each time an artificial drying experiment is attempted, the natural drying conditions are so favorable that the effects of the artificial drying procedures become partially obscured. A brisk dry wind, clear skies, and an air temperature of 103 F accompanied the test shown in Fig. 6.

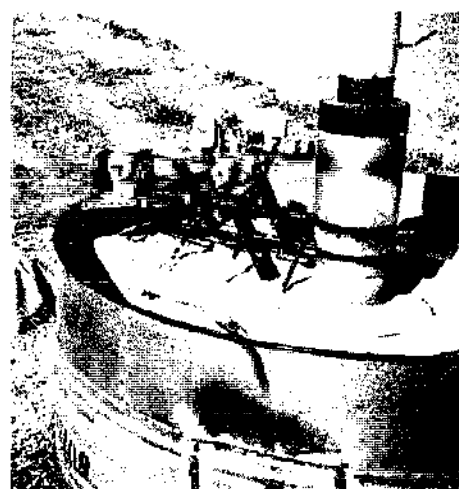


FIG. 5 Experimental drier showing four inclined rods to which stirring blades were attached. Blades covered nearly the complete drier radius. The six plugs shown were connected to thermocouples attached to stirring blades and leveling blade.

means that 0.293 lb of straw (10 percent MC) must be burned for each pound of grain to be dried. Observations made under Asian rice-field conditions indicate that the grain bundles carried to the threshing site were approximately 75 percent grain by weight. This gives a ratio of 0.33 lb of straw per pound of grain and indicates that the straw would provide sufficient fuel to complete the drying operation. The difference between 0.33 and 0.293 lb represents sufficient excess to permit straw of up to approximately 46 percent moisture to be used as fuel. Table 1 gives a summary of the results from the field tests.

‡ Based on 7,000 Btu per lb available from dry matter in straw and 1,100 Btu required for the evaporation of one pound of water from the burning straw.

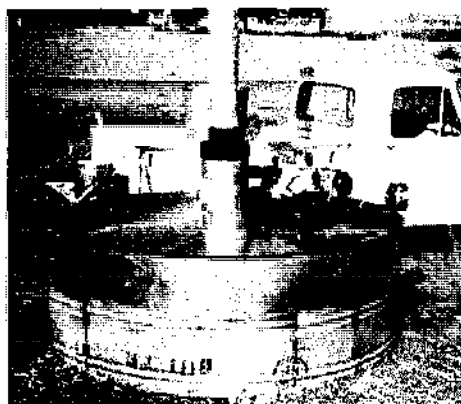


FIG. 4 Experimental drier 8 ft in diameter. Leveling blade shown is attached to engine-driven stirring sweep arm. Also shown are the doors for inserting the straw burned.

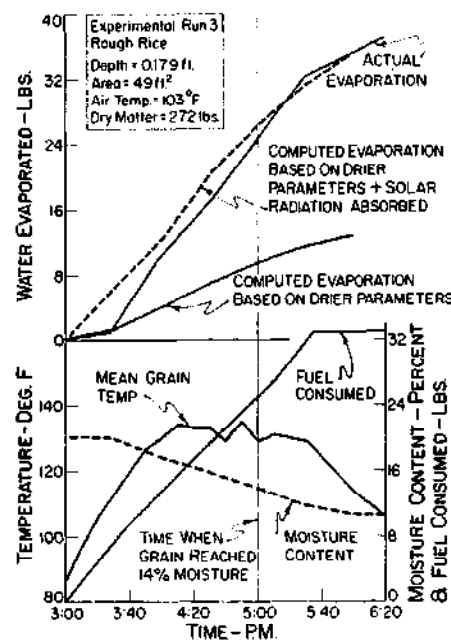


FIG. 6 Results from an outdoor test with the 8-ft-diameter experimental drier. Fuel used was rice straw of 10 percent moisture.

TABLE 1. FIELD DRYING TEST WITH RICE (CALROSE)

8-ft-diameter drier	Run 1	Run 2*	Run 3	Run 4
Depth of grain, ft	0.091	0.274	0.179	0.142
Initial moisture content, percent	20.6	19.1	20.1	19.6
Mean grain temperature between start and 14 percent MC, deg F	142	117°	119	116
Over-all rate of moisture loss start to 14 percent MC, lb per sq ft hr	0.372	0.346*	0.249	0.276
Computed rate of moisture loss, start to actual 14 percent MC, lb per sq ft hr	0.202	0.079*	0.098	0.086
Ratio of fuel burned to moisture loss, start to 14 percent MC, lb per lb	1.7	1.11	1.03	1.02
Time required to reach 14 percent MC, hr	0.73	1.83	2	1.33
Milling yield of artificially dried rice, percent	87.7	64.1	70.6	67.0
Milling yield of control rice, percent	69.8	69.2	69.3	68.4
Head rice—drier sample, percent	38.3	49.3	52.6	38.8
Head rice—control sample, percent	64.3	62.7	58.2	56.4
(Head/milled) from experimental drier, percent	62	85	86	70
(Head/milled) from control sample, percent	62	85	86	70
Seed germination, percent	0	0	0	0

* During Run 2 the depth of grain was so great that the stirring apparatus did not stir all the grain, and thermocouples did not reach the bottom of the grain layer. It is likely that temperatures were higher than recorded. Some grain kernels were overheated and darkened.

We found that, if the heated grain at 14 percent moisture was spread out in the shade—even with cool air temperatures—an additional decrease in moisture content (to approximately 13 percent) would occur. However, rice treated this way suffered a slight decrease in the over-all proportion of head rice (from 46.0 to 40.5 percent).

EFFECTS ON GRAIN QUALITIES

Seed Germination None of the rice dried in the field tests was capable of germination, even though the average germination of the four cool-air-dried control samples was 59 percent (Table 1).

Germination tests were also made for the grain dried in the laboratory drying-parameter tests. Only the results of those tests in which some germination occurred are shown (Table 2). Generally the grain dried with conducted heat did not germinate. This drying process, therefore, should not be used for grain to be used for seed.

Rice Milling Quality The most significant aspect of rice milling quality is the proportion of head rice produced. Of interest here is the proportion of the milling yield which is head rice and how that proportion is affected by this drying process. In Table 1, the proportion of head rice from the field tests is compared with that from control samples which were dried by being spread out in a thin layer on a table in an air-conditioned room for 24 hr. On the average, the proportion of head rice obtained with the drier was 76 percent of that for the control. Some large differences in results between individual tests, however, indicate that greater depths (and thus slower drying rates) tend to result in improved head yield.

Milling tests also were made on some of the samples from the laboratory tests. However, since these samples had been reduced to 10 to 11 percent moisture, the head-rice yields were not as favorable as those from the field tests (13 to 14 percent moisture). Nevertheless,

some trends can be distinguished from the results (Table 3).

These data indicate that the reduction in head yield was due primarily to increases in the maximum rate of moisture content change and that reductions in head yield that accompany higher drying temperatures are due mainly to this factor and not to the temperature level itself.

In general, this drying process is capable of producing a greater proportion of whole grain rice than is the sun-drying process. In 11 sun-drying tests, the average proportion of milled rice that was unbroken was 43.9 percent (9).

Color Changes in Milled Rice Because air movement through the grain is relatively small during drying, the warm, moist atmosphere around the rice kernels caused a slight parboiling effect. Visual comparison of samples 1 and 2 from Table 3 revealed little difference, but side-by-side comparisons between 1 and 3 made a slight yellowing of sample 3 noticeable. Sample 4 had a yellow color which was distinguishable even without comparison with a control. However, after cooking all treated samples were as white as the control (sample 1).

The color of milled samples from field test runs 1, 3, and 4 was inter-

TABLE 2

Grain type	Exposure time, hr	Mean temp., deg F	Max temp., deg F	Germination, percent
Rice	24	72	75	72
Rice	2.5	114	139	35
Rice	5	119	145	15
Rice	11	120	157	1
Wheat	24	72	80	95
Wheat	4.5	118	143	88
Wheat	24	125	156	3
Maize	24	72	75	95
Maize	4	114	130	0

TABLE 3. FACTORS AFFECTING HEAD RICE YIELDS

Sample	1*	2	3	4	5	6
Maximum drying rate, percent per hr	0.5	1.2	2.8	5.2	5.6	9.6
Maximum temperature, deg F	85	157	172	223	165	167
Mean temperature, deg F	80	120	136	160	133	135
Grain depth, ft	0.02	0.165	0.165	0.165	0.094	0.047
Drying time, hr	24	11	5.5	3.0	2.5	1.5
Head yield/milled yield, percent	81	61	44	22	13	1

*Control sample.

mediate between that of laboratory samples 2 and 3 (Table 3). The color of the sample from field test run 2 was clearly noticeable because of its content of occasional browned kernels caused by overheating as a result of inadequate stirring.

Milled-Rice Taste Comparisons Rice usually is consumed in the whole-grain form, and frequently is unmixed with other foods. Because of this its flavor qualities, though mild, are easily distinguishable, and are important to the consumer. Some of the milled samples from tests reported in Tables 1 and 3 were submitted to a taste panel consisting of 13 oriental students, each of whom made each comparison two times. In the first series of comparisons, the judges were asked to rank samples 1, 2, 3, and 4 (Table 3) in order of taste preference. With the scoring system used, if all samples received the same preference they would each have a score of 1.00. The judges ranked the samples as follows:

Sample number (as in Table 3)	1	2	3	4
Taste preference score	1.12	1.18	0.98	0.71

The results indicate that sample 2, which received the highest rating, was at least not objectionable as compared with the control (sample 1). Sample 4, however, which had been subjected to the highest temperature, had a less desirable flavor.

