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STUDIES ON FARMER HOUSEHOLD LEVEL SOLAR GREENHOUSE DRYING UNIT

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ABSTRACT

A small scale solar greenhouse tray dryer suitable for one or few farmer households is designed in place of sunny ground to dry various agricultural products. The tests on the drying of paddy, groundnut and radish slices by this drying unit have been made. The results indicate that this drying unit had a good heat collecting property , a low heat consumption (4518.7 - 5676.1 KJ per kg water removal), a high heat utilizing efficiency (43.75% - 54.25%) , a low operation cost (0.057 kwh - 0.078 kwh per kg water removal) and good drying quality.

Key word: Drying, Solar, Paddy, Groundnut, Radish slices.

INTRODUCTION

In most rural areas of China, the crop growing area of one farmer household is usually less than 1 hectare, but the varieties of crops , such as grains, beans, groundnut and vegetables are diversified. The harvested products are generally spread on mats or sunny ground in thin layer and exposed to the sun for drying. The sun drying is widespread for most farmer households because this traditional method does not consume commercial energy. However . considerable losses could occur during drying due to rodents, birds, and rainy weather. etc. Also the quality of the dried products should be lowered which are not accepted on market . Using mechanical dryers can solve this problem. There are more than 100 kinds of mechanical dryers in China but that have not been utilized widely in rural areas (Li et al, 1990) . The main reasons are the high capital investment for drying installation and the high operation cost because of high energy consumption. Shao et al (1983) studied on the solar grain bin dryer and reported that the drying cost is cheaper than the conventional grain dryers in which the high cost fossile fuel and eletricity are used . Huang (1979) and Shao et al (1985) studied on the solar greenhouse drying units and reported that the greenhouse is satisfactory for absorbing solar radiation and can abtain good drying quality. A multi-product dryer with low cost and small size is an interesting development route.

The objectives of this study are to design a small scale solar drying unit with a simple structure, a low operation cost and good drying quality ; to estimate the drying properties of drying agricultural products with different moisture contents and with different shapes using this drying unit.

METHOD AND MATERIAL

1. Design of the small scale solar greenhouse drying unit

The drying unit consists of a solar greenhouse and a tray drying chamber (see Fig.1.).

The greenhouse is used as a solar collector to heat air. It has horizontal area 18 m² (6 m long, 3 m wide) and 2. 58 m high at north side, 1.84 m high at south side. 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.

A black plastic sheet (4.5 m long, 1.2 m wide) is hung vertically below the roof along the length. The other black plastic sheet (total 4.5 m long , 3 m wide) is spread horizontally 30 cm away from the floor of the greenhouse. They are used as an absorbing material.

The drying chamber (2.1 m long , 1.1 m wide and 2 m high) was set at the north side inside the greenhouse. The drying chamber is divided in three parts from top to bottom: the top heated air chamber , the product trays and the bottom heated air chamber. At the back of the drying chamber, there are 2 heated air inlets with valves which communicate with the top heated air chamber and the bottom heated air chamber respectively. At the front of the drying chamber, there are two exhausted air outlets with valves which also communicate with the top and bottom heated air chambers respectively . Two low pressure axial flow fans (0.55 kw each) are set on the exhausted air outlets respectively . Between the two heated air chambers , a total of 8 product trays with screen plate for containing product are arranged in two columns , each tray has 1 m² of area and 0.13 m in height.

2. Process of drying

Ambient air entered the greenhouse would be heated . There are two possible ways for heat air in circulation . The first way is that the heated air flows through the material and trays from top to bottom. The material is heated and loses its moisture. The wet air evaporated from the material is exhausted from the bottom air outlet . The other way is contrary to the first way. The heated air through the material and trays from bottom to top . Changing the flowing direction of the heated air can obtain a uniform drying .

3. Test method

The drying tests for radish slices , groundnut and paddy were carried out using this drying unit . During the drying tests , the solar radiation intensity was automatically recorded by a solar radiation meter . The following test datas were measured and recorded every hour : the temperatures and relative humidities of ambient air, heated air in the greenhouse and exhausted air ; the temperatures of product in each tray ; the heated air flow rate ; the electricity consumption for fans . The product in each tray was sampled every hour to determine the moisture content by an electronic moisture content meter (for paddy) and by standard oven method (for radish slices and groundnut).

