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STUDIES ON SOLAR DRYING FOR ROUGH RICE

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ABSTRACT

Three types of solar grain dryers, namely, the solar grain bin dryer, the solar greenhouse rotary drum dryer and the small scale solar greenhouse tray dryer, have been tested . The results show that each type of solar grain dryer has its feature. These solar drying units have three main advantages: (1) Required commercial energy to remove 1 Kg moist from rough rice is only 5.3% to 15.8% of the energy consumed by common heated dryer; (2) The area of solar drying system is only about 10% of the area of the sunny ground to give equal drying capacity; (3) There are good drying quality in the moisture uniform , germination percentage, and grain color.

Key words: Solar energy, Drying, Rough rice

INTRODUCTION

Drying is considered as an important part of the system of grain production because it influences directly not only the grain quality but also the real output of grains.

The drying of grains is also a high energy operation use. A large number of the commercial energy used to dry grains should be saved if the energy consumed for drying could be substituted by solar energy.

Drying grains on sunny grounds is a traditional drying method. The advantage of this natural drying method is to save commercial energy. However, sunny ground would occupy some field area, the sun drying would depend upon the weather condition. During an unbroken wet weather, the moist grains could not be dried in time, the deterioration should occur.

In order to overcome the disadvantage of sun drying and to reserve the advantage in saving energy, we have researched and built three types of solar grain dryers since 1982, namely, the solar grain bin dryer, the solar greenhouse rotary drum drying unit, and the small scale solar greenhouse tray dryer. The objective of this study is to investigate the performances of different type of solar grain dryers to improve the design of solar grain drying system.

METERIALS AND METHODS

1. Solar grain bin dryer

The solar grain bin dryer consists of flat plate heat collectoer, a grain bin and a fan. The structure of this dryer is shown in Fig.1.

The flat plate heat collector with 42 m^2 of total lighting area were set on the roof of the grain bin. The cover material of the collector is glass with 5 mm thickness, the absorber material is aluminum plate with black color painting. The insulation material is expanded pearlite.

The floor of the bin with 18 m^2 is perforated plate with 28. 7% of aperture area . A low pressure axial flow fan (4 KW) is used to ventilate heated air .

The principle of the solar grain bin dryer is described as flowing: the heated air from the solar collector enters the heated air duct, then is pulled into the heated air chamber by fan, the heated air then forces through the perforated floor and wet grain. The grain is heated and loses its moisture, The moist air evaporated from grain is exhausted through the exhausted air exits.

2. Solar greenhouse rotary drum drying unit

This drying unit consists of a arch type greenhouse, a rotary drum, a axial flow fan, an auxiliary heating unit and waste heat recoverer. The structure of this drying unit is shown in Fig.2.

The arch type roof and the southern vertical wall of the greenhouse are lighting surface, 5 mm thicknees of glass is used as transparent material. The area of projecting at horizontal of the greenhouse is 48 m^2.

The rotary drum is not only as a product container but also as a absorber for solar radiation. It is 4 m in length, 1.35 m of internal diameter. It is made of apertured steel plate with 28.7% of porosity. The rotary drum has two speeds: 1.395 rpm and 0.0195 rpm.

A low pressure axial flow fan is used to exhaust the moist air evaporated from wet product.

The auxiliary heating unit consists of 6 honeycomb briquet stoves and a tube type heat exchanger.

The waste heat recoverer is brick structure under the floor of the greenhouse, it is used to recover and store the heat of exhausted air.

The principle of the solar greenhouse rotary drum drying unit is described as following: As illustrated in Fig.2, ambient air entered the greenhouse from the cold air duct 9 is heated, the heated air then enters the rotary drum 12 and forces through the product when the fan 7 is started. The grain is heated and loses its moisture. There are three ways to go for waste air. If the waste air were low temperature and high relative humidity, it could be exhausted directly through the first exit 1. If the temperature of waste air were still high, the waste air could pass through the waste heat recoverer 4, and releases its heat energy , then is exhausted through the second exit 2. If the waste air were high temperature and low relative humidity, a part of this waste air would enter the greenhouse from the third exit 3 and be utilized circulately. The roraty drum 12 contained grain can rotate continually or intermittently during drying operation. In raining day or cloudy day, the auxiliary heat unit can be used to heat air.

3. Small scale solar greenhouse tray dryer

This kind of dryer consists of a greenhouse, a drying chamber and two fans.(see Fig.3)

The roof with 7° slope and the vertical walls at south , east and west of the greenhouse are 3 mm thickness of glass as lighting surface. The greenhouse has horizontal area 18 m^2 .

In the drying chamber, total 8 trays with screen for containing product are arranged in two columns , each tray has 1 m^2 of area and 0.13 m in height.