Taste comparisons were also made with milled samples from field test runs 3 and 4. Taste preference scores were as follows:

	Control	From experimental drier
Run 3	1.23	0.77
Run 4	0.92	1.08

In run 4, at least, the taste of the experimentally dried rice was not objectionable in comparison with that of the control. The fact that a preference for the control was shown with rice from run 3 may have been due to a longer drying time and slightly higher temperatures for run 3 as compared with run 4.

A comparison also was made between the artificially dried rice from run 4 that was bagged directly from the drier and that from the same run that was spread out in the shade to cool for an hour before bagging. The direct-bagged material received a score

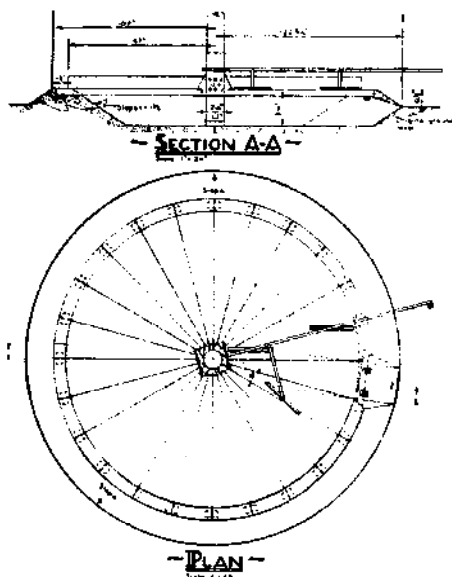


FIG. 7 Side and top views of proposed drier design, all dimensions in inches.

of 0.81 and the air-cooled material a score of 1.19, indicating the cooling procedure to be desirable from the taste standpoint.

CONSTRUCTIONAL ASPECTS OF THE DESIGN

Main Drying Deck Fig. 1 shows the drying deck in circular form. There is no reason why an elongated rectangular form could not be used. It appears from the investigation of drying rates that the most important element involved is the amount of heat-transfer surface in contact with the grain. This surface is also the major element in material requirements and costs. From both heat transfer and cost considerations it is important that the deck materials be

as thin as possible. The design in Fig. 7 utilizes wedge-shaped pieces of sheet metal, with the sides of the wedge folded down at right angles to give rigidity and with the center portion of the wide end folded up to form the outer wall of the dried (Fig. 8). Twenty-four of these wedge-shaped sections bolted together form not only the drying deck but also its supporting structure (with the exception of the supporting post in the center). These sections when folded will nest together for efficient transport and storage.

Stress computations indicate that, for a 16-ft-diameter drier, sheet metal 0.032 in. thick with 4-in. folded sides would be sufficient to carry not only grain weight but the weight of a man who may stand on the structure.

Flame Shield During field tests it was found necessary either to distribute the burning fuel very evenly under the surface or use a shield to prevent the flame from impinging directly on the metal in contact with the grain. The flame shield in the design extends to within a few inches of the edge of the wall on which the deck rests. This allows an opening for the heated gases to enter the passage between the deck and the shield on their way to the stack. The shield also has other advantages. Since all the gases from the burning fuel are forced to pass very near the main heat-transfer surface before going up the smokestack, heat losses from gases going directly up the stack are reduced. In addition, the flame shield could be fastened to the bottom of the structural flanges of the main deck sections at numerous points, thus forming a box section of much in-

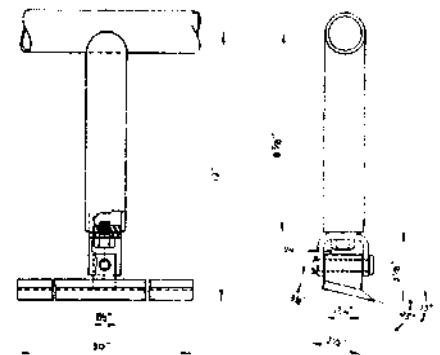


FIG. 9 Detail of stirring-blade construction. A pivoted joint is used to permit blade and main stirrer frame to adjust to surface irregularities without any part of the blade lifting off the deck. Cap screw mounting of blade hinge is to permit angling the blade from a radial position in order to overcome tendency for grain to move from center to edge of drier.

creased strength. This construction is not shown in the design because of problems envisioned in assembly. The material for the flame shield need be only strong enough to support its own weight. Thus sheet steel 0.016 in. thick should suffice, provided flanges are folded on the wedge-shaped flame shield sections. Both the deck section and the flame shield are of such shape that two units may be cut from standard-sized sheets of steel (Fig. 8).

Stirrer Field tests indicated that it was absolutely essential that every sq in. of the drying surface be scraped by the stirrer each min. This was most critical when grain was 2 in. or more in depth. The stirrer shown (Fig. 7) is vertically supported at three points to ensure contact at each point. The stirring blades are pivoted on a tangential axis to allow adjustment for irregularities in the deck surface (Fig. 9). The angle of each blade about a vertical axis is adjustable (Fig. 9). In the field tests it was found necessary to have the blades at an angle to a radial line passing through their center. Such positioning was required because the grain actually started sliding forward on the deck some distance ahead of the blade, causing a general movement of the grain from the center to the edge of the drier. Angling the outer edge of the blade ahead of the radial line can compensate for this movement. The middle blade support is located forward of the main beam (Fig. 7) to achieve stability and to provide a moment to counteract the moment caused by the animal pulling at a level higher than that at which the blades engage the grain.

Center Support and Stack The design in Fig. 10 uses a 12-in. tube of 0.0625-in. steel as a support for the center of the drier. The plate which carries the deck sections has small flanges to which the sections are bolted,

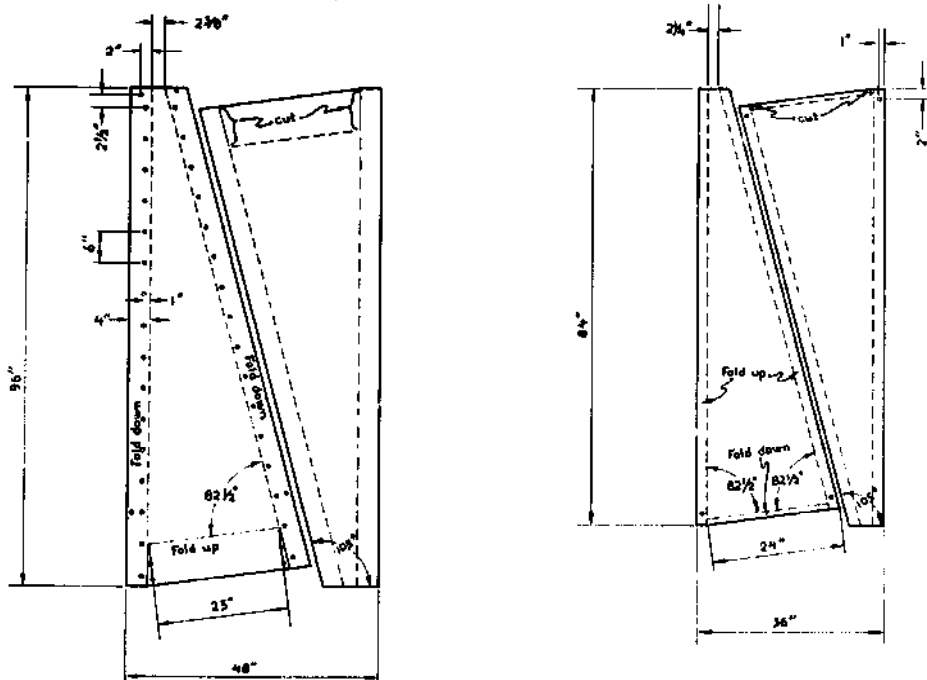


FIG. 8 Layout of standard steel sheets for folding into main-deck and flame-shield sections. Thickness of sheet for main deck sections was 0.032 in. while that for flame shield was 0.016 in. All dimensions shown in inches.

thus giving the support stability relative to the deck. The gases are introduced into the tube through the holes shown. The perforated section is longer than the thickness of the deck and is shrouded with a covering cone so that the holes need not be so close together that the stack is seriously weakened. The stirrer pivots around the stack, attached with a wooden block bearing. If stack temperatures become unduly high, the wood will have to be replaced with a more heat-resistant material.

Firing Door This door (Fig. 11) incorporates sheet-metal, retaining-wall sections to keep the earth in place. These sections also facilitate sealing of the door, thus preventing undue drafts into the burning material and permitting better control of grain temperatures. Fig. 7 shows only one door, but it is likely that at least two doors will be required.

Fire Pit A minimum amount of earth has to be moved if the material excavated from the center is used to form a circular wall. The raising of the deck above the general ground level makes operation more convenient and brings the stirring arm to a convenient height for the draft animal. Side slopes of 1 to 1½ are used in order that the pit may remain stable from year to year. If the drier is removed and the pit fills with water, the pit may prove a hazard for small children.

OPERATIONAL ASPECTS OF THE DESIGN

Temperature Control It will be necessary to attach a durable thermometer to the stirrer as an aid in controlling grain temperature. However, after two

or three runs with the experimental drier during field tests, we were able to estimate temperatures from the smell and feel of the grain. Moisture content also could be estimated fairly accurately from the manner in which the grain flowed over the stirrer. It is to the advantage of the drier operator to use as high a grain temperature as possible, as speed of drying doubles with each 20 F increase in grain temperature. Thermal efficiency, labor efficiency, and capital efficiency increase with the rate of throughput, provided the quality of the grain does not suffer.

Fuel Moisture Content Subsequent tests using rewetted barely straw indicated that straw of up to 65 percent moisture (wet basis) could be burned in the drier, provided the fire could be initially established using dry material. The use of high-moisture material as fuel would require the burning of increased amounts of fuel dry matter (as compared with the use of dry fuel) in order to offset the heat energy required for vaporization of the water in the wet fuel.