4. Test material

Fresh radish were cut into slices with 0.5 cm thickness after epidermis was pared off. Total 96 kg fresh radish slices with initial moisture content of 94.6% (w.b) were spread on the 8 trays.

Total 242 kg fresh groundnut with shell were spread on the 8 trays with 7 cm depth for each tray . The initial moisture content is 40.6% (w.b.).

Total 360 kg wet paddy (long rough rice) with initial moisture content of 27.25% (w.b.) were spread on the 8 trays with 9.5 cm depth for each tray.

The comparative tests : Same wet product samples were spread on mats and exposed to the sun for drying.

RESULTS AND DISCUSSION

1. Quality of products

These three kinds of products dried by the solar greenhouse tray dryer have uniform moisture content, normal color and taste. But some radish slices in comparative test (sun drying) have a little of specks. The dried paddy and groundnut were checked by germination test. Their germination percentages as same as that in comparative test (sun drying).

2. The heat collecting property of the greenhouse

The temperature raice Δt is a index to evaluate the heat collecting property of greenhouse. Enhancing the ability of absorbing radiation and reducing the heat loss can improve the collecting efficiency of the greenhouse.

The floor of the greenhouse served as the energy absorbing surface painted in black colour with less reflection loss. However this black floor surface also would transmit the heat to underground and lose some heat . Therefore , in order to reduce the heat loss and improve the heating efficiency of the greenhouse , during the paddy drying test in November last year, a black plastic sheet was spread horizontally on where there are 30 cm distance to the floor of the greenhouse . It has achieved good results to use this method . Table 1 shows the temperature on black sheet surface (t_b) , the temperature on floor surface covered by black sheet (t_c) and the temperature on floor surface uncovered by black sheet (t_f) . The datas in Table 1 indicate that the temperature on black sheet surface (t_b) is 10 - 14℃ higher than the temperature on floor surface uncovered by black sheet (t_f). It is very favourable to increase the temperature of air in the greenhouse. Moreover , compared with the temperatures on the floor surface covered and uncovered by black sheet , t_c is 6.5 - 11 ℃ lower than t_f, which means that the heat loss transmited into underground would be reduced.

This effect has been demonstrated during the drying tests . The air temperature raise Δt during the tests of drying radish slices , groundnut and paddy are shown in Table 2. From this table , it can be seen that the Δt values of the paddy drying test in November when the floor of the greenhouse was covered by black sheet is higher than that of the groundnut drying test in July when the floor of the greenhouse was uncovered by black sheet, even though the solar radiation intensity in November is lower than that in July .

3. The drying properties of radish slices , groundnut and paddy

The drying curves of radish slices, groundnut and paddy are shown in Fig.2 , Fig.3 and Fig.4 respectively. From the three figures, it can be observed that the drying curve of radish slices is very different from that of groundnut and paddy . The drying curve of radish slices is nearly a straight line in the moisture range of 94.6% to 16.9% . This result means that the whold drying period is almost constant rate period of drying . There are many reasons for this result: (1) The radish slices have high initial moisture content (94.6%), in the initial stages of drying, drying is controlled by moisture evaporation from the surface of radish slices . (2) Because the tissue of radish is porous and the radish slices are thin enough , the rate of moisture difussion from the interior of the slice to the surface is sufficiently high to maintain the surface in a completely wetted condition. (3) There are much shrinkage of the radish slices during drying, the porosity of product lager become larger with the reduction of moisture . Therefore, the resistance of the heated air passing through the product lager decrease and the the air flow rate increase wuith the reduction of the moisture content. It may be a characteristic for drying sliced products.

From the drying curves of groundnut and paddy (see Fig.3 and Fig.4), it can be seen that both have quite clear critical point at which the drying rate starts to decrease and drying enters the falling rate period. However, making a comparison between the two curves, it can be observed that drying of paddy is more rapid in the constant rate period. One of the reasons is that the paddy has greater surface area than groundnut in same volume , in the constant rate period, the greater the surface area the greater the rate of evaporation.

