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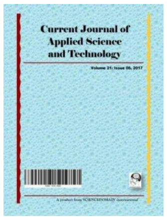
Article *in* Current Journal of Applied Science and Technology · June 2018

DOI: 10.9734/CJAST/2018/42005



Current Journal of Applied Science and Technology

28(1): 1-9, 2018; Article no.CJAST.42005
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Performance Testing and Evaluation of On-Farm Mobile Paddy Dryer

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Authors' contributions

This work was carried out in collaboration between all authors. Authors NSR, YPS and KRS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SVV managed the analyses of the study. Author KCSSK managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2018/42005
Editor(s):
(1) Sait Engindeniz, Professor, Department of Agricultural Economics, Faculty of Agriculture, Ege University, Turkey.
Reviewers:
(1) Onur Taskin, Uludag University, Turkey.
(2) Kabiru Mu'azu, National Research Institute for Chemical Technology, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/25186

Original Research Article

Received 26th March 2018
Accepted 8th June 2018
Published 19th June 2018

ABSTRACT

Efficient drying from any mobile paddy dryer would result in the superior quality of the product within a desirable time. Dryer was evaluated using 5332.5 kg of freshly harvested paddy at 21.01% moisture content (w.b). The air velocity at top layer was found to vary from 0.50 to 0.33 m/s at loading condition and 1.7 to 0.6 m/s at no-load condition. The moisture content, the coefficient of uniformity (Cu) and moisture ratio at bottom of the drying chamber were observed to vary from 21.03 to 13.44% (w.b), 91.47 to 98.32%, and 0.928 to 0.085 respectively during the start to the end of the drying. The temperature of the drying chamber at bottom and top layers were found to vary from 35.57 to 32.47°C and 40.63 to 32.47°C, respectively. The relative humidity values at the bottom and top layers were 95.87 to 94.27% and 72.40 to 93.43%, respectively during drying. At the end of drying after 4.5 h, the final moisture was estimated to be 15.23% (w.b). The thermal

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efficiency, heat utilization factor and effective heat efficiency were calculated to be about 58.5%, 0.99 and 0.89, respectively. The total power requirement was assumed to be 15 kW. The cost of drying was found to be Rs. 943 /h and Rs. 0.79 /kg of paddy.

Keywords: Plenum; centrifugal blower; drying chamber; discharge sprouts; thermal efficiency.

1. INTRODUCTION

According to the International Rice Research Institute, rice is a basic food to almost one-half of the world's population and is produced all over the world as a nutritionist food [1]. Paddy is usually harvested at high moisture content of about 21-22 % (w.b) when it matures. At this high moisture content, paddy has a high respiration rate and is very susceptible to spoilage. It is stated that drying of paddy is the most crucial post-harvest unit operation after the harvest of paddy to remove moisture from grains to a predetermined level [2] Moisture removal is an essential pre-requisite for safe storage of the food grains and protects them against attack of insects, moulds and other micro-organisms during storage. The safe moisture content for cereal grains is usually 12 to 14% on wet basis. Paddy drying is commonly done by two ways. One is the open sun drying and other is the mechanical drying by using the different types of dryers. Sun drying is a traditional, cheap process but it requires large number of labour and degrades product quality. Early harvest, followed by mechanical drying, improves the milling quality of paddy considerably. In mechanical dryers heated air is passed through the grain mass to accomplish the removal of excess moisture from it. Grains can be dried irrespective of weather conditions, day or night, as the process does not depend on any natural sources like sun energy (T.P. Ojha & A.M. Michael., Vol I). The solar batch dryer of 0.5 tonne holding capacity took 3.5 h to dry 500 kg of raw paddy from 23.5 to about 14% (d.b) at 0.30 kg/s air flow rate with the production of the same head yield as in the case of sun drying [3]. Andhra Pradesh state has long coastal line which is frequently hit by cyclones, hence farmers are demanding dryer for on-farm drying. Under these circumstances, the Government of Andhra Pradesh had recognized the need for a blend between research and policy and requested Post Harvest Technology Centre (PHTC), ANGRAU to address the problem to develop and demonstrate the post-harvest management technologies for managing high moisture paddy for reducing post-harvest losses at farmer's field and at warehouses and increasing remunerative prices for farmers through value addition. Accordingly, Post-Harvest Technology Centre (PHTC), Bapatla has developed mobile paddy dryer in collaboration with M/s Kardi Dryers Pvt. Ltd, Chennai.

