Effect of Spirals in an Inclined Bubbling Fluidized Bed Paddy Dryer

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***Abstract*—Present paper deals with the effect of passive inserts and inclination of dryer on drying of cereal grains 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 of 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 were observed with bed inclination of 15° due to the secondary motion created due to the pressure difference between the vertical faces of the dryer. Use of spirals enhanced better mixing of paddy, reduces time for drying as well as reduces energy consumption significantly.**

Keywords— spirals, paddy, inclined, fluidized bed, energy consumption

I. INTRODUCTION

Drying is removal of moisture from the solid by evaporation. It is the most common form of food preservation and it provides the easier handling of product. Paddy drying is important in all paddy-producing countries and it is the most critical operation after harvesting rice crop for reducing the loss due to pest and fungal attack in addition to the requirement of long storage life and lower transportation cost. Delay in drying, incomplete drying or ineffective drying will reduce grain quality and enhance post-harvest losses. Paddy is usually harvested at high moisture content in tropical countries.

In Asia, open sun drying was used for drying agricultural and food products. It is the most widely practiced form of drying in the developing countries because it is cheap, easy and convenient. Even though sun drying requires little capital or expertise, the drawbacks associated with this method of drying food products are mainly undesirable changes in the quality of food products, extremely weather dependent, loss in nutritional value, lack of sufficient control during drying, long drying time, labor intensive, contamination of the product with soil and dust, non-uniformity of dried products, and large space requirements. Thus new technology is required in the Ease of Use drying process and dryers have an important role for processing and preservation of different foods and material.

Drying methods such as: combined microwave or infrared–hot air drying [Das et al. (2009), Sangdao et al. (2011)], super-heated steam drying [Soponronnarit and Prachayawarakorn (2006)] and spouted bed drying [Evin et al. (2008)] have been reported. However, the cost of these drying equipments is significantly high. Fluidized bed drying was found to be a better choice in terms of drying efficiency. Fluidized bed dryers have successfully been used for drying of products such as rough rice, maize, wheat seed, sweet potato, soya-bean and apple.

Veerachandra et al. (2013) reported that drying method and drying temperature have significant effect on drying time. Khanali et al. (2012) carried out fluidized bed drying experiments for rough rice. Thao (2011) carried out experiments for establishing the drying behavior of sweet potato starches under tray, infrared and fluidized bed drying. Srzednicki et al. (2010) conducted drying experiments in the fluidized bed dryer and spouted bed dryer using maize, rice and wheat seed. Naret Meeso et al. (2011) observed that combined near infrared radiation and fluidized-bed drying reduced cracking and breakage of soybean grains. Momenzadeh and Zomorodian (2011) researched shrinkage of shelled corn in microwave-assisted fluidized bed drying. 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. Karbassi and Mehdizadeh (2008) treated the rough rice, medium and long grain in the fluidized bed drier. Hideo INABA et al. (2006) studied the effects of heat and mass transfer parameters on the efficiency of fluidized bed drying.

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. The dynamics and structure of a fluidized bed in inclined columns was investigated experimentally by Yakubov et al. (2007).

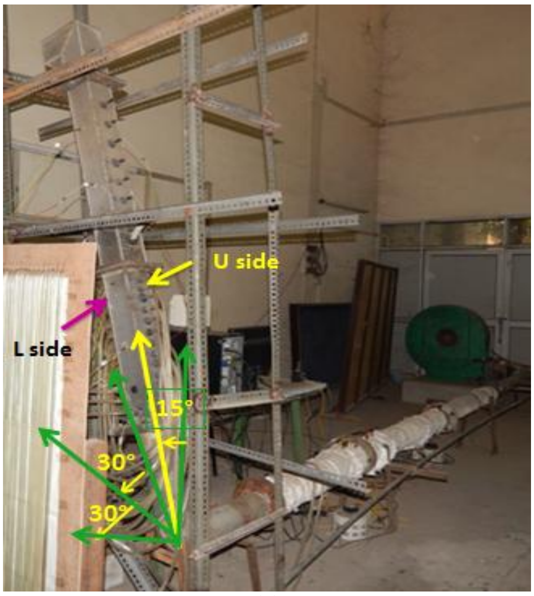
The performance evaluation of an industrial inclined bed dryer to evaluate the impact of drying temperature and air flow on energy consumption and quality of rice during paddy drying was carried out by Sarker et al. (2014). Law et al. (2004) experimentally investigated the effect of vertical baffles in batch fluidized bed dryer. The study involving installation of inner vertical baffles revealed improvement in the performance of the fluidized bed dryer. Weerachet Jittanit et al. (2010) used the fluidized bed dryer as the first stage dryer for industrial drying of paddy. Niamnuy and Devahastin (2005) used an industrial scale batch fluidized bed dryer for drying chopped coconut pieces and reported that the quality of the dried material was influenced by the inlet air velocity and drying temperature. Tasirin et al. (2007) observed that the bird's eye chillies dried using fluidized bed dryer were better in quality compared to those dried under the sun.

