ISSN 2250-3153

Design and Analysis of Solar Paddy Dryer by Natural Convection

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DOI: 10.29322/IJSRP.8.8.2018.p8072
http://dx.doi.org/10.29322/IJSRP.8.8.2018.p8072

Abstract- Myanmar is an agricultural country and has a population of about 50 million. In Myanmar, rice is one of the major crop and the need for drying facilities at the site of the rice production is essential if post production losses to be kept to a minimum. Some dryers are run by diesel or gasoline engines and natural source of sun. In this paper, the drying system will be powered by solar energy sources. It is noted that the designed dryer has advantages over traditional sun drying. Moreover, paddy was free from impurities such as dirt, there was a low incidence of losses from mold or insects, and paddy was not exposed to rain or dew. This dryer can reduce moisture content from 22 % to 14 % (w.b) during 2 days. This solar paddy dryer is designed such as depth of paddy bed, size of paddy box, size of solar collector, air velocity and inlet area, and chimney cross section area. And then, the designed dryer is analyzed by varying the drying capacity with same chimney height.
Index Terms- Paddy bed, paddy box, size of solar collector, chimney cross section area and analysis.

I. INTRODUCTION

IN Myanmar, main crop is rice and there are three types of rice such as early duration rice, medium duration rice and late duration rice. Summer rice is the type of early duration rice and it ages 120-140 days. Summer rice is harvested paddy consists of the right gain, germ and bran, converted with a shell or hill. It moister content is ranging from 20% to 30% wet basis (w.b). The rice production process are involved include harvesting, threshing, drying, storing and milling the grain. If the rich moisture content of paddy during storage, the paddy is spoiled by fungi and insects. Therefore, drying process is essentially required for rice production. Summer paddy is harvested in raining season in Myanmar. Drying can result to get good quality and are protected from attacks of destructive agents. And then, paddy drying can storage long time without deterioration. For drying rice after the harvest, sun drying in the open air is the traditional method used by farmers in Myanmar. In this traditional method, considerable losses can occur in the range from 10% to 25%. For control drying and better quality of grains, use solar dryer with collectors. Collectors are generally made of high absorptivity (black body) material. A solar dryer is an enclosed unit, so the grain is safe from damage by birds and insects. In this dryer, chimney height is used 3 m from the ground level. For the month of May, solar insulation is received 6.525 MJ/day m^2 including the average possible sunshine. The main objective of this paper is to design the solar paddy dryer with improvement of the quality of grain.

II. BASIC INFORMATION OF PADDY DRYING

Drying is the process of removing the excess moister from the paddy. Its moisture content should be reduced as much as possible to about 14% w.b for much longer storage. The drying air temperature is usually kept below 45̊ C for paddy drying. Moisture content is the water contained in the paddy measured as a proportion of the total weight of the paddy. The moisture content of the paddy is interpreted in two ways: moisture contented with wet basis and dry basis. Table 1 shows the moisture contented of the paddy and storable days.

Table I: Storable Day of Paddy

Paddy's moisture contents (%)	12	14	16	17	18	19	20	21	22
Storable day	1825	365	60	38	25	16	11	7	5

In wet basis of paddy, the percentage moisture content of a sample of grain is defined by the following formula.

$$m = \frac{W_m}{W_m + W_d} = \frac{w - d}{w} \times 100$$

In dry basis of paddy, moisture contents are defined by the following formula.

$$M = \frac{W_m}{W_d} \times 100 = \frac{m}{100 - m} \times 100$$

In moisture content, dry basis is frequently and preferably expressed as moisture ratio, that is, pounds of moisture per pounds of dry matter or *M/100*. The quantity of moisture percent at any time is directly proportional to the dry-basis moisture content or moisture ratio.

The equilibrium moisture content of paddy depends upon its variety, temperature and relative humidity of surrounding air. For example at 30 ºC and 75% relative humidity, paddy usually has an equilibrium moisture content of about 14 % wet basis. The approximate values of the EMC of paddy are represented by the curves shown in the Fig 1.