The objective of this study is to study the technical specifications of on-farm mobile paddy dryer and to conduct performance evaluation of the on-farm mobile paddy dryer.

2. MATERIALS AND METHODS

The paddy dryer used for the study was a mobile paddy dryer (Fig. 2.1.), a flatbed batch type with perforated floor, it was mainly consisted of drying chamber where the paddy grain was placed, plenum chamber, discharge sprouts, centrifugal blower with electric motor with adequate air flow rate to dry the product uniformly, indirect type of heat exchanger with combustion chamber, oil burner used was a multi-fuel burner. Dryer can work with power source as well as fuel source also.

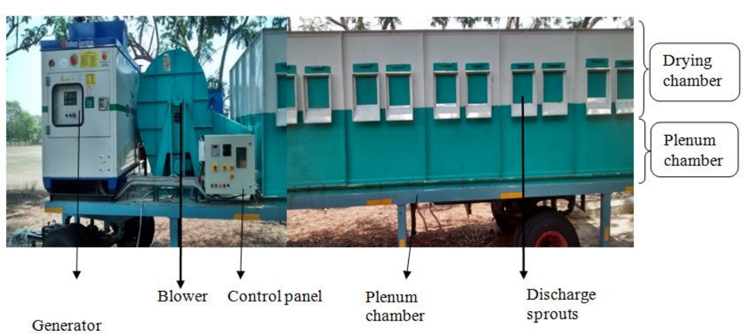

Fig. 2.1. Mobile paddy dryer used for on-farm processing

2.1 Materials

2.1.1 Moisture meter

The quality of grain was influenced by its moisture content. The moisture content of the freshly harvested paddy was determined by placing sample in the moisture meter (Optics Technology).

2.1.2 Temperature cum Humidity indicator (Probe type)

This was used to measure the temperature of the grain and also relative humidity by inserting the probe (Optics Technology) into the grain mass. Readings can be noted down from the digital display.

2.1.3 Digital anemometer

Anemometer (Lutron AM-4201) was used to measure the air velocities and readings were shown by the digital display. Anemometer vane probe was placed where the air velocity was to be measured. It gives the fast and accurate readings. The air velocity readings were taken at no load as well as at loading condition.

2.2 Technical Specifications of Mobile Paddy Dryer

2.2.1 Drying chamber

In the mobile dryer, type of drying section used was a flat-bed with perforated floor. Dimensions of the drying chamber were 4.7×2.5×0.7 m. The size of perforation was 0.21 cm and the mesh consist of 12×12 perforations in 1 inch^2. Thickness of grain dryer (grain depth) in drying section was 65 cm. The grain was distributed manually over the drying chamber. The dried grain was discharged through the discharge sprouts provided on one side of drying chamber. There were about 10 discharge sprouts for discharging the grain each having the dimensions of about 0.3×0.24 m.

2.2.2 Plenum chamber

Dimensions of the plenum chamber are 4.7×2.4 m. The depth of plenum chamber decreased from 50 to 10 cm from blower side to other side. Ratio of plenum volume to the whole drying chamber volume was estimated to be 0.4285.

2.2.3 Blower

The blower type used in the paddy dryer was of centrifugal type. Air blowers generally use centrifugal force to propel air forward. The power required for centrifugal blower was noted as 7.5 hp.