The advantages of fluidized bed technology in drying application are mainly large contact surface area between solids and gas, high thermal efficiency with uniform and closely controllable temperature in the bed which was promoted by intensive solid mixing due to the presence of bubbles, rapid transfer of heat, less drying time, high reliability and low maintenance cost.

Drying is the most energy-intensive operation due to the high latent heat of evaporation. 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 facilities along with good quality of dried products. In the present paper an inclined fluidized bed dryer with spirals inside the dryer column for obtaining good mixing of solids and gases was used for drying paddy. The hydrodynamics behavior of the vertical and inclined beds and drying characteristics such as moisture removal rate, effect of load, temperature, velocity, bed inclination and effect of spirals on the energy consumptions during drying were investigated.

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, orifice plate, distributor plate, dryer column, manometer, thermocouples and data acquisition system. Spirals were used inside the dryer column to improve the heat transfer and to reduce the drying time. The desired inclination of the dryer was achieved by the inclination flange with 15° interval which was 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 as shown in Figure 1(a). The pressure drop was measured by the manometer using water as the manometer fluid. Readings were taken every 10 minutes of drying. 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}. The blower was switched on and air mass flow rate and velocity were adjusted by means of a 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 K-type thermocouple and it was calibrated at the laboratory before starting and using data recording. The required weight of paddy was loaded into the bubbling fluidized bed dryer. The pressure at different sections of the dryer column was recorded to obtain the pressure drop across the bed for various air flow rates. Sample of paddy was taken out at 10 minutes interval for determination of the moisture content using digital grain moisture meter with an accuracy of ±0.5%. For the determination of the paddy moisture content, the moisture meter was pre-calibrated using the standard oven method. The experiment was terminated when the moisture content in the paddy attained 12%. The photographs of the dryer column with and without spirals are shown in Figure 2 (a) and (b) respectively whereas the photograph of the spiral is shown in Figure 3.



(a)

Fig. 1 Bubbling fluidized bed dryer (a) 15° inclination

(b)
Fig. 1 Bubbling fluidized bed dryer (b) 0° inclination

(a) (b)

Fig. 2 Fluidized bed dryer column
(a) without spirals (b) with spirals

Fig. 3 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.

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

where *U* is superficial velocity

For orifice plate, superficial velocity is

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

where $\dot{m}_a$ is mass flow rate of air, ρ is density of air, A_b is cross sectional area of dryer and ΔP is pressure drop

Mass flow rate of air is

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

B. Energy consumption

The main performance factor to be considered in assessing the performance and acceptability of a dryer is the specific energy consumption. Lower the specific energy, the higher the acceptability by the industry. 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

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

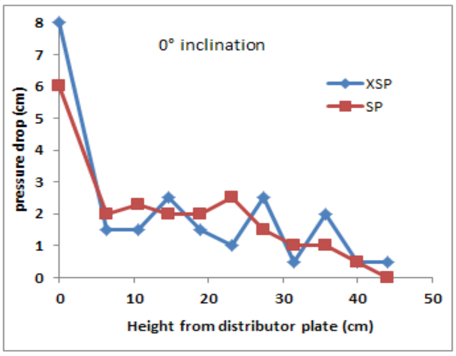
where *Q* is heat input *V* is input voltage, *I* is Ampere, *t* is time (minute) and *P.F* is power factor.

