Performance Enhancement of Inclined Bubbling Fluidized Bed Paddy Dryer by Design Modification

Phyu Phyu Thant, P. Mahanta, P.S. Robi

Abstract— **Present paper discusses the bed inclination and passive inserts of dryer on drying of paddy in a bubbling fluidized bed dryer. Paddy was dried in three different inclined positions, viz., vertical bed (0° inclined), 15° and 30° in a bubbling fluidized bed. Experiments were conducted for 0.5 to 2.5 kg batch size with superficial velocities of 1.1 m/s and 1.6 m/s. All the experiments were repeated with and without spirals inserts. Results were obtained for air temperature of 55°C, 60°C and 65°C and air velocities of 1.1 ms^{-1} and 1.6 ms^{-1} respectively. Better results in terms of energy consumption and moisture removal rate were observed with bed inclination of 15°. Use of spirals inside the drying chamber with inclined dryer reduces drying time as well as reduces energy consumption significantly.**

Index Terms— **energy consumption, fluidized bed, paddy, spirals**

I. Introduction

Paddy drying is carried out after harvesting with the aim of reducing the loss due to pest and fungal attack, long storage life, and easy handling with minimum damage. Delay in drying, incomplete drying or ineffective drying will reduce grain quality and enhance post-harvest losses. Sun drying is the most widely practiced form of drying in the developing countries due its advantages like low cost, easiness and convenience. However, sun drying is extremely dependent on weather conditions, long drying time, labor intensive, contamination of the product with soil and dust, non uniform drying leading to poor product quality, and large space requirements. By using dryers, paddy with consistent and desirable quality can be obtained which can be preserved for long time periods. Even though several types of dryers exists, fluidized bed dryers have been found to be very efficient for drying cereal grains such as paddy, rice, wheat, corn, etc.

Veerachandra et *al*. (2013) reported that drying method and drying temperature have significant effect on drying time. Srinivasakannan (2012) utilized spirals as internals to reduce the axial mixing of solids in fluidized beds and reported the drying rate in a continuous fluidized bed is lower than the rate of drying in batch fluidized bed. Okoronkwo et *al*. (2013) carried out fluidized bed dryer performance in drying of cassava and reported that drying at temperature below the optimal temperature results in lower rate of moisture removal and longer drying time. Drying above the optimum temperature leads to products having physical defects such as decoration, cracking, shrinking and non-uniform drying. Oluwaleye and Adeyemi (2013) reported achieving fine and uniform drying of products using a batch hot air fluidized bed dryer. Yakubov (2007) carried out the dynamics and structure of a fluidized bed in inclined columns and observed that the air velocity varied with the column inclination angle. Hung (2013) studied the fluidized bed drying and observed that the drying method and drying temperature had significant effect on drying time. Gornicki (2013) studied the fluidized bed drying of apple and observed that increase in drying air temperature caused a decrease in the drying time and an increase in drying rate.

Lim et *al*. (2014) reported the bed pressure drop fluctuation along the fluidized bed was proportional to the superficial gas velocity. Srinivasakannan and Balasubramanian (2009) investigated the drying characteristics of millet in fluidized beds and reported that the drying rate increased with increase in temperature. Promvonge (2011) reported that increase in air temperature and air velocity in the fluidized bed dryer accelerated the drying rate of peppercorns. Hematian and Hormozi (2015) investigated the drying behavior of a batch fluidized bed dryer and observed that the moisture ratio decreased continuously with time. Özahi and Demir (2014) observed that the drying time was reduced by increasing the drying air velocity during the fluidized bed drying of corn and unshelled pistachio nut. Jaiboon et *al*. (2009) reported that higher head rice yield was obtained when the air temperature in a fluidized bed dryer was increased. Samson et *al.* (2015), by means of a multi-orifice distributor plate in a gas-fluidized bed dryer, observed that the swirling flow induced by the helix significantly improved heat transfer characteristics inside the dryer. Nakamura et *al.* (2013) reported improvement in particle mixing and heat transfer characteristics in a rotating fluidized bed having inclined holes in the distributor plate.