2.2.4 Oil burner

An oil burner is a mechanical device that combines fuel oil with proper amounts of air before delivering the mixture to the point of ignition in a combustion chamber. It was essential for the efficiency of the combustion process that the oil/air mixture was well homogenized and with as few pure droplets of fuel oil as possible. Dimensions of oil burner used in the dryer were 2.0×0.5×0.9 m (Make: RBL, Model: Riello, 40, G10).

2.3 Methodology

Heated air from oil burner is sucked by the blower and force through the grain bulk mass. Once drying begins heated air moves up, drying the grain and absorbing the moisture. Totally 9 observations were taken at each layer (S-R, S-M, S-L, M-R, M-M, M-L, E-R, E-M, E-L) (Fig. 2.2). So that, a total of 18 readings were obtained for 2 layers. The readings were taken at top and bottom layers of drying chamber at 9 places in each layer. The drying rate varies with the drying temperature.

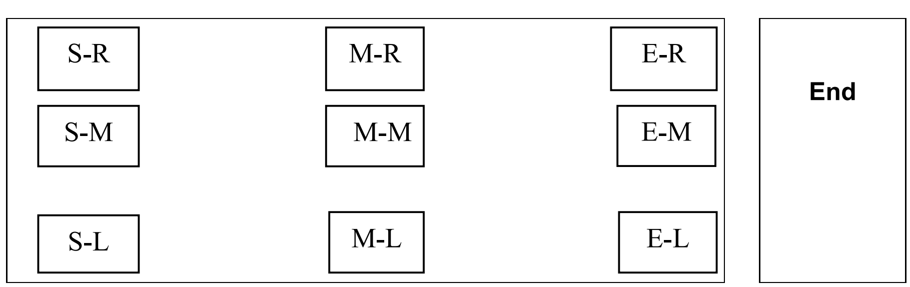

Fig. 2.2. Delineation of drying chamber for the purpose of taking observations
S: Start (Section -1), M: Mid (Section -1), E: End (Section -1);
L: Left, R: Right, T: Top, B: Bottom

Table 2.1. Specifications of paddy dryer and its accessories

Name of the unit/part	Sl. no.	Items	Specifications
Dryer	1	Name of the dryer	Mobile paddy dryer
	2	Type of dryer	Flatbed batch type
	3	Model of dryer	Not specified
	4	Manufactures name and address	Kardi Dryers Pvt. Ltd, 284, Avvai Shanmugam Salai, Chennai-600086
	5	Holding capacity of dryer (tons)	5.4 ton per batch
	6	Dimensions of dryer(cm)	7.7×2.4 m
	7	Total height of dryer and ground clearance (cm)	1.6 m, 0.3 m
	8	Total weight of dryer (kg) (empty)	5580
	9	Total hp requirement	20.1 hp
	10	Total power requirement (kW)	15 kW
	11	Price of the dryer (Rs.)	Rs.16,44,000/-
Drying chamber	1	Type of drying section (screen, baffle, etc)	Flat-bed with perforated floor a sided air duct with line System
	2	Dimensions (m)	4.7×2.5×0.7 m
	3	Grain holding capacity (kg)	5000 -5350 kg
	4	Dimensions of plenum (for double screen and baffle type)	4.7×2.5×0.5 m
	5	Ratio of plenum volume to the whole drying chamber volume	0.4285
	6	Thickness of grain dryer (grain depth) in drying section	65 cm
	7	Mesh no. of the screen (for double screen)	1
	8	Dimensions and position of hopper	No hopper
	9	Grain distribution mechanism	Manually
	10	Grain discharging mechanism	Gravity discharge sprouts provided on one side of drying chamber
Blower	1	Blower type	Centrifugal blower
	2	Dimensions (m)	1.2×0.4 m
	3	Rated capacity of blower (m^3/min)	Not given (confidential)
	4	Rated hp of blower motor	7.5
Control systems	1	Drying air temperature range and control	50 ± 0.5 °C
	2	Air flow rate control	No control provided
	3	Grain flow rate control	No control provided
		Air heating system	
		Type of fuel used and its calorific value (kcals/kg)	Multi fuel burner (Diesel oil or kerosene oil)
		Direct or indirect firing	
Oil burner	1	Dimensions	2.0×0.5×0.9 m
	2	Built-in-type or separator	Built-in-type
	3	Type of burner	Multi fuel
	4	Material of construction	-
	5	Capacity of the fuel storage tank	50 to 60 L
	6	Method of ignition and extinguishing	Battery ignition and Auto-off