III. Results And Discussion

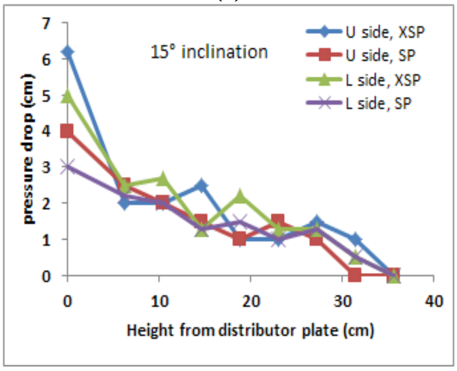
From the experiment hydrodynamics behaviour of the vertical and inclined beds, drying characteristics such as the effect of bed inclination, load, temperature, air velocity and spirals on the moisture removal rate, and energy consumption were investigated. The results obtained are presented in the subsequent sub-sections.

A. Hydrodynamics behaviour of the system

Hydrodynamic behaviour of the system was investigated via system pressure drop and fluidization height. The manometer readings from each pressure tapings during the drying process were recorded at an interval of every 10 minutes and the pressure drop determined. In the inclined fluidized bed, one side of the column was named as lower side (L side) and another side as the upper side (U side). The pressure drops from the both sides of the column were different for the inclined bed. For the inclined bed, two air motions; (i) clock-wise and (ii) counter clock-wise direction, accompanied by swirling were observed. The pressure drop was very high across the distributor plate. Pressure drops were fluctuating at the intermediate height from the distributor plate and finally it became stable. System pressure drop and fluidization height for a bed inventory 2 kg , U_1 (=1.1 m s^{-1}), T = 60 °C, and bed inclinations of 0°, 15° and 30° for the fluidized bed dryer without spirals (XSP) and with spirals (SP) are shown in figure 4 (a) to (c).



(a)



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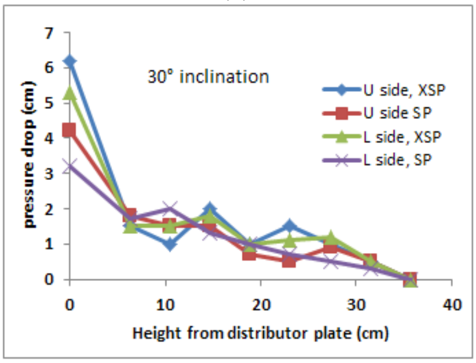


(c)

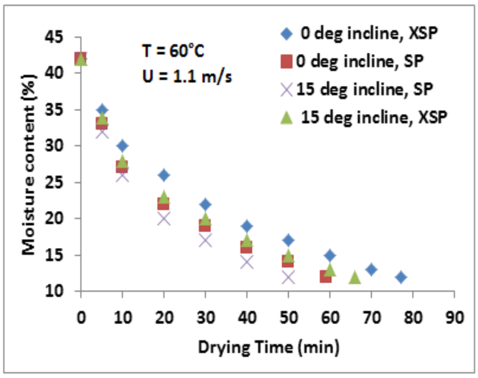
Fig. 4 System pressure drop and fluidization height (a) 0° inclination (b) 15° inclination (b) 30°inclination

It was observed that fluidized bed pressure drops decreased in the dryer with spirals. Maximum bed pressure drop across the distributor plate for 0° bed inclination was around 8 cm with the use of spirals where as it was 6 cm when used without the spirals.

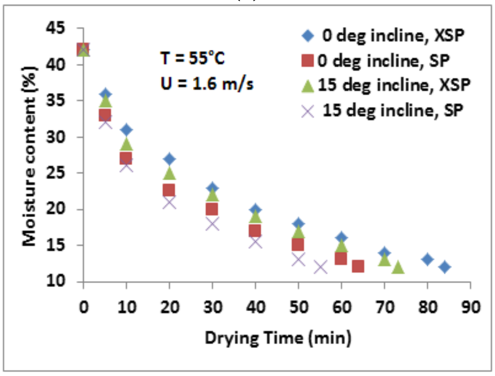
For the bed inclinations of 15° and 30° the maximum bed pressure drops at the distributor plate were around 6 cm at U side and 5 cm at L side when drying was carried out without spirals. The corresponding pressure drops decreased to 4 cm at U side and 3 cm at L side when dried using spirals. The plot of pressure drop vs. height from distributer plate indicates fluctuations at intermediate positions and became stable at around 45 cm height for the 0° inclined dryer. For the 15°and 30° incline dryers, the pressure drop stabilized at a height of 35 cm from the distributor plate. Presence of spirals inside the drying chamber reduced pressure drops and improved the particle mixing. This enhanced the heat transfer characteristics resulting in faster drying and lower energy consumption compared to the drying without the use of spirals.