Sarker (2015) studied the energy and exergy analysis of industrial fluidized bed drying of paddy and suggested that exergy can be increased by providing sufficient insulation to dryer body and recycling the exhaust air. Ozahi and Demir (2015) investigated the drying performance of a batch type fluidized bed regarding energetic and exergetic efficiencies and observed that both energetic and exergetic efficiencies strongly depends on air mass flow rate, particle mass and moisture content of particle to be dried. Golmohammadi et *al.* (2015) reported substantial reduction in energy consumption in intermittent paddy dryer by employing tempering stages in paddy drying. Sarker et *al*. (2015) studied the industrial scale fluidized bed paddy dryer and observed that drying rate was slow with paddy having high initial moisture content. Literature reveals that crop drying is a high energy-intensive operation due to the removal of latent heat of evaporation in the crop. One of the key issues to be addressed in drying technology is to reduce the cost of energy sources and increase the efficiency of drying without compromising on the quality of the dried products. This can be achieved by techniques which improve the heat transfer characteristics in the bubbling fluidized bed dryer by inserting spirals inside the

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drying chamber. The present paper investigates the drying characteristics of a fluidized bed dryer by inclining the bed, subsequent using spiral inside the drying chamber. The drying characteristics and energy consumption in a bubbling fluidized bed paddy dryer for various combinations of bed inclination, air flow rate, air temperatures and bed inventories have been investigated. The results obtained are compared with that of the vertical bed dryer.

II. MATERIALS AND METHODS

The bubbling fluidized bed dryer system used for the investigation is shown in Figure 1. It consists of a centrifugal blower powered by a 15 HP electric motor, three electric heaters each of 1kW capacity and fitted inside the air flow pipe, orifice plate, distributor plate, dryer column, manometer, thermocouples and data acquisition system. The desired bed inclination at an interval of 15˚from the vertical is achieved using the inclination flange which is connected to the air flow pipe. The dimensions of the dryer are 100 mm x 100 mm cross sectional area and 1625 mm column height. Twenty six pressure taps were used to measure the fluidized bed pressure drops on both sides of the column. The pressure drops were measured from the manometers using water as the manometer fluid. The manometer readings from each pressure tapings during the drying processes were recorded at an interval of 10 minutes from which the pressure drops were determined. The dryer column was fabricated from Plexiglas for visual observation. The paddy bed of batch sizes 0.5 kg, 1 kg, 1.5 kg, 2 kg and 2.5 kg were fluidized at three different dryer positions: vertical bed (0˚ inclined), 15˚ and 30˚ inclined beds with drying air temperatures of 55˚C, 60˚C and 65˚C and air velocities of 1.1 ms^{-1} and 1.6 ms^{-1}. At the start of the experiment, the blower was switched on and air mass flow rate and velocity were adjusted by means of gate valve installed in the air flow pipe. Air was heated and maintained constant at the required temperature by means of heater coils placed inside the air flow pipe. Drying air temperature was measured by the pre-calibrated K-type thermocouples and continuously recorded using the data acquisition system. Paddy of required inventory was loaded into the bubbling fluidized bed dryer. The pressure at different sections along the column of the dryer was recorded to obtain the pressure drop across the bed for fluidized bed behavior. Few grams of paddy samples were taken out at 10 minutes interval for the determination of the moisture content using a digital grain moisture meter having an accuracy of ±0.5%. The moisture meter was pre-calibrated using the standard oven method. The experiment was terminated when the moisture content in the paddy dropped to 12% wet basis. Spiral is shown in Fig 2.

(a)

(b)

Fig. 1 Bubbling fluidized bed drier (a) 15° inclination and (b) 0˚ inclination

Fig. 2 Spirals

A. Drying Parameters

System velocity and mass flow rate of air are the main parameters for fluidized bed drying system. When a gas passes through a bed of particles the bed tend to get fluidized. Depending upon the superficial gas velocity, the flow regimes are categorized as fixed bed, bubbling bed, slug bed, turbulent bed, fast bed and pneumatic transports [Davidson and Harrison (1963), Othomer (1956)]. The superficial velocity (U) is defined as the volume flow rate of air per unit cross-section of the bed.

i.e., $$U = \frac{\text{Volume flow rate of air through the bed}}{\text{cross-sectional area of the bed}} \quad (1)$$

where U is superficial velocity

For orifice plate, superficial velocity is determined by the relationship [From the orifice plate design]

$$U = \frac{\dot{m}_a}{\rho \times A_b} = 1.117\sqrt{\Delta P}\,\text{ms}^{-1} \quad (2)$$

where $\dot{m}_a$ is mass flow rate of air, ρ is density of air, A_b is cross sectional area of the dryer and ΔP is the pressure drop. Mass flow rate of air is determined using the relationship [From the orifice plate design]

$$\dot{m}_a = 0.01303 \times \sqrt{\Delta P}\ \text{k gs}^{-1} \quad (3)$$

B. Energy consumption

The energy consumed by the dryer is used partly for heating the air and partly for driving the blower fan. The energy calculations presented in this paper is based on the energy input to the dryer and energy consumption by the blower. The energy input for removing the moisture from the wet paddy is

$$Q = V\,I\,t \times P.F. \times 60 \times 10^{-6}\ \text{MJ kg}^{-1} \quad (4)$$