3. RESULTS AND DISCUSSION

In this chapter, drying performance and testing, cost economics for drying operation were presented. [4] Generalized the factors that affect drying rate as temperature, air flow rate, relative humidity, exposure time, initial moisture content.

3.1 Evaluation of dryer

3.1.1 Changes in air velocity

It was observed that the air velocity readings at no load condition in Fig. 3.1. (a) at section 1 (near the blower) observed were lower. The velocities found to vary in between 0.6 – 0.8 m/s. The velocities of air observed at section 2 and section 3 were on higher side. However, at the middle point in section 2, the velocity was found to be lower due to lower upward thrust of air causing lower velocities. Velocities at section 2 and section 3 were found to vary in between 0.8 – 1.7 m/s. Thus, velocity of air over entire grain bed was not uniform.

At loading condition, it was observed that the air velocity distribution was found to vary from 31.31 to 79.43 % (coefficient of uniformity) as the time of drying progress. Further, it was found in Fig. 3.1. (b) that the air velocity at section 3 was rapidly changing when compared to section 1 and section 2. At section 3 the air velocity was varying from 0.37 to 0.77 m/s, at section 1 and section 2 it was 0.33 to 0.48 m/s and 0.23 to 0.53 m/s respectively. The reason might be the difference in the configuration of plenum chamber from section 1 to section 3 causing upward thrust of air. It is observed that as the air passes through the grain mass, the specific airflow rate becomes smaller and smaller, until it reaches a minimum value at the surface of the grain [5].

3.1.2 Rates of moisture removal

It was observed in the Fig. 3.2(a), average bed moisture content at section 3 rapidly decreases from 21.03 to 12.87% as the drying progressed when compared to average bed moisture content at section 1 and section 2 which changed from 21.03 to 13.30% and 21.03 to 14.17%, respectively. This might be due to increased air flow rate at section 3 due to configuration of plenum chamber which caused increase in thrust of air flow to pass through the plenum chamber causes rapid removal of moisture from section 3. The rate of removal of moisture was slower at section 1 as the flow rate at section 1 near blower was low due to minimum upward thrust of air flow through plenum chamber at section 1.

Further, it was observed in Fig. 3.2(b), that moisture content at the top layer at section 3 decreased moderately from 21.03 to 15.47% when compared to the section 2 and section 1 top layers which changed from 21.03 to 17.80% and 21.03 to 17.83%, respectively. Above stated reasons for the bottom layer might be attributed to the trends followed in the top layer.

The changes in average moisture content in top and bottom layer with respect to time of drying was depicted in Fig. 3.3. From the graph it was evident that in deep bed drying all the grains in the dryer were not fully exposed to the same conditions of drying air. The condition of drying air at any point in the grain mass changes with time and at any time it also changes with the depth of grain bed. Thus in a deep bed, entire bed is stratified as dried grain, drying zone and wet grain zone. At any particular point of time, lower layer in the bed had lower moisture content when compared to top layer. Rate of moisture removal in bottom layer was rapid as the air flow was in direct contact with lower layer of grains.