Fuel Insertion A long-handled pushing tool would be an aid in getting the fuel toward the center of the fire pit. While the flame shield makes fuel location not particularly important, having the fuel close to the center of the pit would tend to make for the most uniform heat distribution. In instances where the straw is very moist, it may be advisable to stack the straw on the bank around the edge of the drier to promote its drying prior to burning.

Drier Loading The drier was designed to accommodate approximately a 2-in. depth of grain. With rice, in particular, more shallow depths lead to more rapid changes in moisture content and thus to more grain cracking. On the other hand, too deep loading results in increased temperatures for the bottom of the grain layer, which may contribute to off-flavors in rice. The use of a 2-in. depth and grain temperatures of 130 to 135 F is expected to be the best compromise for rice. For grains in which cracking is not a problem, operation at depths less than 2 in. should permit more rapid drying due to the increase in the value of the X factor. Where mean grain temperatures of 160 F can be used, the 16-ft diameter drier should be capable of drying 400 lb of grain per hr from 24 to 14 percent moisture. Such an operation would most likely involve batches from 800 to 1,600 lb and running times of 2 to 4 hr.

Unloading the Drier A wooden scraper board which can be set in front of the stirrer would make the movement of grain from the center to the edge of the drier relatively simple. A square-edged scoop then could be used

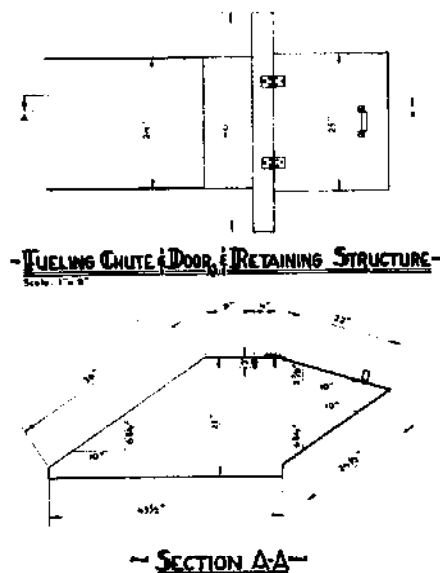


FIG. 11 Firing door showing metal plates for use as earth-retaining walls. It is important that the door along with other points of installation provide a tight seal to prevent uncontrolled drafts in the fire pit.

for unloading the grain from the edge of the drier.

Preventing Corrosion of Heated Parts Scouring of the top of the deck by the grain prevents corrosion encrustments from accumulating there. But it was expected that the underneath side of the drier would be susceptible to corrosion. However, during the field tests, in which rice straw was burned it was found that the temperature of the drier surface was sufficiently low to permit a thin coating of tar from the smoke to accumulate uniformly on the underneath surface. Because of this it is possible to use low-cost, nongalvanized steel for drier fabrication. If the drier is stored when not in use, it would be advisable to coat at least the upper surface with a heavy lubricant.

CONCLUSIONS

In summary, the following conclusions may be drawn from this investigation:

1 Grain can be dried using heat conducted from a metal surface to supply the heat of vaporization of the water removed.

2 At practical rates of conductive heat transfer, the grain must be thoroughly and frequently stirred to prevent overheating grains in contact with the metal surface.

3 The average rate at which moisture leaves grain, doubles with each 20 to 21 deg F increase in the mean grain temperature during conducted heat drying.

4 The 16-ft-diameter drier operating with mean grain temperature of 160 F can dry 1600 lb of 24 percent moisture grain to 14 percent moisture in 4 hr. Rice requires lower grain tem-

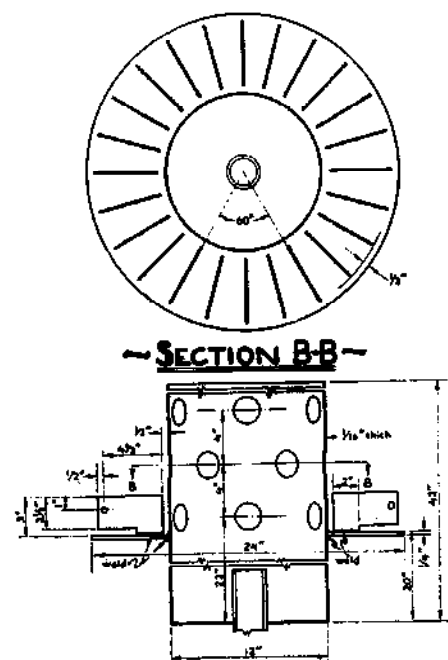


FIG. 10 Center support and smokestack base. The vertical flanges welded to the shoulder are to be bolted to the main deck sections upon assembly to secure support to drier.

peratures, and when in contact with a 200 F metal surface, it will have an average grain temperature of 137 F and lose moisture at a rate of 0.15 lb per sq ft per hr. Thus a 200 sq ft-drier (16-ft diameter) could dry 968 lb of rice from 24 percent to 14 percent moisture in 4 hr.

5 The fuel requirements for this drying process can be met by burning the straw normally contained in the bundles associated with the grain to be dried.

6 Grain dried by this method will not germinate and thus cannot be used for seed.

7 The amount of rice-kernel breakage related to this drying process increases with the rate of moisture content decrease. However, in field tests rice losing 3 percent moisture per hr had 89 percent as much whole-kernel rice as did a control sample very carefully air dried over a long period of time at low temperature.

8 When milled, rice dried by this

process may appear slightly more yellow than carefully air-dried rice. The degrees of yellowing increases with increases in the temperature of the grain during drying. However, upon cooking no traces of yellowing are detectable.

9 Generally, rice dried at normal temperatures by this process was not distinguishable from carefully air-dried rice on the basis of taste.

10 A design of a simple drying structure has been formulated. The design incorporates a stirring apparatus which uses only animal power. This stirrer is the only moving part. The manufacture of the structure does not require highly industrialized facilities.

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References

- 1 Moss, C. J. Future world needs of mechanical power in agriculture, address to the British Association, section M, Cambridge, 1965.
- 2 Hall, D. W. Some essential considerations on the storage of food grains (cereals, legumes and oilseeds) in tropical Africa. Informal working bulletin No. 24, agricultural engineering branch, land and water development division, Food and Agricultural Organization of the United Nations, Rome, Italy, 1963.
- 3 Chancellor, W. J. Transport distances for gathering and distributing materials on an open rectangular field. *Malayan Agricultural Journal* 44:(1)151, 1963.
- 4 Boyce, D. S. Aspects of in-bin drying of padi in Malaya utilizing the waste heat of an internal combustion engine. *Malayan Agricultural Journal* 39:(4)277, 1956.
- 5 NIAE Test Reports for Users Nos. 461. Oct. 1965 and 488 Dec. 1965. National Institute of Agricultural Engineering, Silsoe, Bedford, U. K., 1965.
- 6 A'Brook, J. Artificial drying of ground nuts: A method for the small farmer. *Tropical Agriculture* 40:(3)241, July 1963.
- 7 Chancellor, W. J. Characteristics of conducted heat drying and their comparison with those of other drying methods. *Transactions of the ASAE* 11:6 (this issue), 1968.
- 8 Chancellor, W. J. An experiment on sun drying of padi. *Malaysian Agricultural Journal* 45:(1), January 1965.
- 9 Angladette, A. Rice drying principles and techniques. Informal Working Bulletin No. 23, Agricultural Engineering Branch, Land and Water Development Division, Food and Agriculture Organization of the United Nations, Rome, Italy, 1962.

Field Testing a Simple Grain Drier in Asia

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RESearch on conducted-heat drying was done in an arid climate using laboratory-scale equipment and a half-scale model of a simple drier design (1, 2)^o. The grain was initially less moist than that for which artificial drying would be required in tropical climates. Consequently, tests were planned to investigate:

1 the feasibility of the full-scale proposed drying structure,

2 the performance of the conducted-heat drying process under humid, tropical conditions,

3 the practicability of using animal power for extended periods near the large, heated, drying structure,

4 the suitability of moist straw and other locally available materials as fuel sources for the drier, and

5 the performance of the drier with very moist grain, such as might be obtained in rice double-cropping areas due to rains at harvest, or to harvest at a less mature stage of development.

Seven test runs were made using rice grain with moisture concentrations ranging from 20 to 40 percent (w.b.). One test run was made in the rain. Drying periods from 2 to 6½ hr were tried. Rice husks and wet, green straw (moisture content 64 percent, w.b.) as well as dry straw (11 to 16 percent moisture) were tried as fuel. Grain depths ranged from 0.096 to 0.183 ft while temperatures ranged from 122 F to 169 F during drying. Animals were used for periods of up to 2 hr without stopping.

Drier Construction and Installation

The design tested is shown in Fig. 1. Details of the constructional features are like those given in reference (1). The cost of all materials for the drier, excluding the canvas canopy used in the field, was approximately \$160.

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Special acknowledgment is made to Mr. Sutin Sakarnukit, who supervised the drier construction in the Engineering Division workshop and drier installation in the field, and to Mr. Kumnuan Tunpan of the Agricultural Engineering Dept., Kasetsart University, for his help and advice during the installation and initial testing of the drier.

^oNumbers in parentheses refer to the appended references

The drier was preassembled in the workshop to minimize problems at the field installation site (Fig. 2). In disassembled form (Fig. 3) it could be carried on a pickup truck. At the field site the drier deck and flame shield were assembled into four 90-deg subassemblies (Fig. 4). The flame shield sections were bolted at regular intervals to the main deck section flanges to produce a box-section type of structure (Fig. 5). A 23 ft x 23 ft canvas was placed over the drier site to protect workers from sun and rain. A fire pit was dug using a wooden template of the appropriate radial cross section (Fig. 6). Subse-

quently, the two fuel chutes were installed diametrically opposite each other in the fire pit wall (Fig. 7). The work required for installation is indicated in Table 1.