4. Analysis of the drying parameters

Following 6 parameters are used to evaluate the drying properties: the total water removal (W_s), drying rate (u), heat consumption (q_r) , mechanical energy consumption (q_e) , total energy consumption (q) , and heat utilizing efficiency (η_r).

The main test datas are listed in Table 3. The values of the parameters of drying these three products are listed in Table 4.

The analysis of the test datas and the values of drying parameters in these three kinds of products are summarized as following:

(1) The small scale solar greenhouse tray dryer can be used to dry the products with high M.C. (e.g. 94.6%) , medium M.C. (e.g. 40.6%) and low M.C. (e.g. 27.25%), and to dry the sliced product (e. g. radish slices), the large partical product (e. g. groundnut) and small partical product (e.g. paddy) . The good drying quality can be abtained .

(2) All the drying tests for these three kinds of products abtain a satisfying heat utilizing efficiency which are 54.25%. 51.92% and 43.75% for drying the radish slices , groundnut and paddy respectively. The highest drying rate ,the lowest heat consumption and the highest thermol efficiency were abtained on drying radish slices compared with groundnut and paddy. There are many reasons for these results : Firstly, the moisture removal range of radish slices is higher than that of other two products; Secondly, the evaporation and the diffusion of water in radish slices are easier than both the groundnut and paddy with shell; Thirdly, the total depth of the radish slices layers reduces significantly with the moisture loss because there are much shrinkage of the radish slices. Which results in the low air through the product layers. On the contrary, for drying partical products (e.g. groundnut and paddy) , the porosity of the product layers become smaller with the shrinkage of the products. The air flowing resistance will be

increased even if the total depth of the product layers decrease only a little.

(3) Because solar radiation offers a free heat source, all drying tests for these three kinds of products get a lower drying cost. It needs only a few of electricity for the fan to move the heated air. the electricity consumption for 1 kg water removal are only 0.0571 kwh, 0.069 kwh, and 0. 0758 kwh for drying groundnut , paddy and radish slices respectively.

(4) Changing the flowing direction of the heated air can obtain a uniform drying . However , a frequent changing of the heated air flowing direction would rewet the product that has been dried . It is optimum time to change the flowing direction of heated air when the moisture content of the driest layer has reached final moisture content or when the driest layer has appeared a little overdrying .

CONCLUSION

1. This small scale solar greenhouse tray dryer is suitable for one or few farmer households to dry various of agriaultural products.

2. To cover a black plastic sheet 30 cm away from the floor of the greenhouse can improve significantly the heat collecting ablity and raise the temperature of hot air. The heat loss can be reduced due to the heat dissipation of the floor .

3. This solar dryer has obvious saving energy result. It has the characteristics of a high heat utilizing efficiency (43.75% to 54.25%), a low heat consumption (4518.67～5676.06 KJ for 1 kg water removal), a low operation cost (0.076～0.057 kwh for 1 kg water removal) and good drying quality.

4. Drying sliced product is different from drying partical product. The porosity of the sliced product layer will be increased with the shrinkage of the product and the moisture reduction, which improve the drying condition in convection drying.

Table 1. Effect of black sheet cover on temperature of floor surface

Time	10:00	11:00	12:00	13:00	14:00
Temperature on black sheet surdface (t_b) ℃	49	50	55	53	52
Temperature on floor surface covered by black sheet (t_c) ℃	29	30	30	31	31.5
Temperature on floor surface uncovered by black sheet (t_j) ℃	39	40	41	40	38

Table 2 The air temperature raise in drying tests

Drying tests	Δt ℃		
	$\Delta t_{min.}$	$\Delta t_{max.}$	$\Delta t_{avr.}$
Radish slices drying test in April (1)	2.0	6.2	4.1
Groundnut drying test in July (1)	3.6	9.2	6.5
Paddy drying test in November (2)	4.4	9.2	7.3

Note: (1) The floor surface in greenhouse uncovered by black sheet .
(2) The floor surface in greenhouse covered by black sheet.