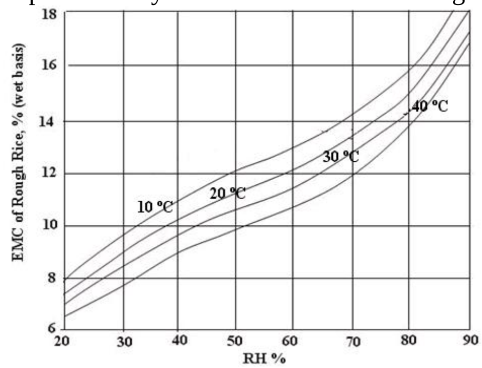


Fig 1. EMC Curve of Paddy

In drying system, there are three main types: (1) Traditional sun drying (2) Solar drying (3) artificial drying. In solar drier, solar radiation would be allowed to pass through a transparent sheet where heat absorbent are placed and in turn heat the air. The heated air is conveyed into the drying platforms where grain drying is taking placed. Simple single-glazed solar collection systems are used to slightly raise the temperature of drying intake air, thus it speeds up the drying process. Solar drying are two types. There are direct solar dryers and indirect solar dryers.

Direct solar dryers are cheap to make and easy to use, but allow almost no way to control the temperature. It is hard to protect the product that is drying from external factors.

Indirect solar dryer has a flat plate collector and a separate drying chamber. In this type, the paddy is placed on trays inside an opaque drying chamber to which is attached an air type solar collector. It can result in higher temperature than the sun drying, and can produce higher quality product. The indirect dryer is more efficient than the direct dryer.

III. Solar Grain Dryer

A. Type of solar collector

In solar collection systems, there are two main categories: (1) focusing collectors and (2) flat plate collectors. The flat-plate collector requires no tracking device to capture the sun's energy and absorbs solar radiation typically is a flat metal surface with a black coating. This collector type is capable of providing temperatures up to 150 to 200 degrees F and is relatively simple to build. Because of these factors, the flat plate collector is chosen logically for agricultural space heating needs. There are many different designs for flat plate collectors, but they all have two basic characteristics: (1) A flat plate to absorb energy from the sun and (2) A circulating medium to pick heat up from the plate and transport it to storage. The two media most commonly used for absorbing and transferring the heat are air and water.

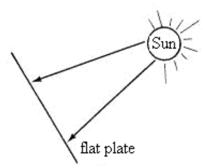


Fig 2. Flat plate collector

B. Collector efficiency

The efficiency of a solar collector is the ratio of the amount of useful heat collected to the total amount of solar radiation striking the collector surface during any time period. One of the problems with flat plate systems is the relatively low efficiency compared to other heating systems because of the high losses in collection and transport of solar energy. Heat is lost through the front, sides and back of the collector, by reflection from the cover, and by direct radiation from the heated flat plate. Typical day-long efficiencies for different types of flat plate collectors are presented in Table II.

Table II: Collection efficiencies for flat plate collectors

Type	Day-long efficiency
Plastic tube type	25 percent
Bare plate	30 percent
Covered plate	35 percent
Suspended plate	40 percent
2-cover suspended plate	45 percent

C. Parts of Solar Paddy Dryer

The solar paddy dryer is composed of three important components. These are solar collector, paddy box and the chimney, as shown in the Fig 3.