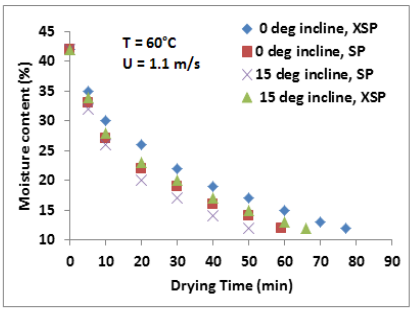
where Q is heat input V is input voltage, I is Ampere, t is drying time (minute) and $P.F$ is power factor.

III. RESULTS AND DISCUSSION

From the experiment, drying characteristics and energy consumption of vertical and inclined beds for drying were investigated. The results obtained are presented in the subsequent sub-sections.

A. *Drying Characteristics*

The moisture content viz. drying time for the fluidized bed dryer with the use of spirals (SP) and without the use of spirals (XSP) for a bed inventory 2.5 kg, air velocities U_1 (=1.1 ms^{-1}) and U_2 (=1.6 ms^{-1}) and different air temperatures are shown in figure 3 (a) to (d) . The reading obtained for the moisture content viz. drying time for bed inclinations of 15˚ and 30˚ were found to be same. Hence only the data corresponding to that for the bed inclination of 30˚ is not presented.



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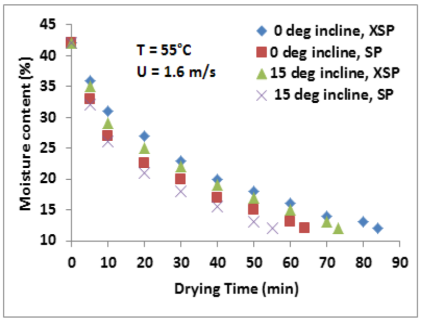

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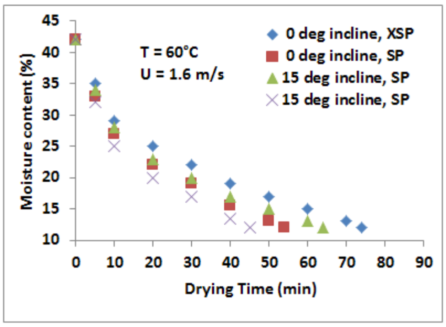

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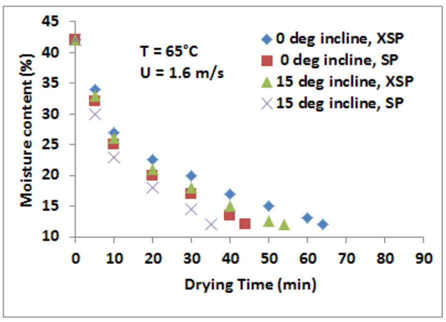

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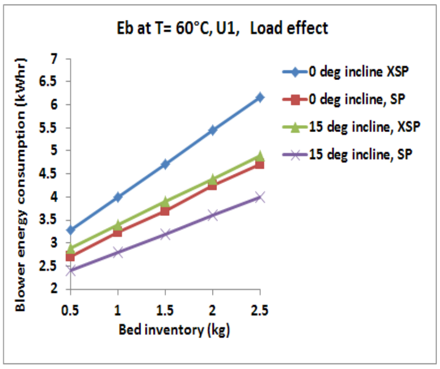
Fig. 3 Moisture content vs. drying time plots for (a) T = 60˚C and U_1, (b) T = 55˚C and U_2 (c) T = 60˚C and U_2 (d) T = 65˚C and U_2

The plots indicates high moisture removal rate at the beginning of the drying process and is attributed to the removal of the surface moisture of the paddy. The drying rate decreased with further drying time. The slow moisture removal rate during the later stages of drying process is due to the removal of the internal moisture from the paddy grains. From the figures it is evident that drying rate increased with increase in air temperature. Fluidized bed drying is found to be more efficient with the inclined bed compared to the vertical fluidized bed dryer. From the figures it is evident that use of spirals decreased the drying time by 20 minutes compared to the drying without the use of spirals for the drying conditions studied.

B. *Energy Consumption*

Energy consumptions for drying paddy, with and without the use of spirals, was investigated for various combination of inventory, air temperatures, air velocities for three bed inclinations (0˚, 15˚, 30˚ inclinations). Fig. 4 plots the blower energy consumptions (E_b) vs. different input parameters when dried with and without the use of spirals.