Table 3. Test Datas on three products drying

Test	Total drying time (hr)	Wet product weight (Kg)	Initial M.C. (%)w.b.	Final M.C. (%) w.b.	Initial depth of product layer mm	Final depth of product layer mm	Ave. solar radiation intensity (w/m^2)	Total electricity consumption (KWh)	Air flow m^3/hr
Drying radish slices in Apr.	21	96	94.6	16.9	200	60	294.57	6.95	756-1485
Drying groundnut in July	15	242	40.6	10	267	244	397.93	4.7	1499
Drying paddy in November	12	360	27.25	13.1	380	300	427.89	4.05	1055

Table 4. The parameters of the tests on the products drying

parameter of drying	radish slices drying	Groundnut drying	Paddy drying
Total water removal (W_s) Kg H_2O	88.77	82.28	58.62
Drying rate (u) % M.C./hr	3.71	2.04	1.18
Heat consumption (q_r) KJ/Kg H_2O	4518.67	4700.87	5676.05
Electrity cemsumption (q_e) KWh/Kg H_2O	0.0758	0.0571	0.069
Total energy consumption (q) KJ/Kg H_2O	4800.71	4956.51	5924.77
Heat utilizing efficiency (η_r)%	54.25	51.92	43.75

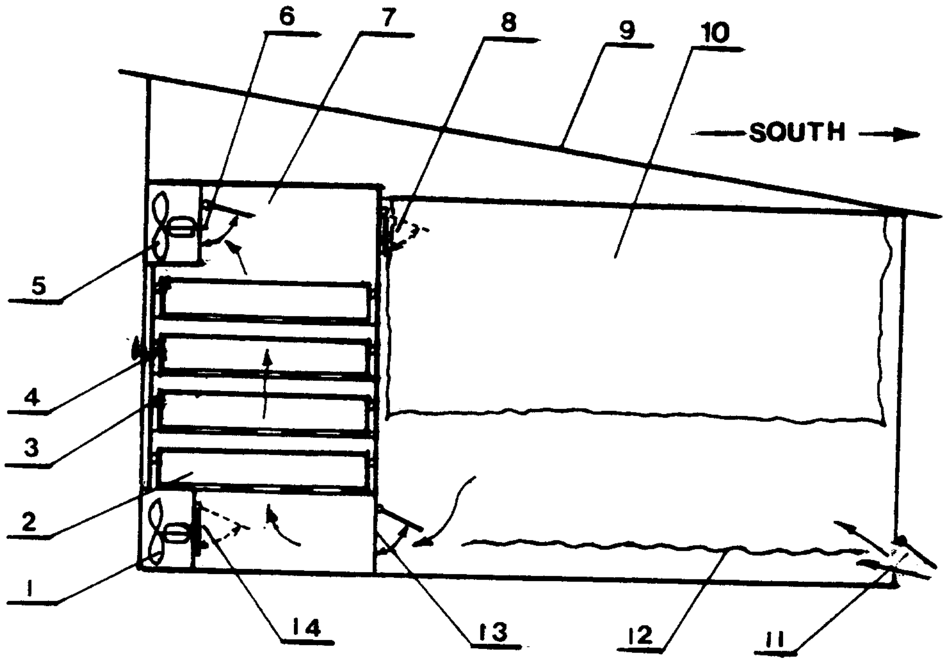

Fig. 1. Solar greenhouse Tray Dryer
(1) bottom fan (2) tray (3) air seals (4) door (5) top fan (6) top air outlet with valve (7) top heated air chamber (8) top heated air inlet with valve (9) glass (10) black plastic shheet (11) ambient air inlet (12)black plastic sheet (13) bottom air inlet with valve (14) bottom air outlet with valve