TABLE 1. MAN HOURS REQUIRED FOR DRIER INSTALLATION

Operation	Man Hours Required
Making subassemblies	16
Digging fire pit	12.4
Installing fuel chutes	9
Placing and joining subassemblies	41
Levelling and completion of installation	21
Total	109.4

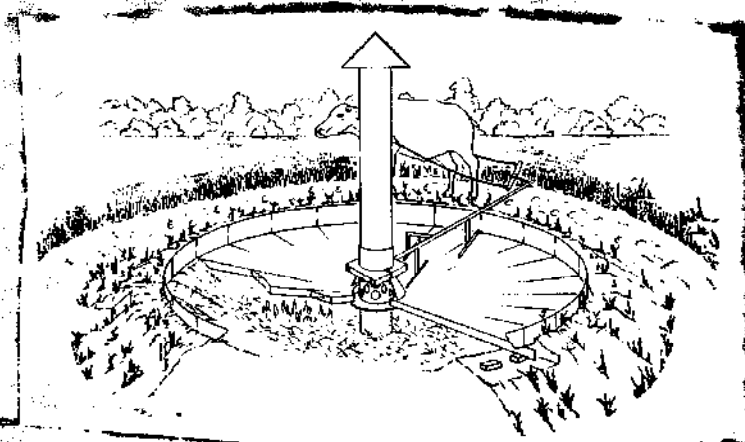


Fig. 1 Illustration of drier design tested. Outside diameter was 15 ft, 8 in., and the main drying deck was 2 ft above the fire pit floor



Fig. 2 The drier was preassembled in the workshop to minimize problems at the field installation site. It was necessary to support the outer edges above the floor to simulate support that would be given by the fire pit wall



Fig. 4 The center support was 4 ft in diameter so that drier sections could be made from sheets 79 in. long

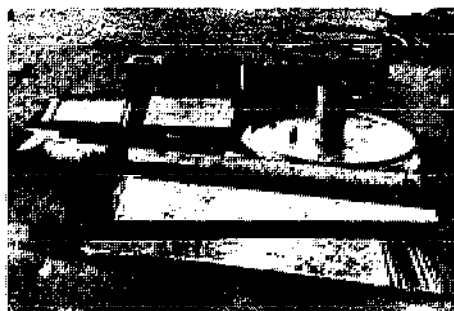


Fig. 3 Drier parts when fully disassembled could be nested together to minimize space consumed



Fig. 5 Box-section form of drier segments was constructed by folding the main deck or top piece to form the box sides, and by bolting the lower surface or flame shield to these sides



Fig. 6. The fire pit was dug using a wood frame template to guide both the form and level of the pit. The mound of earth in the center was removed as the pit was completed.

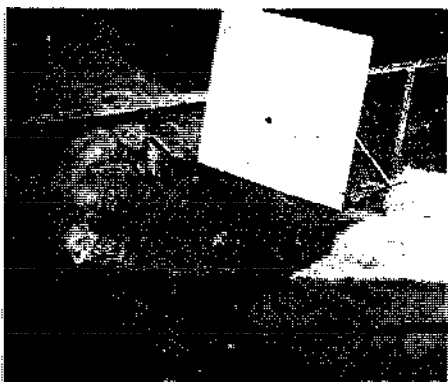


Fig. 7. Two fuel doors were installed in the fire pit wall at points diametrically opposite to each other. Metal retaining walls were incorporated in the fuel door assembly.

After installation, preliminary tests were made of various individual features of the drier.

1 Three men stood near the mid-span point of one radial joint line, loading it with about 420 lb. No buckling or permanent deformation occurred.

2 Dry straw was placed in the fire pit and ignited. Burning was satisfactory, causing a dial thermometer to



Fig. 8. Over-all view of the drier in operation. The stick under the edge of the fuel door was used to regulate the air supply to the fire.



Fig. 9. The stirring sweep was supported vertically at three points only, and each blade was pivoted. The tendency for chaff to accumulate on top of the grain can be noticed.

cated between the flame shield and main deck section at the outer wall to register 300 F.

3 The draft animals performed satisfactorily only in pairs and only when moving in a counterclockwise direction, with a hitch similar to that used with a comb harrow. A driver was needed behind the animals at all times (Fig. 8).

4 For a 2-in. grain depth it was found that the stirring apparatus had to have a 6-in. beam clearance to avoid interference with the grain (Fig. 9).

After these tests and modifications, the drier was ready for performance tests.

Grain Drying Test Runs

Grain Unhusked rice was used in all tests. It was obtained in a naturally moist state by harvesting before the conventional harvest date, since in the locality in which tests were made harvest normally occurred during a dry

season. Three different varieties of rice, including medium and long-grain types, were used.

Just before each drying test, about 45 lb of the moist grain was spread out on a 75-sq ft plastic sheet inside a well-ventilated building. This control sample was later compared with the artificially dried material on the basis of milled grain characteristics.

Fuel Rice straw from a 1-year-old stack was used in most tests. Various samples of this straw had moisture concentrations ranging from 6.6 to 15.8 percent (w.b.).

Test runs 4 and 5 used wet, green straw and rice husks, respectively, for fuel. These fuels will be described later.

Drier Operation Before each test run began, about 30 lb of straw was placed in the fire pit. The draft animals were attached to the stirring sweep, and the grain was poured onto the drier from 20-liter cans. The moving sweep quickly levelled the grain. The fuel was then ignited, and the duration of the run measured from this time of ignition.

A dial thermometer with an 11-in. stem was inserted radially inward through the earth wall about 1½ in. beneath the main deck level (Fig. 10). It was located half-way between the two fuel chutes and was used to measure the temperature of the gases entering the passage beneath the drying deck (duct temperature).

The drying temperature was controlled according to the duct temperature reading. Temperatures were increased by adding more fuel or opening the fuel-chute doors a small amount to permit air entry for combustion. Temperatures were reduced by using small amounts of fuel, increasing time intervals between fuel additions or by

tightly closing the fuel-chute doors to restrict the air.

To prevent the fire from going out during low-temperature runs, the fuel was pushed (with a long wooden pole) toward the center of the fire pit where higher temperatures could be more easily maintained. Duct temperatures were generally controlled in the range between 180 and 250 F.

Stirring Animals were generally used for stirring during the beginning hours of the runs, and relieved by a 4½-hp hand tractor. A metal pipe projected forward from the tractor frame so that a rope tied between the pipe and the stirring sweep could guide the tractor automatically in a circle (Fig. 11). The draft force was supplied through a rope running from the rear of the tractor to the stirring sweep hitch point. The force, as measured during two runs, was 23 lb at a radius of 179 in.

The animals during the first tests pulled the stirring sweep at 1 rev per 35 sec, but this speed gradually decreased with succeeding runs until 1 rev per 50 sec was obtained during the fifth run. The tractor generally operated at 1 rev per 40 sec.

Even though the stirring blades were angled inward about 15 deg from radial lines through their centers, the grain gradually moved from the center to the outer edge. This was counteracted by using a 16x6-in. pushing board, with handle attached, to push about half the grain radially inward



Fig. 10. The duct temperature thermometer extended through the fire pit wall and into the space between the main deck and the flame shield.

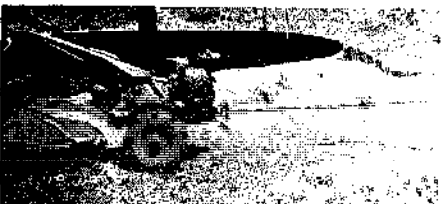


Fig. 11. A two-wheel tractor was sometimes used to pull the stirring sweep.

every 15 to 20 min. This also increased the stirring effect.

Temperature Measurements The duct temperature was measured as described above. The grain temperature was measured with a dial thermometer having an 8-in. stem, 0.125 in. in diameter. The thermometer was inserted into the grain at four circumferential positions 1 to 2 ft from the outer radius of the drying deck. The values reported are averages of the four readings.

Wet bulb and dry bulb air temperatures were measured with a sling psychrometer. All temperatures were measured half-hourly or quarter-hourly, and the periods of measurement coincided with the periods of sampling for grain moisture determinations.

Measurements of Moisture Content Samples were taken from the grain on the drier at the intervals indicated above. Sample size ranged from 0.4 to 0.8 lb. Each sample was collected from at least four points circumferentially distributed around the drier. The samples were weighed within 2 or 3 min after collection and placed in a ventilated oven at 230 F for 24 hr to dry.

Samples were first taken by scooping up small amounts of rice, using the hand or a round container. In the first two runs, the moisture content values seemed to increase shortly after the start. However, when a rectangular can was used to scoop up samples, the problem seemed to disappear.

A 45-lb sample was taken at the end of the run to determine milled grain characteristics. The grain remaining after sampling was put in bags.

Moisture determinations were also made on portions of each 45-lb sample before and after cooling as well as from the material bagged after drying. Moisture determinations were also made for

control samples before and after the air-drying process.

Features of Each Drying Run Table 2 gives the parameters describing the conditions during each of the seven runs. However, during each run there were other special factors involved; these are discussed below.

Run 1 was the only test of a long grain rice variety. The rice was naturally dried to the lowest moisture content before artificial drying. In addition, the material was used in an attempted run the previous day, during which heat had been applied for 20 min before the test was stopped and the rice bagged. During those 20 min some rice had become warm.

The rice in run 2 was very green and contained some external moisture and a large amount of unfilled grains and chaff.