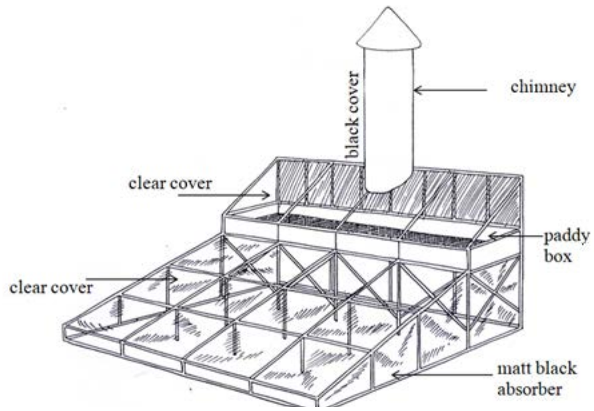


Fig 3. Parts of solar paddy dryer

(i) Solar Collector

The solar collector is heart of the dryer. It consists of a matt black substance spread on the ground, and has a clear material as a cover and on the sides. The clear cover slopes up from the air inlet towards the paddy box to direct the heated air through the grain. Supporting structure is used to support and provide enough incline for the clear cover, so that no water pools will form on it. A low-cost material for the structure is bamboo and high-cost structures have frames of wood, concrete, or metal.

(ii) Paddy box

The height of the paddy box is at waist level. The bottom must be made of perforated material which allows the air to pass through easily, but does not allow the grain to fall through. The sides of the box should be made of material strong enough to resist grain pressure. There is a door to load and unload paddy at the back. The roof and sides are covered with clear material. The perforated area floor should be 10 % or more of the total surface area in order to that the pressures drop though the perforations may be neglected.

(iii) Chimney

The chimney consists of a light, strong frame covered with a matt black substance, and a cover above the chimney keeps out the rain. The base of the chimney is at the highest part of the roof. The chimney structure may be made from bamboo, wood, or metal. The black materials used for the chimney must have high durability and be weather resistant and air proof. The materials may be plastics, galvanized iron sheet painted dull black, metal or concrete pipes painted black, etc. A cap mounted 150 mm above the top of the chimney must be provided.

(iv) Working Principle of Solar Paddy Dryer

Solar radiation, both direct radiation from the sum and indirect radiation from the sky, passes through the clear substance and warms the air inside the collector. The matt black substance changes the solar radiation into heat and transfers the heat to the air. Since the warm air has a low density, it passes up through the bed of the paddy and the drying starts gradually from the bottom layer into the middle. Solar radiation passes through the clear roof and increases the buoyancy of the moist warm air over the rice bed. The remaining solar radiation directly heats the top layer of paddy and then the middle layer, and in this way drying starts from the top and continues into the middle layer. Hence, the drying in the solar dryer proceeds both from the top and the bottom into the middle layer. Solar radiation absorbed by the black chimney provides a full column of warm air to increase the air flow through the bed by natural convection.

IV. Design Calculations of Solar Paddy Dryer

The following calculations are the basic design for half ton solar paddy dryer. The basic calculation is to determine the required energy to remove the moisture content of the paddy. And then required solutions are thickness or depth of the rice bed, size of the paddy box, size of the collector area, size of the air inlet and the chimney cross-section area. In this paper, the size of paddy box is calculated for 500 kg capacity.

Drying capacity = 500 kg
Initial moisture content of the paddy = 22 %
Final moisture content of the paddy = 14 %
Drying period = 2 days
Density of the paddy = 600 kg/m^3
Type of collector = Flat plate solar collector
Specific latent heat of vaporization of water, L = 2.5 MJ/kg

The amount of heat required to evaporate the water the drying equation is

$$Q_w = m_w L \qquad (1)$$

Where, the weight of water removed from paddy is

$$m_w = initial\ weight \times \frac{M_{initial} - M_{final}}{100 - M_{final}} \quad (2)$$

The required parameters of rice bed thickness of dryer are shown in Fig 4.