Two low pressure axial flow fans are set respectively at the top air outlet and the bottom air outlet in the drying chamber.

The principle of the small scale solar greenhouse tray dryer is: As illustrated in Fig.3, ambient air entered the greenhouse is heated. The heated air then forces through product layer from top to bottom when the bottom fan is started. The heated air can also pass through product layer from bottom to top when the top fan is started.

All drying tests for above three grain dryers were carried out according to "The Test Method of Grain Dryer" (National Standard of P. R. China).

RESULTS AND DISCUSSION

1. Test Results

For evaluating the drying properties of the three solar grain dryers , following five parameters are calculated .

(1) Heat consumption q_r — the heat consumption for removing 1 Kg water from product, KJ/Kg (H_2O);

(2) Mechnical energy consumption q_J — the electricity consumption to drive fan and transmission mechanism for 1 Kg water removed from product, KJ/Kg (H_2O) ;

(3) Thermal efficiency of drying η_g — the ratio of the quantity of heat required to evaporate moisture of product to the real heat consumption, % ;

(4) Dehydration intensity W_d — the average quantity of water removed from grain per day per square metre of horizontal area of collecter or greenhouse.

(5) Drying intensity G_d — the average quantity of wet grain which can be dried per day per square metre of horizontal area of collector

or greenhouse, Kg (wet grain)/m^2.day .

In order to make a rational comparision among these three solar dryers, as calculating the values of W_d and G_d for the three solar grain dryers, the same numerical values in mean solar radiation intensity, initial and final moisture content are taken , which are 16215.5 KJ/m^2.day, 23% and 13.5% respectively.

The performence parameters of the three kinds of solar dryers are shown in Table 1. From Table 1, the results can be summarized as following:

(1) Energy consumption and drying thermal efficiency

The results indicate that the numerical values of the heat consumption q_r, the mechanical energy consumption q_j and the drying thermal efficiency η_g of the three solar dryers are satisfactory . From the Table1, it can be seen that the solar greenhouse rotary drum dryer has the highest drying thermal efficiency and the lowest heat consumption in contrast with the solar bin dryer and the solar greenhouse tray dryer. The reason is the arch type greenhouse has larger lighting surface at unit projecting area. It absorbs not only the direct radiation and scattering radiation and also the reflective radiation from ground. Contrarily, the solar bin dryer need higher heat consumption. The main reason is the heat loss because the heated air must pass through a long duct from the collecter to the heated air chamber. The small scale solar greenhouse tray dryer consumes less mechanical energy compared with other two dryers, which relate to the air flow amount and the depth of grain.

In total energy consumption (q_r+q_j) , only q_j is commercial energy, it is just 5.3% to 15.8% of the energy consumption of the common heated air dryers. Therefore, a large number of commercial energy could be saved if the common heated air were replaced by solar dryers.

(2) Dehydration intensity and Drying intensity

From the Table 1., it can be observed that the solar greenhouse rotary drum dryer has the highest dehydration intensity (W_d) and the highest drying intensity (G_d) compared with other two solar dryers. The results also indicate that the drying intensity may be higher with higher dehytration intensity. The drying intensity can reach 28 to 35 Kg wet rough rice (23% of moisture content) per day per square meter of horizontal area of collector or greenhouse. The area needed of the solar dryer is only about 10% that of the sunny ground to give equal drying intensity or drying capacity. It is very favorable for rural area in the situation of large population but small field land area.

(3) Drying quality

The dried rough rice has a high germination percentage (97%) , a unifore moisture content and normal color and taste.

(4) Multiple utilization ability

The solar greenhouse rotary drum drying unit and the small scale solar greenhouse tray dryer have been used to dry cabbage , radish slices, sweet popato slices, groundnut and fish. The tests achieved good results. The solar grain bin dryer can be used to store grain, after drying grain does not need moving.

2. Discusion

(1) About gravel layer

There was a gravel layer under the perforated floor of the bin in the first design. The heated air first passed through the gravel layer, then entered grain layer to dry grain. It was not very effective for drying. The drying rate was only 0.286% (m.c.)/hr, because the gravel layer would absorb a part of heat energy. After removing the gravel layer, the drying rate increase significantly and reach 0.47% (m.c.)/hr. The test results indicate there is no need to set gravel layer if the drying operation carry out only in day time. However, for the solar dryer with auxiliary heating unit, if the drying operation carried out in day and night , it would be desirable to set a gravel layer to recover the heat of exhaust air. For this reason, in the solar greenhouse rotary drying unit, the latticed brick was set in the waste air duct.