Run 3 had the largest amount of grain to be dried. The temperature was held down during this run, consequently the fire went out several times.

The smallest amount of material and the lowest level of grain temperature were used in run 4. However, green, wet straw of 64 percent moisture content (w.b.) was used for fuel. After the fire was started with dry straw, wet straw was put into the fire pit. However, it did not appear to burn, so a mixture of wet and dry straw was fed in. Only after about 2½ hr did the green, wet straw start to slowly burn.

However, hot green straw extracted from the fire pit burst into flame in the free air. It is believed that the fire could have been maintained with green straw once it had started to burn. The average moisture content of the total mixture of green and dry straw was about 44 percent (w.b.).

In run 5, rice husks (12.7 percent moisture content, w.b.) were used for

fuel. The fire was started with dry straw. Husks thrown into the fire pit along side the straw did not burn significantly even when small amounts of kerosene were applied at spots. However, 1½ days after the test, the husks were still smoldering in the fire pit.

Grain that was partially dried in run 3 was used in run 6. At one point in the run, the temperature of the grain rose to 178 F, but was subsequently controlled at about 160 F.

In run 7, grain combined from the outputs of runs 4 and 5 was used. The grain in these runs originally came from the same lot. An attempt was made to control temperatures at lower levels than in run 6. The last half of the run was subjected to high winds and rain; some rain did get under the canvas canopy and into the grain.

In addition, measurements of stirring force were made to see if the greater grain depth would require larger forces than in run 5. No change in force levels was noted.

Results of Drying Test Runs In addition to the specific parameters included in Table 2, the principal results from the drying runs are presented in Figs. 12 through 18.

The stirring force of 23 lb at a radius of 179 in. and a typical speed of 1 rev per 45 sec, represented a power requirement of 0.087 hp. After 2 hr of work (during which drivers were alternated several times), the draft animals were weary but did not appear physically stressed. The animals were accustomed to being rested at 11:00 a.m. when doing field work. However, when they were used for stirring, they worked until 12:00 noon. When a second pair of oxen was tried for stirring in the counter-clockwise direction, and the standard type of hitch arrangement

TABLE 2. DRYING TEST RUN PARAMETERS

Drying test run no:	Rice variety	Grain length	Initial moisture content, percent w.b.	Final moisture content, percent w.b.	Total time on drier, hr	Dry matter on drier, lb	Grain layer depth, ft	Average grain temp, F	Maximum grain temp, F	Average duct temp, F	Fuel type	Average dry bulb temp, F	Average relative humidity, percent	Total water evaporated, lb	Total straw burned, lb
1.	Nang Paya	Long	20.15	9.4	3	665	0.136	164	178	266	Dry straw	84.2	76	99.5	147
2.	Khaw Loong	Medium	38.7	15.25	4	490	0.121	168	178	244	Dry straw	84.6	74	207	236
3.	IR-8	Medium	33.5	21.3	6½	775	0.183	153	167	220	Dry straw	83.2	73	181	215
4.	IR-8	Medium	31.25	22.6	4	420	0.096	122	133	185	Wet green straw	85.2	72	68	149
5.	IR-8	Medium	30.7	21.3	3½	485	0.101	140	152	219	Rice husks	83.9	74	83	209
6.	IR-8 (from run 3)	Medium	19.7	11.1	3	690	0.163	158	178	—	Dry straw	80.1	87	82	113
7.	IR-8 (from runs 4 and 5)	Medium	20.1	15.3	3	730	0.172	143	154	227	Dry straw	79.3	88.3	55	87