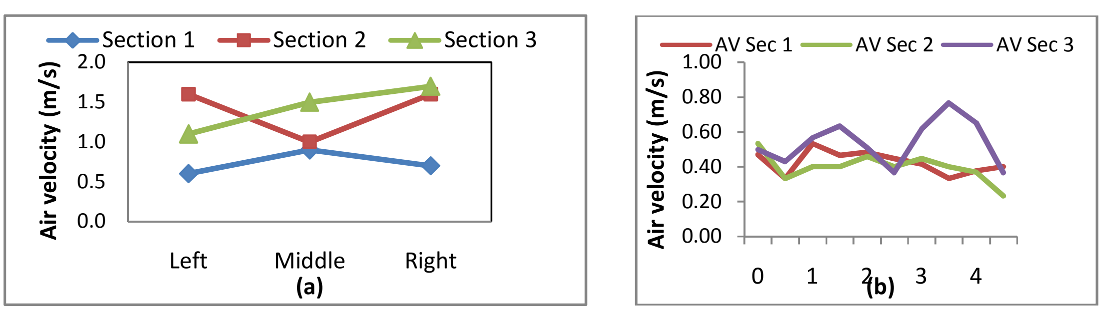

Fig. 3.1. Distribution of air velocities at different sections at (a) no load (b) loading condition

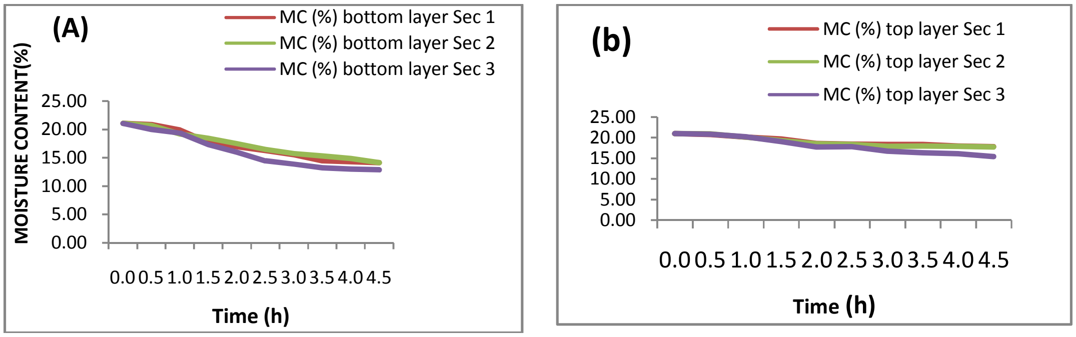

Fig. 3.2. Changes in moisture content at (a) bottom and (b) top layer with time of drying

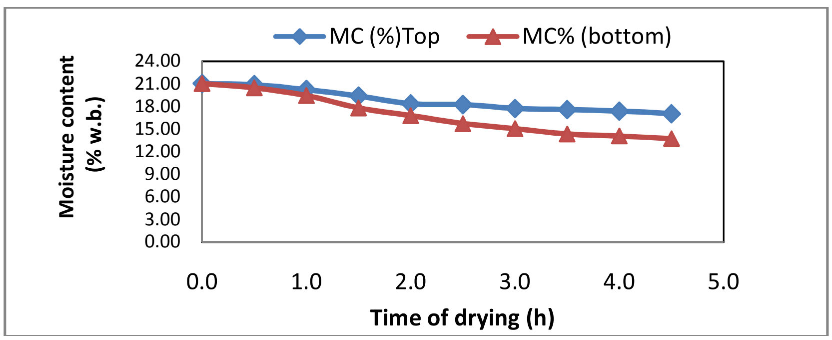

Fig. 3.3. Changes in moisture content at top and bottom layers with time of drying

Moisture was removed from the dried layer until equilibrium moisture content is reached. Further, it was noted that rates of moisture removal from bottom layer was rapid after time of drying elapsed 2.5 h as drying zone was moving towards the top of the grain bed.

3.1.3 Changes in exit air temperature

The temperature distribution at the bottom layer of drying chamber was shown. It was found to be varied from 97.31 to 99.80% and from Fig. 3.4 it was observed that temperature at three sections was found to be varying equally but varying little higher at section 3 as the air moves rapidly through it which was able to remove the moisture quickly when compared to other two sections and hence the temperature at section 3 was higher. Similar trends were observed at top layer in case of temperature distribution.