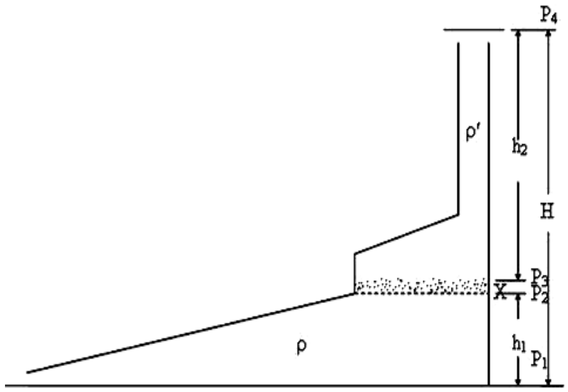


Fig 4. Parameters of rice bed thickness of dryer

The following calculation indicates the appropriate bed depth of paddy in relation to temperature difference. From the Fig 4, the following equations hold:

$$P_2 = P_1 - h_1\rho' g \quad (3)$$
$$P_3 = P_4 + h_2\rho' g \quad (4)$$
$$P_4 = P_1 - (h_1+h_2)\,\rho g \quad (5)$$

The pressure loss across the rice bed can be divided from the above equations and the result is that;

$$P_2 - P_3 = (h_1+h_2)(\rho - \rho')g$$
$$\Delta P = H\,\Delta\rho\, g \quad (6)$$

The relation between depth of the paddy bed X and the air velocity entering and leaving the rice bed V is;

$$V = k\frac{\Delta P}{X}, \quad (7)$$

Where, k is constant and 0.03 m^2/min.Pa

For one cubic meter of paddy spread to a depth of *X* meter. The cross-section area is;

$$A = \frac{1}{X}\ m^2 \quad (8)$$

The air flow rate, with an air velocity V m/min passing through a cross-section area of A m^2, will be;

$$Q = VA \quad (9)$$

From equation 6 to 9,

$$Q = \frac{0.03\,\Delta\rho}{X} \times \frac{1}{X} = \frac{0.03\,H\,\Delta\rho\, g}{X^2}$$

$$X = \left(\frac{0.03\,H\Delta\rho g}{Q}\right)^{\frac{1}{2}}$$

In the case of drying, *Q* should be in the range from 1.5 to 8 m^3/min base on cubic meter of paddy.

Chimney height, H = 3 meters (from the ground level)
Ambient air temperature = 30 ºC
Warm air temperature = 45 ºC
Density of the ambient air, ρ = 1.1514 kg/m^3
Density of the warm air, ρ' = 1.1014 kg/m^3

$$\therefore\ X = \left(\frac{0.03\,H\Delta\rho g}{1.5}\right)^{\frac{1}{2}} \ to\ \left(\frac{0.03\,H\,\Delta\rho g}{8}\right)^{\frac{1}{2}}$$

This range is the depth of the paddy bed for 1 m^3 of paddy. Using this data, depth of the paddy bed is assuming 100 mm for 0.83 m^3 of paddy.

The volume of a 500 kg of paddy bed is calculated from the bulk density of rough rice. The bulk density is expressed in Appendix F. This depends on the variety of rice, the moisture content of rice, and the packing.

$$Half\ ton\ of\ paddy\ volume = \frac{mass}{density} \quad (10)$$

And then, the floor area of the paddy bed can be calculated by the following equation.

$$\text{The floor area of the paddy bed} = \frac{\text{volume}}{\text{depth of the paddy bed}} \quad (11)$$

Where, one side of the paddy box height is 70 cm and other side of the paddy box height is 30 cm.

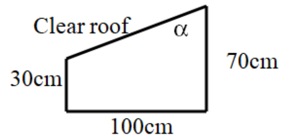


Fig 5. Dimension of the paddy box

Thus, the angle between the clear roof and side of paddy box is $\alpha = tan^{-1}(100/40)$ and clear roof is inclined 68º from the chimney base. Solar insolation for May (summer paddy is harvest in April-May) and average possible sunshine is 0.4 for Yangon. Where,

$$\text{Total solar radiation, } I = 16.3125 \times 0.4$$

$$\text{Received energy from the collector} = I \times t \times \eta_c \quad (12)$$

Where, the collector efficiency, η_c is 0.35 from Table II. Thus, collector area is

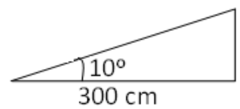
$$\text{Collector area} = \frac{\text{required energy for the dryer}}{\text{received energy from the collector}} \quad (13)$$

The perforated floor should be placed at waist level, or about 80 cm from the ground. If the width of a paddy box suitable range is 100 cm, then the collector wide is 300 cm. The slope of the inclined clear cover is 10 degrees or over. In this design, clear cover inclines 10 degrees from the perforated floor.