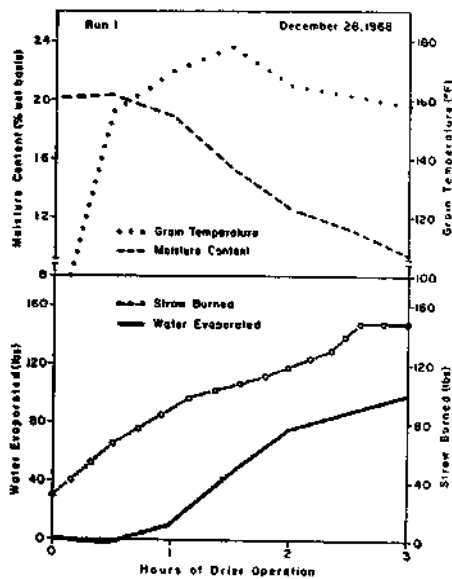


Fig. 12 Performance of the simple drier during run 1

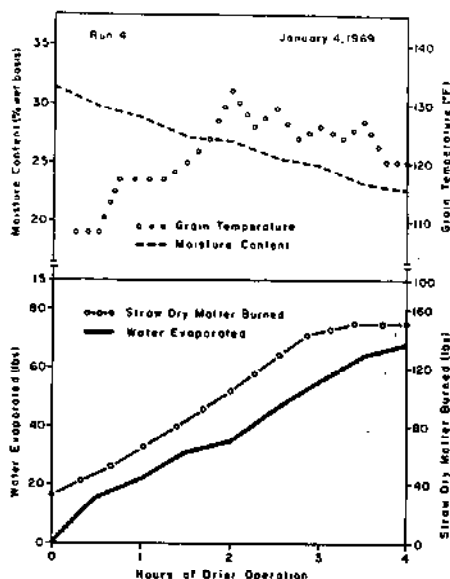


Fig. 15 Performance of the simple drier during run 4

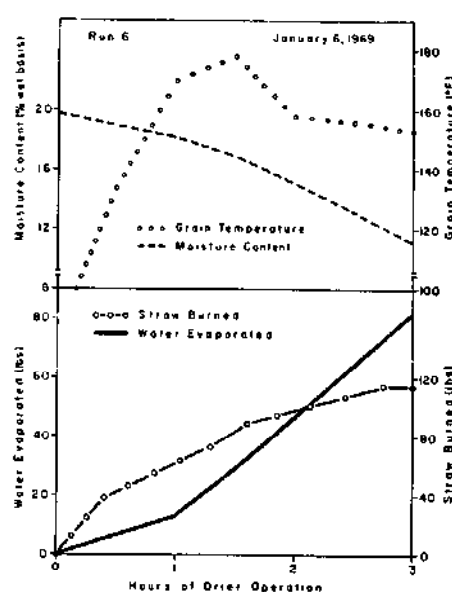


Fig. 17 Performance of the simple drier during run 6

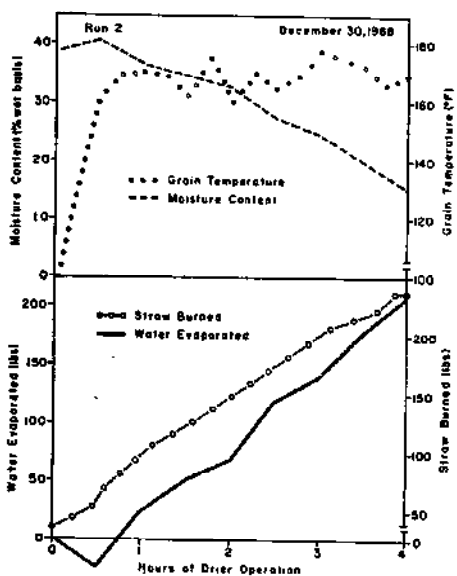


Fig. 13 Performance of the simple drier during run 2

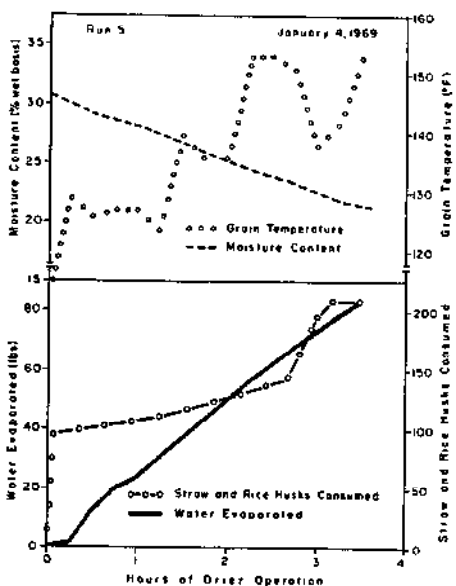


Fig. 16 Performance of the simple drier during run 5

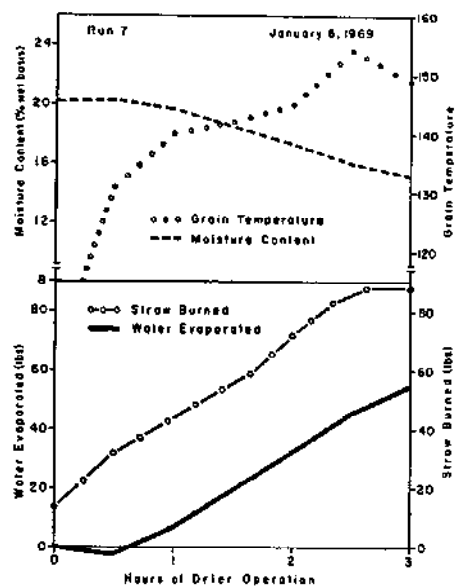


Fig. 18 Performance of the simple drier during run 7

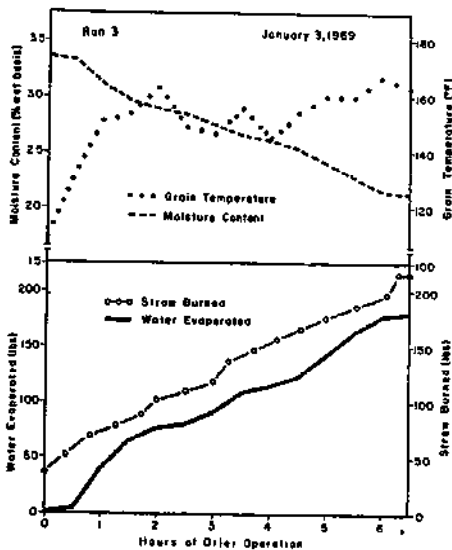


Fig. 14 Performance of the simple drier during run 3

TABLE 3. RICE MILLING TEST RESULTS

Test run no.	Rice data			Laboratory milling tests			
	Moisture content, percent w.b.	Hours on drier	Brown rice, percent	White rice, percent	White head rice, percent	White broken rice, percent	Head rice White rice, percent
1	14.5*	Control	75.2	68.7	48.2	20.5	70.1
1	15.5	2	73.5	68.0	42.5	25.5	62.6
2	14.8*	Control	73.0	62.7	45.7	17.5	72.9
2	15.1	4	75.0	69.0	59.7	14.2	86.5
3	16.2*	Control	72.5	62.0	31.2	25.7	48.8
3	16.3*	6½	74.0	67.0	56.2	10.7	84.0
4-5	16.0*	Control	74.5	65.5	45.5	20.0	69.7
4	16.8*	4	77.2	68.5	52.7	15.7	77.1
5	16.1*	3½	75.7	67.5	58.7	8.7	86.0
6	11.8	3	73.0	64.2	47.5	16.7	74.0
7	16.2	3	74.2	67.0	53.5	13.5	80.0

* These samples were air dried on plastic sheets for several days after the original test conditions to obtain a moisture content suitable for milling.

was used, the animals had no problem in adapting.

A few grains were damaged by the stirrer to the point of being cracked open. However, the number of such grains was small; no more than three or four were noticeable on the drier at one time.

The average moisture content of the six 45-lb samples taken near the ends of runs 3, 4 and 5, and spread out to cool for 1 to 2 hr, decreased from 22.9 to 22.5 percent w.b. during the cooling process.

Rice Milling Tests Milling tests were run using laboratory test equipment, including a McGill No. 2 mill†. The materials processed are described in Table 3.

In these tests, 100 g of padi were husked in a Satake laboratory husker; husked rice milled in a McGill No. 2 mill for 30 sec. Four of the 100-g quantities were tested for each rice sample, and the results of the four tests were averaged. The proportions of the original padi, which appeared as brown rice and subsequently white rice, were determined. The amount of unbroken and broken white rice was determined in proportion to the original weight of padi.

Observations of the white rice samples from the laboratory milling tests were as follows:

1 Grain dried in run 1 contained some slightly brown grains, but very few fully brown grains. Thus, the appearance was somewhat more brownish than that of the control.

2 Grain dried in run 2 contained no fully brown grains, but all grains were more grayish-brown than those of the control.

3 Grain from run 3 was less white than that in the control. The difference was probably due to a number of greenish colored grains in the artificially dried sample.

4 There were no brown grains in runs 4 and 5. In fact, the artificially dried grains appeared whiter than the grains in the controls.

5 Grain dried in run 6 contained some fully brown grains, some partly brown grains and some of the greenish grains, which existed in the material (initially partially dried in run 3). Thus, browning was clearly evident as an effect of the treatment received.

6 The rice dried in run 7 (originally partially dried in runs 4 and 5) contained some brown grains (a few fully brown), and appeared more brown than the grain dried in runs 4 and 5. How-

ever, the grain had about the same degree of whiteness as that in the control samples for runs 4 and 5.

Discussion of Results

Drier Construction and Installation Generally, the drier construction satisfactorily met all physical loads placed on it, including that caused by having the stack support the center of the canvas canopy during rain and strong winds. However, problems and delays indicated certain modifications in construction are needed to make field assembly and installation easier.

1 Using a single point center support would end problems experienced in levelling the large center support frame.

2 If sheet metal sections were used to form the outer wall, the following advantages might be obtained:

(a) A larger radius; thus, a larger capacity drier could be made from 8-ft long metal sheets if the outer wall sections could be extended above the drying deck to contain the grain.

(b) The fire pit would no longer be needed so the drier could be moved from place to place with less labor.

(c) The fuel doors could be made much less expensively so there would be no major amount of labor involved in their installation.

3 If the flame shield could be attached with flexible hanger brackets, its installation could be easily made after assembly of the main deck. The main deck assembly bolts would then be easily accessible.

Drier Operation The power level required for stirring (0.087 hp) indicates a single animal could easily pull the stirring sweep, if it were trained to work alone. However, more than one animal is needed to allow the animals to rest alternately. Two persons operate the drier—one drives the animals and one controls the fire. Since driving the animals is a tedious job, these two persons could exchange jobs periodically.

The fire (and consequently the grain temperature) is easily controlled using the readings of the duct thermometer. These readings respond rapidly to a change in fire intensity; the grain mass causes grain temperature to respond from $\frac{1}{4}$ to $\frac{1}{2}$ hr after a change in fire condition occurs. Avoiding high peak temperatures for even short periods of time is important, as these temperatures cause grain to darken, even though little drying benefit may be obtained if temperatures are quickly lowered.

There appeared to be no advantage for greater or lesser grain depths. However, the greatest grain depth used (0.18 ft) worked well with the stirring apparatus, and did not result in undue temperature differences between the top and bottom of the grain layer.

Grain Drying Performance When dry straw was used as fuel, about 1 lb of straw was consumed for each pound of water evaporated, once the grain became warm (Figs. 12, 13, 14, 17 and 18). This indicates a thermal efficiency of about 15 percent. Normal bundles of rice, which contain about 0.33 lb of straw per pound of grain, contain more than enough straw to evaporate the 0.116 lb of water, which must be removed from each pound of grain to reduce it from 24 to 14 percent moisture.

The intermittent nature of the test operation should result in a lower overall efficiency than for continuous operation. Nevertheless, the average amount of dry straw burned per unit of water evaporated was 1.35 lb straw per pound of water for runs burning dry straw only. Fig. 16 shows that when wet straw was used, about 2 lb straw dry matter were burned per pound of water evaporated. This reduction is probably due to the extra heat required to evaporate the moisture in the wet straw.

Generally, drying took place slowly until the temperature of the grain was raised to nearly the operating level. The overall drying response to temperature in these field tests was less than in laboratory tests conducted previously. For these field tests, the average drying response to temperature is represented by the equation:

$$\frac{\text{lbs water evaporated}}{\text{sq ft, hr}} = 0.0066 e^{0.0208 \text{ MGT}}$$

where MGT is the mean grain temperature in degrees F, and e is the natural logarithmic base (Fig. 19).

After the grain became quite dry, it tended to dry more slowly at any

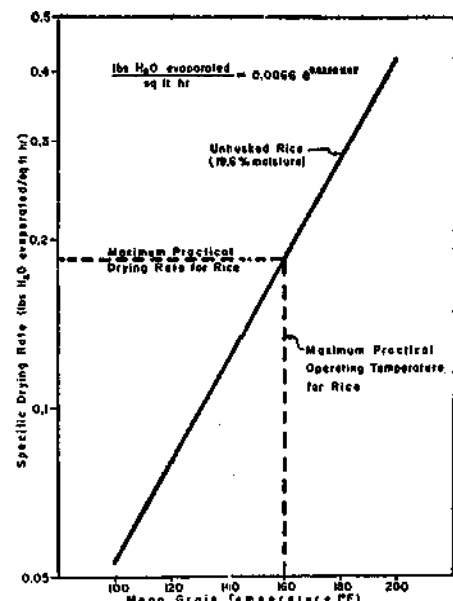


Fig. 19 The semilogarithmic relationship found in field tests between grain temperature and the rate of water evaporation per unit of drier area (at a grain moisture content of 19.6 percent w.b.)

† Acknowledgment is made to the personnel of the Rice Department, Breeding Division, Grain Laboratory for doing these laboratory milling tests.

‡ This is equivalent to 157 lb of straw for each 1000 lb of grain dried from 24-14 percent moisture content. This is about half the straw normally contained in the bundles which would yield the 1000 lb of grain.

temperature. The equation representing the average response of rice in the field tests is

$$\frac{\text{Observed water removal rate}}{\text{Expected water removal rate}} = 0.616 + 0.0196 (\text{moisture content})$$

Moisture content is given as a percentage on the wet weight basis; the expected water removal rate is determined by the equation above (Fig. 20). Grain temperatures of up to 160 F could be tolerated without undue breaking or discoloration of the grain. At this temperature, grain of 19 percent moisture loses water at the rate of 0.18 lb per sq ft per hr.

If the maximum feasible moisture loss rate (0.18 lb per sq ft per hr) was combined with the increase in drier size (diameter = 17.7 ft), obtained by using sheet metal to form the fire pit wall and the main deck wall, 44.4 lb of water per hr would evaporate from moist rice. This is equivalent to drying 383 lb of rice from 24 to 14 percent moisture in 1 hr. This would most likely be done by drying a batch of 1530 lb for 4 hr. For such an operation, however, an additional 30 min would probably be required at the beginning of the process to raise the grain temperature to 160 F.