3.1.4 Computation of dryer efficiencies

The performance of the mobile dryer was evaluated in terms of overall thermal efficiency; heat utilization factor, total heat efficiency.

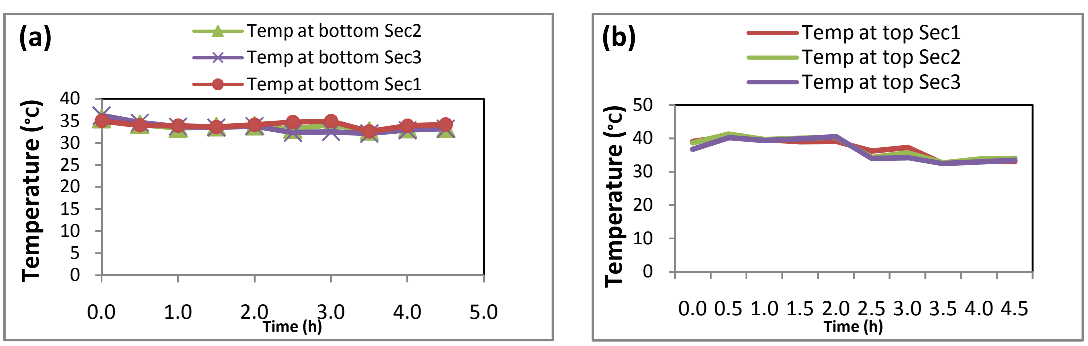

Fig. 3.4. Changes in temperature distribution at (a) bottom, (b) top layers with time of drying

a) Overall thermal efficiency

The overall thermal efficiency gives an idea about the amount of heat utilized against amount of heat available.

$$Overall\ Thermal\ efficiency = \frac{Amount\ of\ moisture\ removed\ (kg) \times\ latent\ heat\ of\ evaporation\ \left(\frac{kJ}{kg}\right) \times\ humid\ volume\ \left(\frac{m^3}{kg}\right)}{air\ flow\ rate\ \left(\frac{m^3}{s}\right) \times\ difference\ in\ enthalpy\ \left(\frac{kJ}{kg}\right)\ \times\ drying\ time(s)}$$

$$= \frac{363.6\ \times\ 2501.6\ \times\ 0.91}{5.36\ \times\ (123 - 106) \times\ 4.5\ \times\ 3600} \times 100$$

= 58.5 %

Therefore, a higher thermal efficiency of 58.5 % is obtained when compared to the overall thermal efficiency of the mobile paddy dryer (46.83 %) designed at the Institute of Post-harvest Technology, Sri Lanka [6].

b) Heat utilization factor:

Amount of heat utilized during drying. If the paddy absorbs all heat of drying air, the heat utilization factor should approach to unity.

$$Heat\ utilisation\ factor = \frac{Drop\ in\ dry\ bulb\ temperature\ of\ drying\ air, °C}{increase\ in\ dry\ bulb\ temperature\ of\ ambient\ air, °C}$$

$$= \frac{50-35}{50-34.92}$$

= 0.99

Therefore the average heat utilization factor of this dryer was found to be 0.99 which indicates high heat utilization efficiency. It was found from previous studies that the average heat utilization factor of the mobile dryer [6] was found to be 0.82 only.

c) Effective heat efficiency:

By definition, total heat efficiency is always smaller than heat utilization factor at any time.

$$Effective\ Heat\ Efficiency = \frac{t_1 - t_2}{t_1 - t_{w1}}$$

$$= \frac{50-35}{50-33.33} = 0.89$$

The average value of total heat efficiency for the present dryer was found to be 0.89, indicating higher efficiency.

3.2 Cost Economics for Operation of Dryer

The economic analysis is the most important for farmers as well as the end users for finding out the cost of drying. The methodology used to predict the fixed and variable cost was that given by Kenneth [7].