(2) About uniformity of drying

For the solar grain bin dryer , heated air pass through grain layer from bottom to top. As the grain at the top layer approaches desired moisture content, the grain at the bottom layer would be overdrying. However, the overdry could be dispelled if the dried grain stored in bin for some time. (Shao, 1985)

In order to overcome the moisture gradient from the bottom to the top of the grain layer, to convert the flowing direction of the heated air during drying can obtain uniform drying. This method has been adopted in the small scale solar tray dryer and achieved good results.

In the solar greenhouse rotary drum drying unit, heated air only pass through grain layer from top to bottom, but the drum can rotate that cause the grain in the drum turning up and down continually which is useful for uniform drying. However, following items should be paid attention to the operation.

i. Suitable depth of grain

As the depth of grain is equal to or less than the radius of the drum, all grain kernels can be turned with the drum rotating. If the depth of grain is greater than the radius of the drum, only grain in the range of "D-d" can be turned with the drum rotating. The grain in the range of diameter d would remain stable.(see Fig.4) As the result, this part of grain has never chance to move to the top position to receive the best drying condition. Therefore, the suitable depth of grain is equal to or less than the radius of the drum.

ii. Suitable rotating time of drum

If the drum rotates continually in drying process, the mechanical energy consumption should inrease but the drying rate could not increase. The drum rotating intermission can make uniform drying and reduce the mechanical energy consumption.

iii. Keep the surface of grain layer in drum horizontal state.

When the drum rotate, the surface of grain layer would be inclined (see Fig.5). These will be very low air resistance through the thin layer , and all the heated air will pass through the thin grain layer. Which result in ununiform drying and very low thermal efficiency. Therefore , it is better to dry the grain in unrotated drum for a long time (2 - 3 hour) and then rotate the drum for even grain drying .

(3) Selection of solar dryer

Compared with these three kinds of solar dryers, the greenhouse dryers have higher drying thermal efficiency and better drying properties. But the grain must be removed out of dryer as soon as possible after drying , because of the high temperature in the greenhouse. It would be advantageous to select greenhouse dryer if drying operation is frequent.

The drying properties of the bin dryer is not quite good compared with greenhouse dryer. But it has advantage of using not only for drying and also for storage . It could be selected if the drying operation were not continued.

CONCLUSIONS

1. All these three kinds of solar grain dryers have a significant results to save energy in drying grains. The commercial energy consumption for removing 1 Kg water from the product is only 5.3% to 15.8% of the energy consumed by common heated drying.

2. The arch type of greenhouse has a better heat collecting property because it has larger lighting surface at same projecting area. Therefore, the solar greenhouse rotary drum drying unit has the highest drying thermal efficiency and lowest heat consumption in contrast with other two solar dryers.

3. The solar greenhouse rotary drum drying uint has the highest dehydration intensity and the highest drying intensity compared with other two dryers under the same drying condition (the same solar radiation and the same moisture remove ranges).

4. All these three kinds of solar grain dryers have good drying quality in germination percentage , color and taste. For the rotary drum dryer , turning grain by rotating the drum at suitable time can obtain uniform drying. For the tray dryer, reverting the flow direction of the heated air at suitable time also can gain uniform drying.

5. The land area required for the solar dryer is only about 10% of that the sunny ground required for equal drying capacity.

Table 1. The performance of three solar dryers

performance	Solar grain bin dryer	Solar greenhouse rotary drum dryer	Small scale solar greenhouse tray dryer
Heat consumption q_r KJ/Kg(H_2O)	5870	4750	5723
mechanical energy consumption q_J KJ/Kg(H_2O)	598	486	248
Drying thermal efficiency η_g %	41	51.7	43
Dehydration intensity W_d Kg(H_2O)/m^2 day	2.76	3.41	2.83
Drying intensity G_d Kg(wet grain/m^2.day	28.62	35.37	29.36

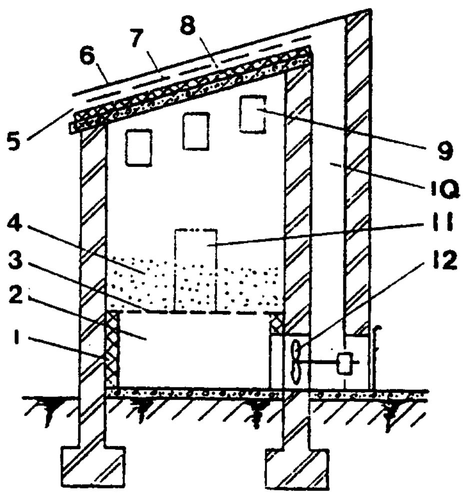

Fig. 1. Solar grain bin dryer

1. Thermal insulation
2. Heated air chamber
3. Perforated plate
4. Grain layer
5. Ambient air inlet
6. Glass
7. Alluminum flat plate
8. Thermal insulation
9. Exhaust air outlet
10. Heated air duct
11. Door
12. Axial flow fan