Results from the milling tests show that drying moist rice with the conducted-heat drier keeps the grains intact more than a slow air-drying process. Only in run 1, in which the rice was originally about 20 percent moisture, was the head rice percentage for the artificially dried sample lower than for the control sample. There is no apparent reason for the low percentages

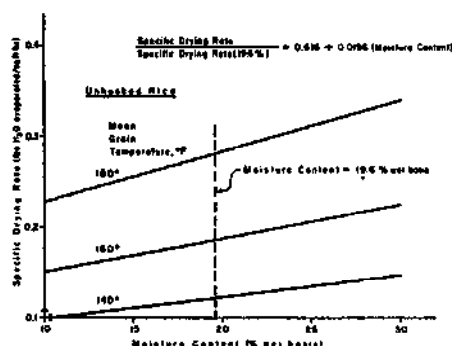


Fig. 20 A linear relationship was found in field tests between the drying rate at any given grain temperature and the moisture content of the grain

§ Drying also caused the white rice yield to be higher (an average of 68.0 percent for rice dried in runs 1-5 as opposed to an average 64.7 percent for controls). This 3 percent increase represents considerable additional value in the final product from each field—a value which could offset drying costs.

to the control samples. These samples were dried in enclosed buildings, but changes in the ambient humidity due to evening rains or dews may have caused some cracking.

All samples were milled at moisture contents in the 14-16 percent range except the sample from run 6, which was 11.8 percent. This low moisture content may have been another reason for the low head rice percentage—the high peak temperature during the drying run may have been another.

Actually, the head rice percentages for the rice dried in runs 2, 3, 4, 5 and 7 were above 50 percent, despite the fact that run 2 involved high temperatures, run 7 had two stages of drying and run 3 was stirred 6½ hr. Rice used in these runs was harvested in a rather immature, high-moisture condition which may have contributed to the lack of grain breakage in drying.

The fully brown grains in the samples from runs 2 and 6 indicate the importance of avoiding high temperatures during drying runs. Uniform stirring is also important to insure that no grains become overheated.

Summary of Findings

The drying and operational characteristics found in the field tests of this grain drier were closely related to those predicted on the basis of laboratory and scale-model tests. Specific findings were:

1 The design met all requirements for structural strength imposed during actual operation.

2 About 100 man-hours were required for field assembly and installation. Modifications of the design to reduce this labor requirement are feasible.

3 Dry straw could be burned satisfactorily, and the fire could be controlled to provide appropriate temperatures for drying.

4 The amount of dry straw used was only 1.35 lb per pound of water evaporated, and less than that usually contained in the bundles of grain to be dried.

5 Very wet straw burned when mixed with some dry straw (moisture content of mixture—44 percent), and then only after time was allowed for the wet straw to become fully heated.

6 Rice husks could not be used for fuel in the fire pit as designed (without special structures for spreading the fuel or permitting air to flow through it).

7 The power required for stirring (0.087 hp) did not cause physical fatigue for a pair of light oxen working continuously for 2 hr.

8 The oxen worked satisfactorily only when going in a counter-clockwise direction.

9 The heat transmitted from the sides of the drier was almost unnoticeable.

10 The rate of moisture loss from the grain increased with increases in grain temperature.

11 The rate of moisture loss from grain decreased with decreasing moisture content.

12 The rate of moisture removal from rice (19 percent moisture) at 160 F, was about 0.18 lb per sq ft per hr.

13 Rice heated above 160 F sustained browning of the grains. When temperatures reached levels of 178 F, some grains became dark brown, but not charred.

14 Rice placed in the drier at an initial moisture content above 30 percent w.b. contained higher proportions of whole-grain milled rice than the control samples dried slowly at low temperatures inside a building.

15 Generally, rice dried in the drier with initial moisture contents above 30 percent, contained 50 percent or more whole-grain milled rice than unhusked rice.

16 The drying process was satisfactory under conditions of high atmospheric humidity (average relative humidity during all tests was 78 percent) including those of near saturation.

Conclusion

The 16-ft diameter, simple grain drier, designed to conduct heat, can dry 1000 lb of rice from 24 percent moisture to 14 percent moisture in 4 hr by:

(a) allowing the first 30 min of the 4-hr period for bringing the grain to operating temperature,

(b) using two alternating animals for stirring,

(c) using 157 lb of moderately dry straw for fuel,

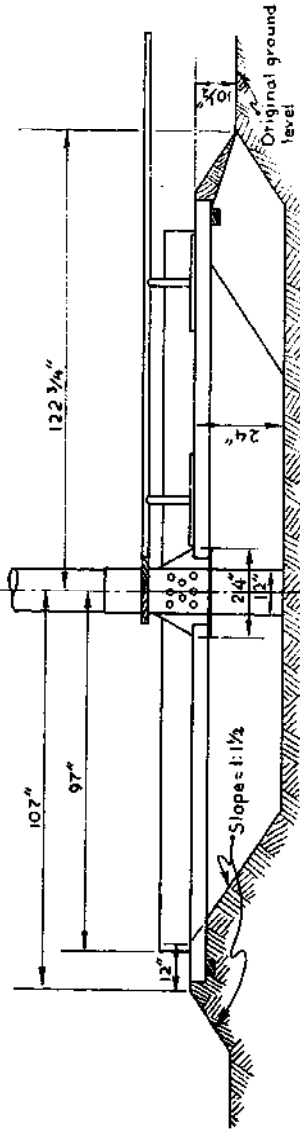
(d) avoiding temperatures so high as to cause undue discoloration of the milled rice,

(e) obtaining whole-grain milled rice percentages on the order of 50 percent by weight of the unhusked rice milled,

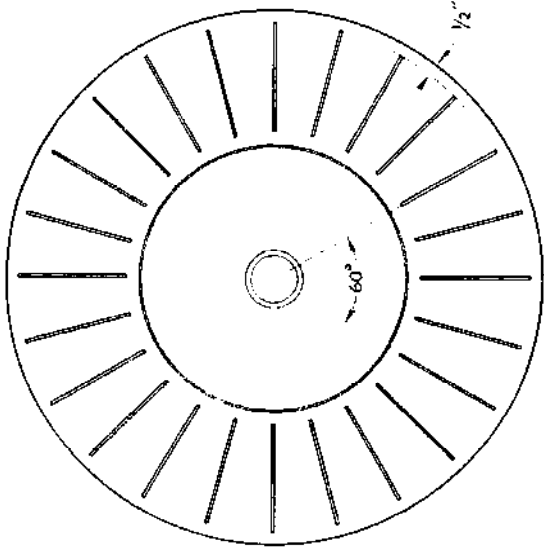
(f) operating in humid or rainy atmospheric conditions.

References

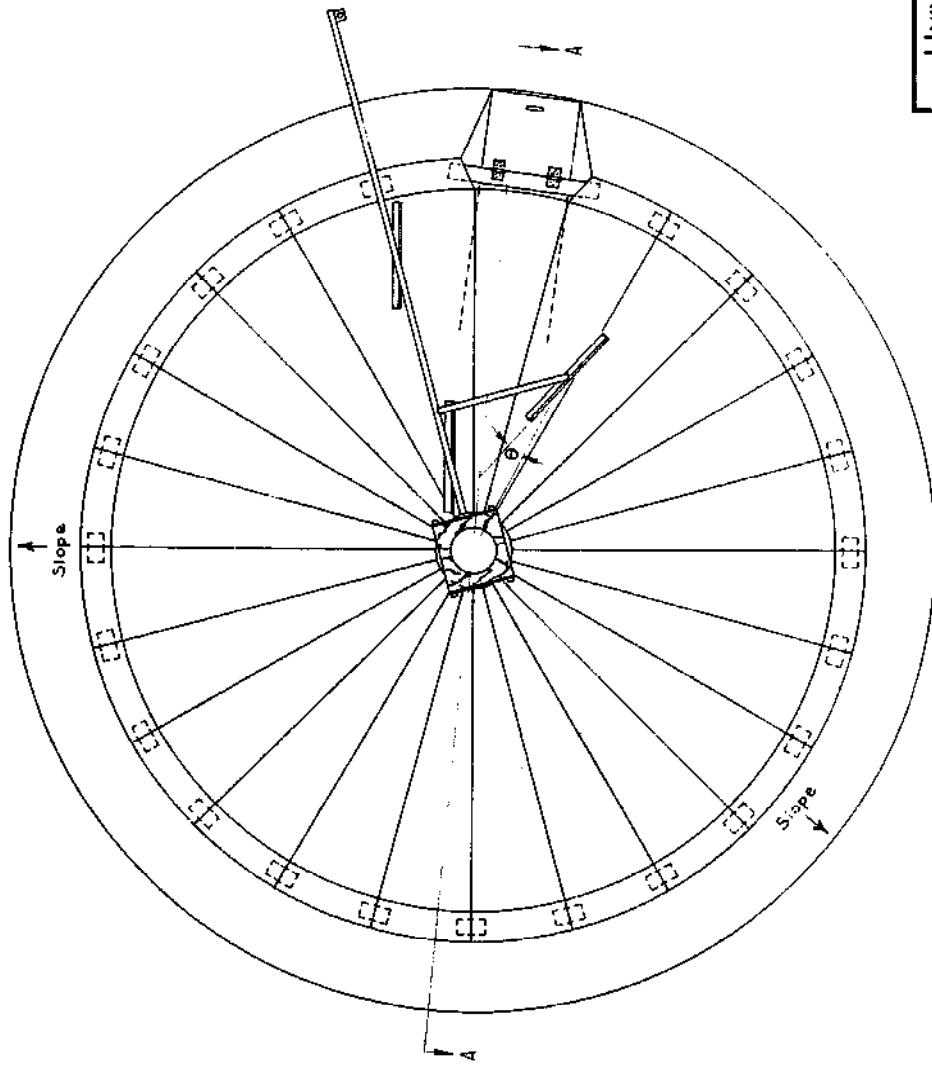
- 1 Chancellor, W. J. A simple grain drier using conducted heat. *Transactions of the ASAE* 11:(6) 857, 1968.
- 2 Chancellor, W. J. Characteristics of conducted heat drying and their comparison with those of other drying methods. *Transactions of the ASAE* 11:(6) 863, 1968.