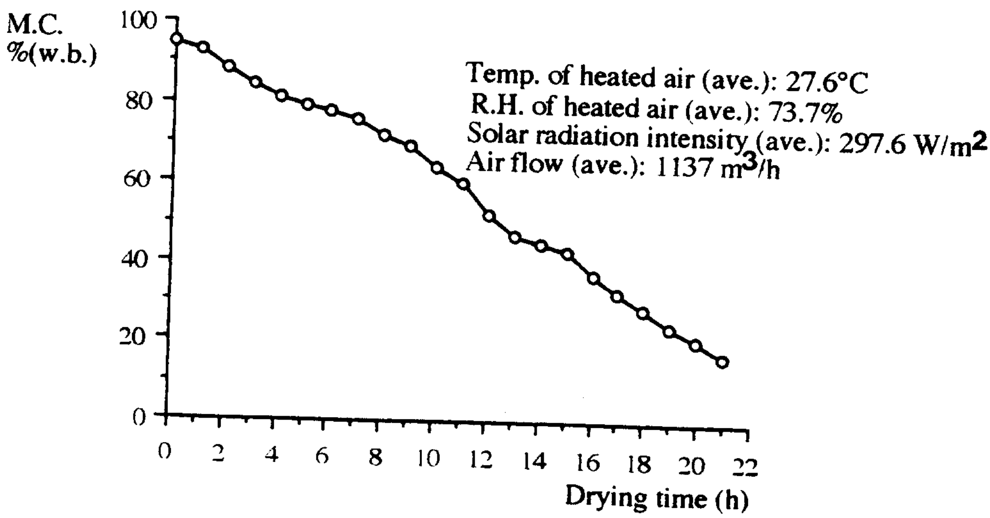

Fig. 2. Drying Curve of Radish Slices

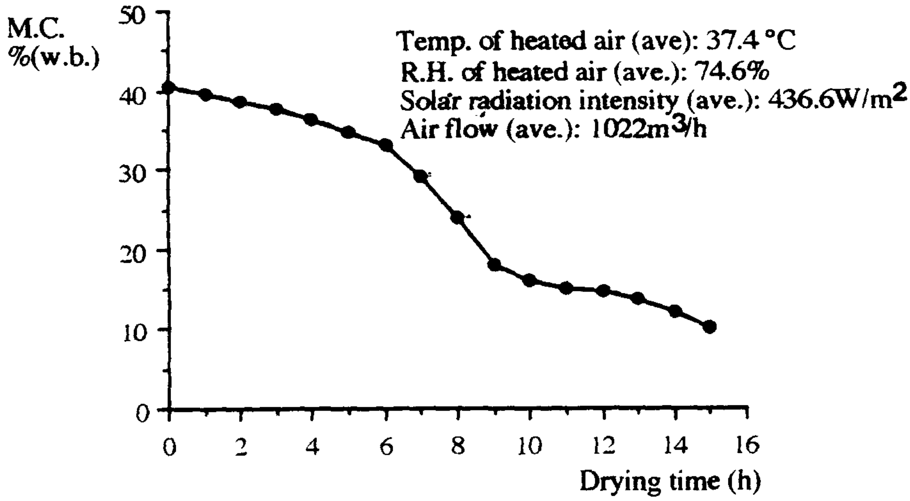

Fig. 3. Drying Curve of Groundnut

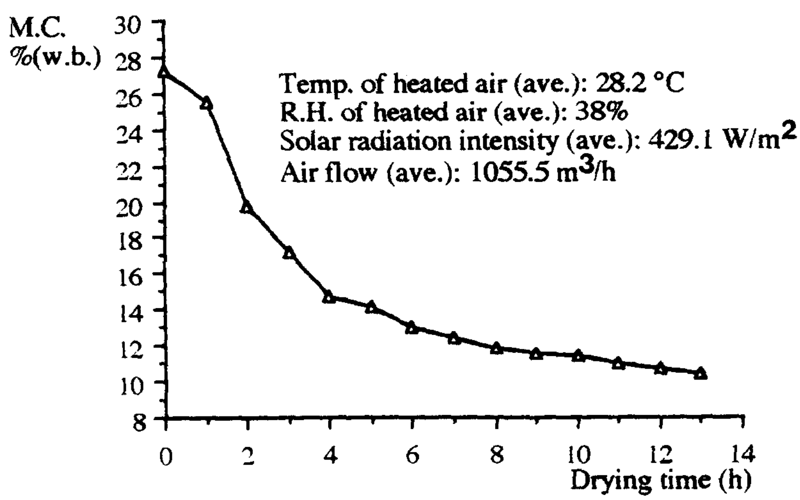

Fig. 4. Drying Curve of Paddy in First Tray

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