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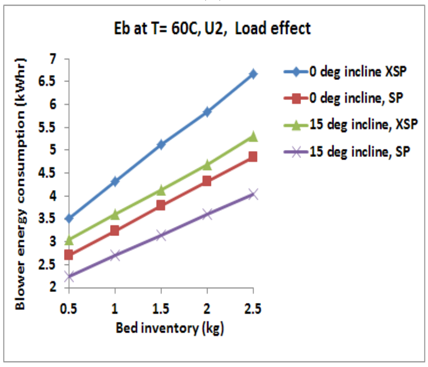

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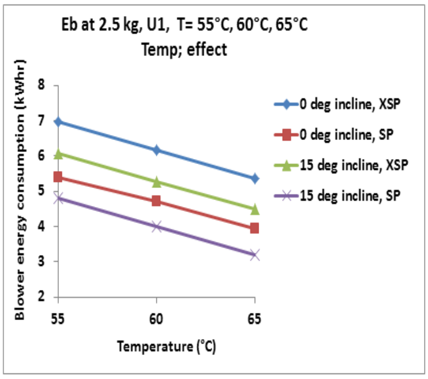

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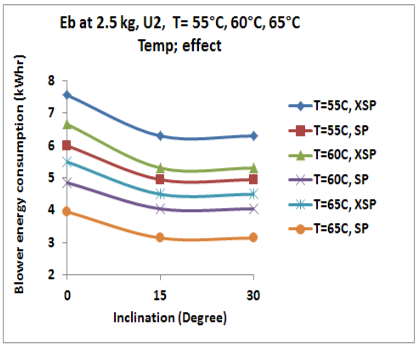

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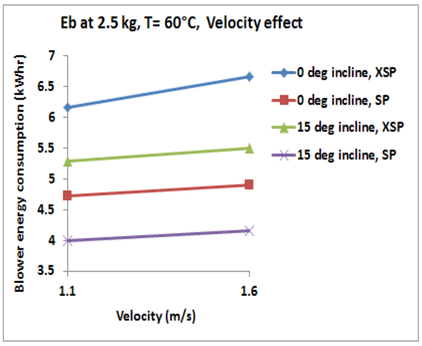

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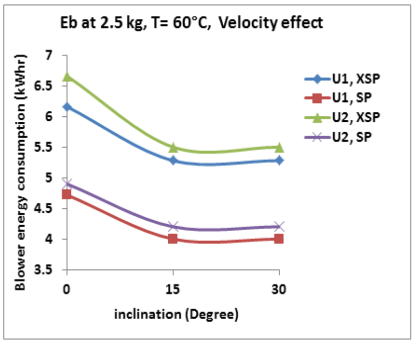
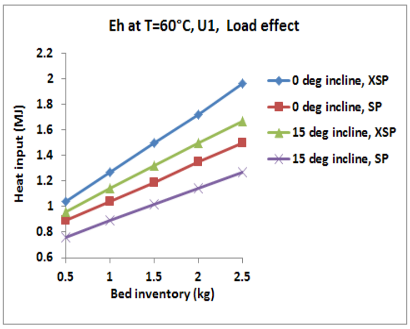


(f)

Figure 4 Plots showing the comparison of (E_b) with and without the use of spirals, for different input parameters during paddy drying

Figure 4 (a) & (b) indicate decrease in blower energy consumption with increase in bed inventory with the use of spirals. Blower energy consumption for 1 kg paddy (E_{bu}) at a load of 2.5 kg with drying air temperature 60°C and velocity U_1 reduced 23.37% for the vertical bed and 18.36% for the inclined bed respectively when spirals were used. At load of 0.5 kg, the reduction in E_{bu} with the use of spirals under the same conditions is 17%. The corresponding reduction in E_{bu} at air velocity U_2 are 27% for load of 2.5 kg and 23% for 0.5 kg, respectively when spirals were used. Figs. 4 (c) & (d) indicate decrease in E_{bu} with increase in drying air temperature with the use of spirals. The use of spirals reduced E_{bu} by 22% when spirals were used for drying paddy at a load of 2.5 kg at 55°C, whereas, the reduction was 28% at air temperature of 65°C. Figure 4 (e) & (f) shows the use of spirals reduced E_{bu} by 24% at U_1 and 26.4% at U_2 for drying paddy at a load of 2.5 kg with dryer air temperature 60°C. E_{bu} reduced by average 26% with the use of spirals compared to the dryer without the use of spirals, for all drying conditions. Figure 5 plots the heat input (E_h) vs different input parameters when dried with and without the use of spirals.