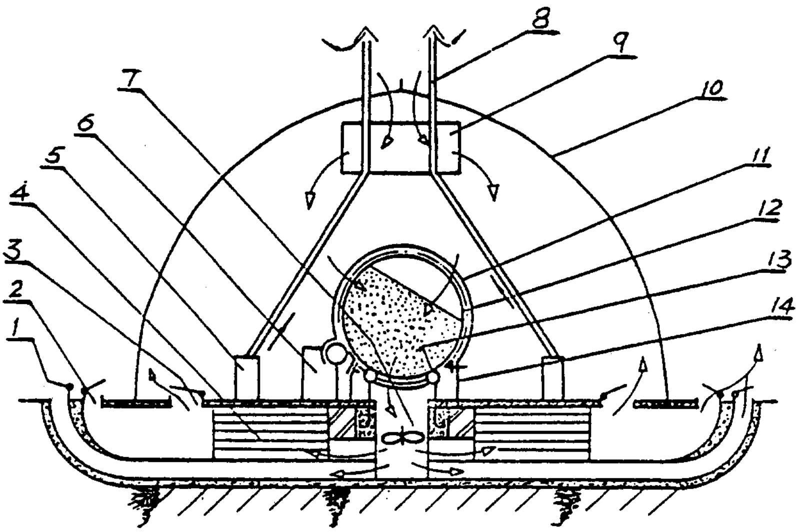

Fig.2.   Solar greenhouse rotary drum drying unit

1. First exit of waste air   2. Second exit of waste air
3. Third exit of waste air   4. Waste heat recoverer   5.Farnace
6. Gear box.   7. Fan   8. Flue piper   9. Air duct   10. Glass
11. Gearwheel   12. Rotery drum   13. Support wheel   14. Air seals

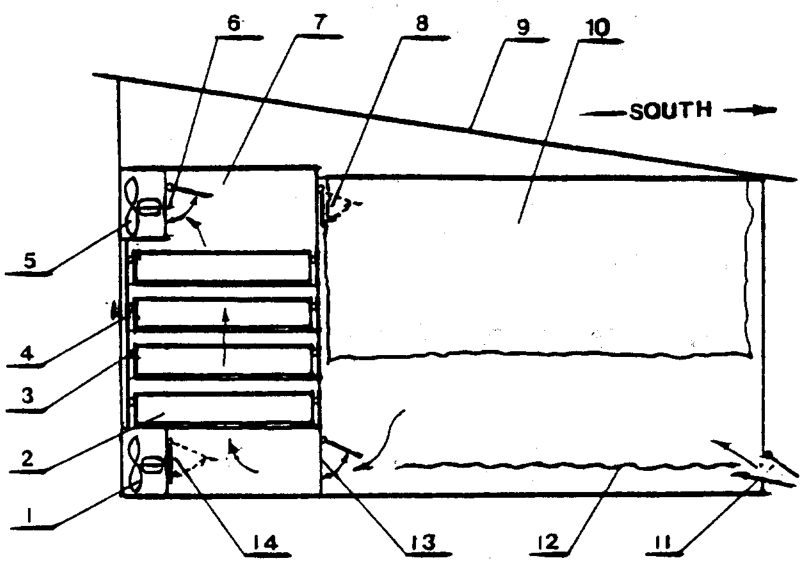

Fig.3. Small scale solar greenhouse tray dryer

1. Bottom fan   2. Tray   3. Air seals   4. Door   5. Top fan   6. Top air outlet with valve   7. top heated air chamber   8. Top heated air inlet with valve   9. Glass   10. Black plastic sheet   11. Ambient air inlet   12. Black plastic sheet   13. Bottom air inlet with valve   14. Bottom air outlet with valve

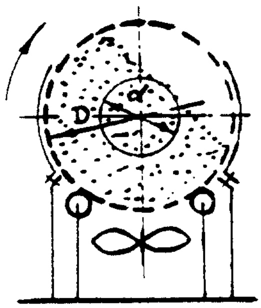

Fig.4. Turning of grain in rotary drum

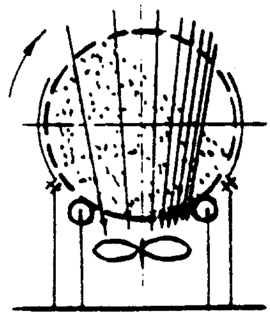

Fig.5. Air distribution in grain layer

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