3.2.1 Fixed cost

Depreciation = Rate x (Purchase Price – Salvage Value) = Rs. 98.64 /h

Interest $(I) = \left(C + \frac{S}{2}\right) \times \left(\frac{i}{H}\right)$ = Rs. 165.2 /h
Housing cost = Rs. 16.44 /h
Insurance cost = Rs. 16.44 /h
Taxes = Rs. 16.44 /h

Total fixed cost/h
=98.64+165.2+16.44+16.44+16.44 = Rs. 313.16

3.2.2 Operating cost

Total operating cost/h = Fuel cost + repairs and maintenance + wages of workers and operators = Rs. 629.84

3.2.3 Operating cost per kg of paddy

Total cost/h = fixed cost + operating cost
=313.16+ 629.84 = Rs. 943

Therefore, total cost of drying operation per hour = Rs. 943

Operating cost/ cost of drying per kg of paddy
= Rs. 0.79

As the cost of drying per kilogram of paddy was Rs. 0.79 only which is economical, when compared to the cost of drying per kilogram of paddy (Rs. 1.2) by using solar assisted paddy dryer [8]. On the basis of overall thermal efficiency; heat utilization factor; total heat efficiency; it is concluded that the performance of the mobile dryer available at Post Harvest Technology Centre, Bapatla, Andhra Pradesh is found to be good. Hence, this dryer could be used to dry freshly harvested paddy on hiring base.

Table 3.1. Test report for the performance of the static deep bed batch dryer

Name of the part/unit	Sl. no.	Type and model No. of dryer: Type of grain and variety	Specifications
Grain	1	Initial wt. of wet grain (kg)	5332.5
	2	Final wt. of dried grain (kg)	4968.9
	3	Initial moisture content (percent)	21.01
	4	Final moisture content (percent)	15.23
	5	Dryer loading time (h)	0.5
	6	Dryer unloading time (h)	0.67
Air	1	Air flow rate (m^3/min)	321.6
	2	Average ambient d.b. temp (°C)	34.92
	3	Average ambient w.b. temp (°C)	25.88
	4	Average heated air d.b. temp (°C)	50
	5	Average heated air w.b. temp (°C)	33.33
	6	Average exhaust air d.b. temp (°C)	35
	7	Average exhaust air w.b. temp (°C)	25.92
Drying capacity	1	Total drying time (h)	4.5
	2	Total moisture evaporation (kg)	363.6
	3	Rate of moisture evaporation (kg/h)	90.9
	4	Rate of dried grain productions (tons/h)	1.193
Heater and fuel	1	Air heating method (oil fired burner/husk fired furnace)	Oil fired burner
	2	Type of air heating(direct/indirect)	Indirect
	3	When oil fired burner/husk fired furnace is used	
		a) Type of fuel and cal. value	Diesel and 10,500

4. CONCLUSION

The dryer was able to dry the paddy from initial moisture content 21% to a moisture content of 14 %. Results showed that the mobile paddy dryer has the considerable advantages over the open sun drying method in terms of faster drying rate and handling convince. The mean drying rate of the dryer was 1193.67 kg/h for every 5332.5 kg. This on-farm mobile paddy dryer took 4.5 h or drying the 5.33 tons of paddy up to 15.23%. Furthermore, an economic analysis was also performed for the dryer. The cost of drying was found to be Rs. 943 /h and Rs. 0.79 /kg of paddy. The total capacity of the dryer was about 5.3 ton per batch. The total weight of the dryer was 5.8 tons and total power requirement was assumed to be 15 kW. After its evaluation, the dryer was approved by government of Andhra Pradesh for hiring purpose to farmers.

The suggestions furnished for future work are:

i) Drying air temperature was set at 50°C, experiments may be conducted to evaluate dryer performance by enhancing temperature of drying air to 55°C.
ii) Design and development of gasifier coupled to dryer for drying applications.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/25186