The air inlet height = (tan 10º ×300) = 12 cm

The air inlet area = 12 cm × 830 cm = 0.996 m^2

The area is approximately 0.1 times of the paddy false floor area.



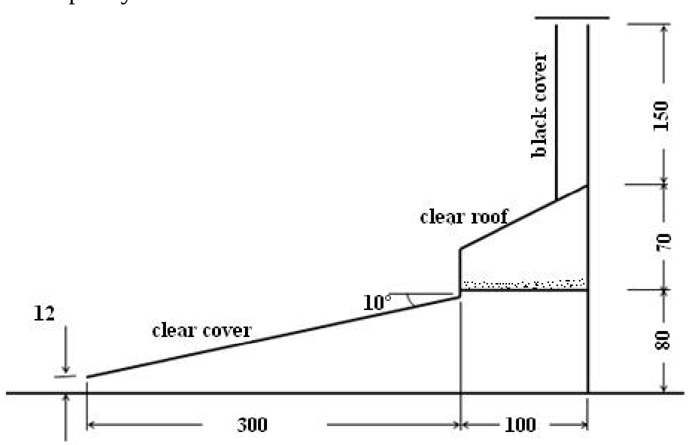


Fig 6.Dimension of the dryer

Where, the range of air flow rate Q is from 1.5 to 8 m^3/min for 1 m^3 of paddy. Thus, the maximum air flow rate of 0.83 m^3 of paddy is

$$Q_{max} = 0.83 \times 8 = 6.64\ m^3/min$$

$$\text{air inlet velocity} = \frac{Q_{max}}{\text{air inlet area}} \quad (14)$$

The pressure loss due to abrupt contraction and gradual expansion is

$$\text{pressure loss} = C_r C_1 \left(\frac{V^2}{2g} \right) \quad (15)$$

In this equation, C_r and C_1 are loss coefficient for area change. These values are expressed in Appendix A.

$$\text{Pressure loss in Pa} = C_2 \rho g \left(\frac{\text{chimney air velocity}}{2\,g} \right) \quad (16)$$

After that, the cross-sectional area of chimney can be calculated by using chimney air velocity and maximum air flow rate. This area is approximately 0.02 times of the false floor area of the paddy. The total area of the air outlet should be at least equal to the cross-section area of the chimney.

V. Summary Of Design And Analysis Of The Solar Paddy Dryer

In order to dry paddy from the initial moisture content of 14 % wet basis within 2 days in the wet season, the dryer will have

Depth of the paddy bed	100 mm
Collector area	3 times that of the paddy floor area
Air inlet area	0.1 times that of the paddy floor area
Air outlet area	0.02 times that of the paddy floor area
Chimney cross section area	0.02 times that of the paddy floor area
Height of the chimney	3 meters from the ground level

The solar paddy dryer is analyzed by changing the drying capacities with same chimney height. The calculation are based on the drying capacities are 500, 1000 and 1500 kg .The following table III shows the required energy, depth of the paddy bed, size of the paddy box, collector area, air inlet area and chimney cross-section area, for various drying capacity at the same chimney height. These calculations are the same.