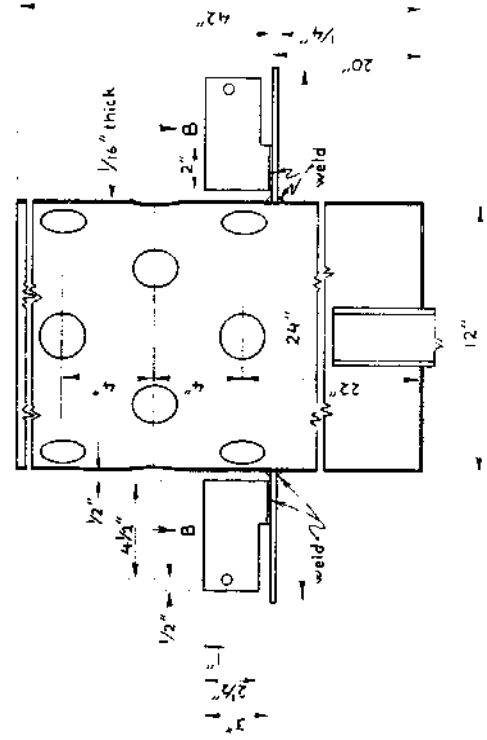
SECTION A-A
Scale: 1" = 24"



SECTION B-B



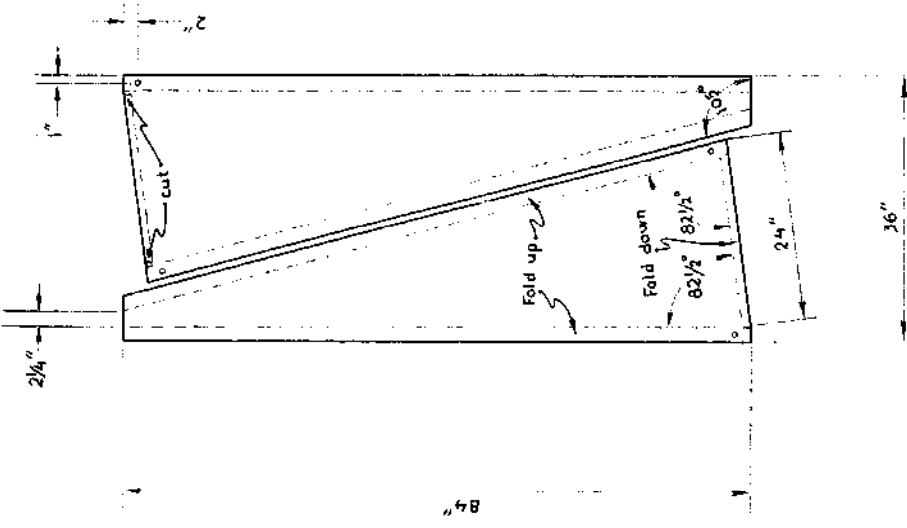
PLAN
Scale: 1" = 24"



**DETAIL OF CENTRAL
SUPPORT & STACK BASE**
Scale: 1" = 4"

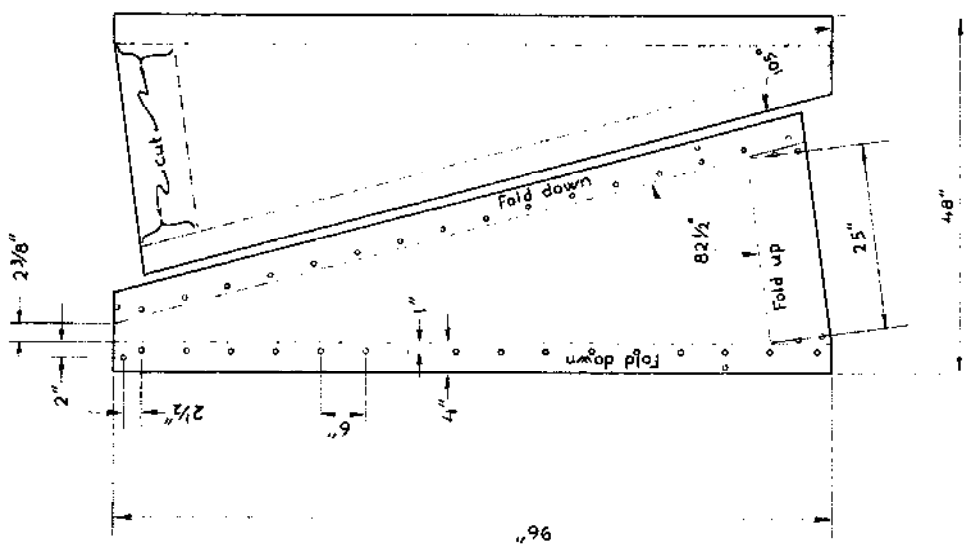
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FLAME SHIELD ELEMENTS

Scale: 1"=12"



DECK ELEMENTS

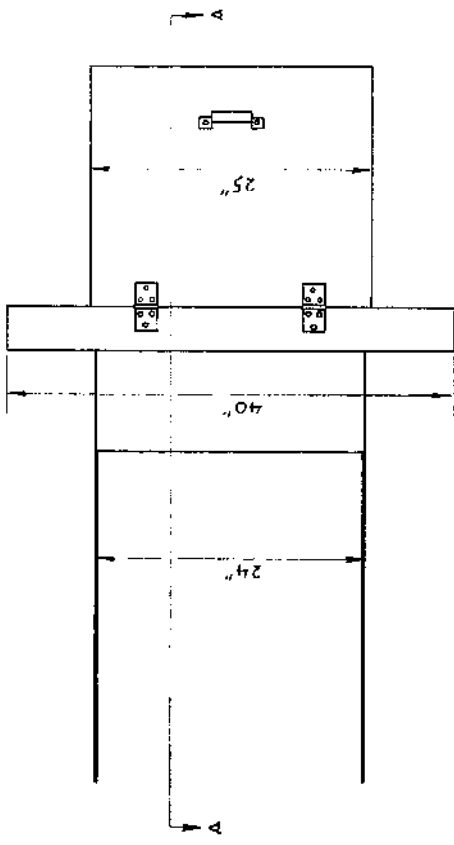
Scale: 1"=12"

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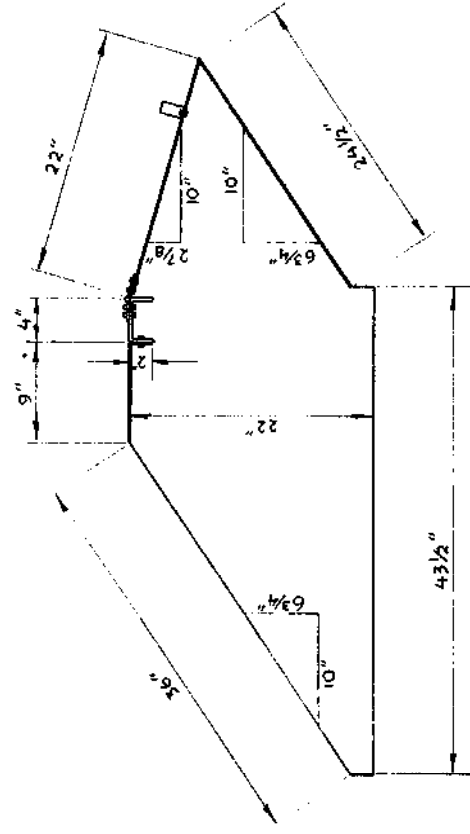
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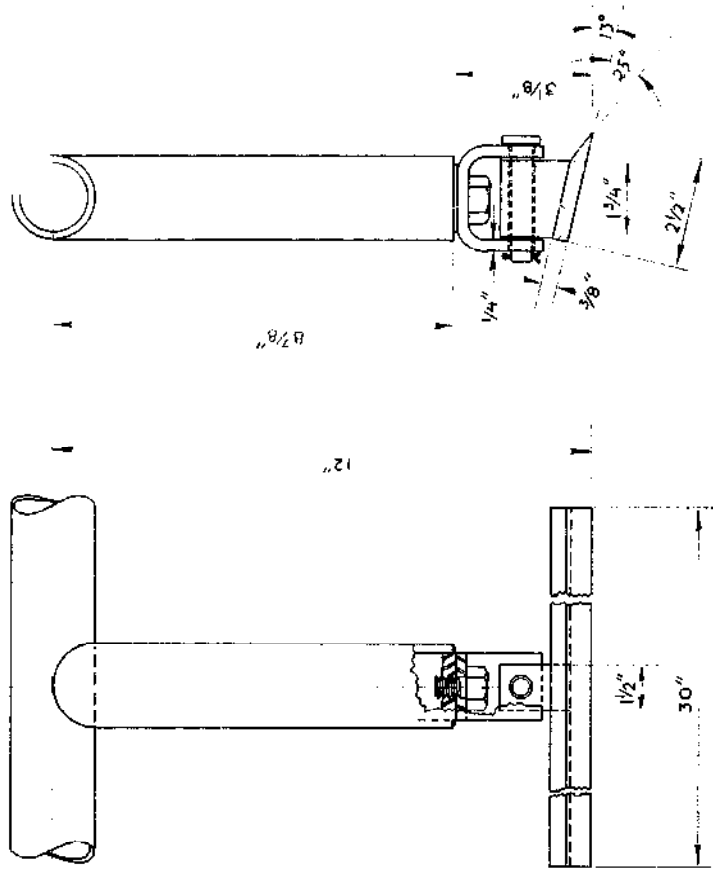


FUELING CHUTE & DOOR, & RETAINING STRUCTURE

Scale: 1" = 8"



SECTION A-A



STIRRER

Scale: 1" = 2"

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