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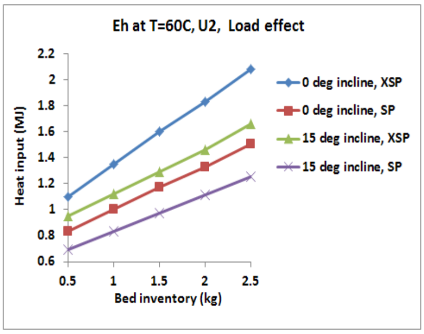

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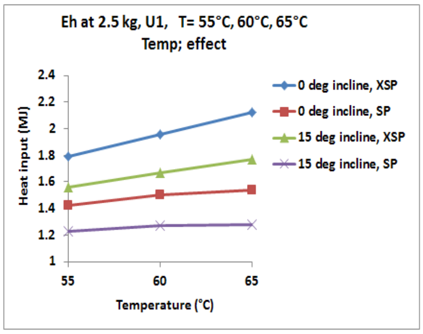

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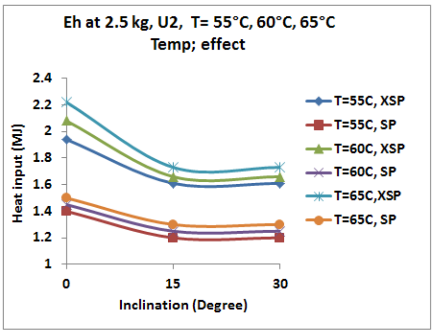

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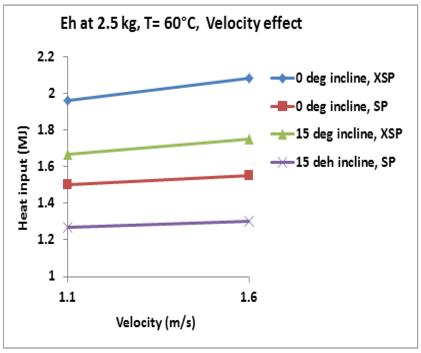

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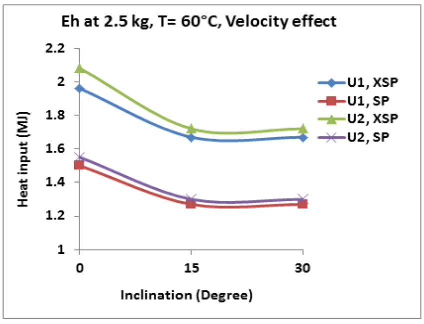

(f)

Figure 5 Plots showing the comparison of heat input (E_h) with and without the use of spirals, for different input parameters during paddy drying.

Figure 5 (a) & (b) indicate decrease in heat input with increase in bed inventory with the use of spirals. Heat input for drying 1 kg paddy (E_{hu}), at a load of 2.5 kg with drying air temperature 60°C and velocity U_1 reduced 24% when spirals were used. At load of 0.5 kg, the reduction in E_{hu} with the use of spirals under the same conditions is 14.4% and 20.83% respectively for the vertical bed and inclined bed. The corresponding reduction E_{hu} (Fig. 5(b)) at air velocity U_2 are 27.74% for load of 2.5 kg and 24.54% for 0.5 kg, respectively when spirals were used. Figs. 5 (c) & (d) indicate that the use of spirals reduced E_{hu} by 21% when spiral were used for drying paddy at a load of 2.5 kg at air temperature of 55°C, whereas, the reduction was 26% at air temperature of 65°C. Figure 5 (e) & (f) show the use of spirals reduced E_{hu} by 24% for air velocity U_1 and 25.7% for U_2 for drying paddy at a load of 2.5 kg with dryer air temperature 60°C. E_{hu} reduced by average 26% with the use of spirals compared to the dryer without spirals, for all drying conditions.

IV. CONCLUSION

The drying characteristics of bubbling fluidized bed paddy dryer with three bed inclinations, three inlet temperatures, and two air velocities for different bed sizes were investigated. The energy consumptions were lower for the inclined bed compared to the vertical bed dryer. The blower energy consumption decreased by 28% with 10˚C increase in air temperature. Blower energy consumption and heat input decreased 15% when the dryer was used in inclined position. In addition, blower energy consumption and heat input decreased 26 % in the dryer with the use of spirals. The results indicate highest drying efficiency and minimum energy consumption for the inclined bubbling fluidized bed dryer with spirals. Modification of dryer design could reduce drying time and energy consumption significantly.

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