Table III. Results of Solar Paddy Dryer for Various Drying Capacity with Same Chimney Height

Drying capacity	(kg)	500	1000	1500
Required energy	(MJ)	116.28	232.5	348.837
Depth of the paddy bed	(cm)	10	13	15
Size of the paddy box	(m^2)	8.3	12.85	16.67
Collector area	(m^2)	25.458	50.903	76.372
Air inlet area	(m^2)	0.996	1.542	2
Chimney cross-section area	(m^2)	0.23897	0.23897	0.23897

VI. CONCLUSION

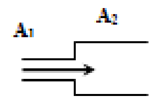
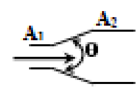
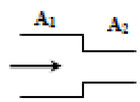
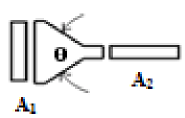
In this paper, the design of indirect solar paddy dryer with chimney is calculated. These calculations consists of the required energy to remove moisture of the paddy, thickness or depth of the rice bed, size of the paddy box, size of the collector area, size of the air inlet and the chimney cross-section area. From the design calculation for 500 kg of solar paddy dryer, it can be seen that the required energy to remove moisture content from 22 % to 14 % for paddy is 116.28 MJ. The received energy from the collector is 6.525 MJ/day m^2 for May. The depth of the rice bed is 100 mm. So, the floor area of the paddy bed is 0.83 m^2. The required collector area is 25.458 m^2. The size of the air inlet area is 0.996 m^2 and the chimney cross-section area is 0.23897 m^2. In this design, solar chimney height is used 3m from the ground level. And then, solar paddy dryer is analyzed by changing the drying capacities with same chimney height. Due to increase in drying capacity, the amount of paddy volume is increased. But by keeping the width of paddy box constant, the length of paddy box and depth of paddy is changed for its increase in volume. Without changing the chimney height, the new collector area form more heat to dry up and outlet air become slow which can cause overheat to the paddy. The effect of overheated, due to the same chimney height, the paddy can be broken and the quality of rice can be poor. Hence to avoid overheat problem it should be suggested to change the outlet air move faster by increase of chimney height. According to the results data from table III, it can be seen that, much energy require for greater drying capacity. So, the collector area will increase and the temperature inside the dryer will also be increased. From the calculation, chimney cross-section area is based on the pressure loss, which is also based on the chimney height. So, for the same chimney height, the chimney cross-section areas will be the same. For the larger collector area with same chimney height can cause overheating effect. To eliminate this effect, the chimney height should be increased.

Appendix

Table A 1. Monthly Average Sunshine Hour for Yangon

Month	Average Sunshine Hour
Jan	9.43
Feb	9.95
March	9.27
April	9.85
May	6.3
June	2.88
July	2.37
Aug	2.59
Sep	4.21
Oct	6.54
Nov	8.79
Dec	8.94

Table A2. Loss Coefficient for Area Changes

Type	Illustration	Conditions	Loss Coefficient	
		A_1/A_2	C_1	C_2
Abrupt Expansion		0.1	0.81	81.00
		0.2	0.64	16.00
		0.3	0.49	5.00
		0.4	0.36	2.25
		0.5	0.25	1.00
		0.6	0.16	0.45
		0.7	0.09	0.18
		0.8	0.04	0.06
		0.9	0.01	0.01
		θ	C_r	
Gradual Expansion		5°	0.17	
		7°	0.22	
		10°	0.28	
		20°	0.45	
		30°	0.59	
		40°	0.73	
Abrupt Exit		$A_1/A_2 = 0$	$C_1 = 0$	
		A_2/A_1	C_2	
Abrupt Contraction Square Edge		0.0	0.34	
		0.2	0.32	
		0.4	0.25	
		0.6	0.16	
		0.8	0.06	
		θ		
Gradual Contraction		30°	0.02	
		45°	0.04	
		60°	0.07	
			C_1 OR C_2	
Equal Area Transformation		$A_1 = A_2$, $\theta \leq 14°$	0.15	

Source: ASHARE (1969)

ACKNOWLEDGMENT

The author would like to expressed his special thanks to Dr. Nyi Nyi, Professor, Department of Mechanical Precision Engineering, University of Technology (Yadanarpon Cyber City) for his kind supervision, encouragement, suggestion and valuable guidance of this paper.

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