B. Drying characteristics

The reading obtained for the moisture removal rate 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. The moisture removal rates for the fluidized bed dryer with and without the use of spirals for a bed inventory 2.5 kg, air velocities U_1 (=1.1 ms^{-1}) and U_2 (=1.6 ms^{-1}) and different temperatures are shown in figure 5 (a) to (d).



(a)



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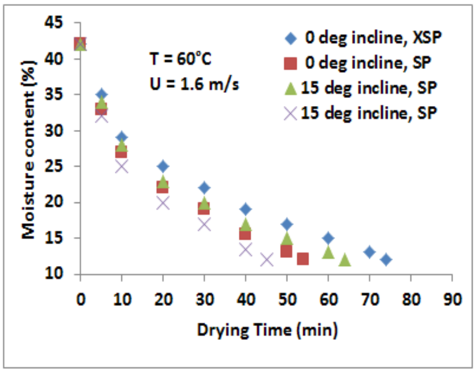

(c)

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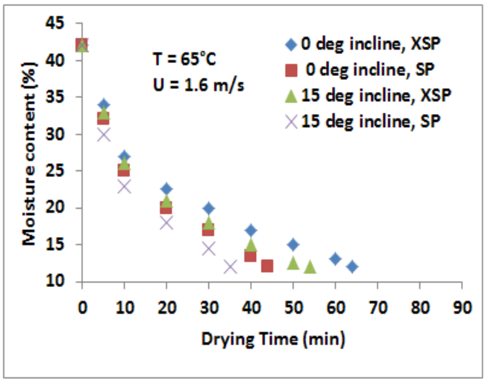


(d)

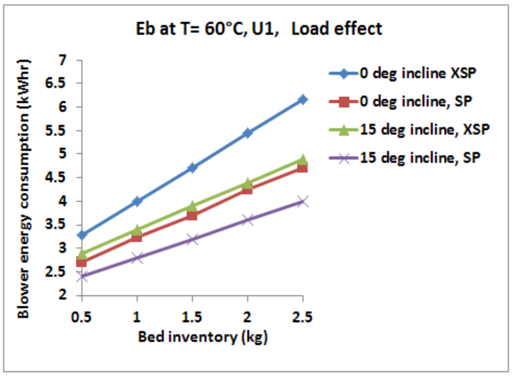
Fig. 5 Moisture content vs. drying time plots for
(a) T = 60°C and U_1, (b) T = 55°C and U_2
(c) T = 60°C and U_2 (d) T = 65°C and U_2

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. The initial drying rate increased with increase in air temperature. From the figures it is evident that use of spirals decreased the drying time by around 20 minutes compared to the drying without the use of spirals for the drying conditions studied. Fluidized bed drying is found to be more efficient with the inclined bed compared to the vertical fluidized bed dryer.

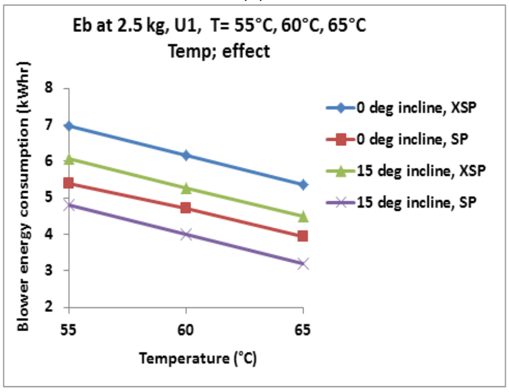
C. Energy consumption

Figure 6 shows the plots of effect of (a) load at U_1, (b) temperature at U_1, (c) velocity, (d) load at U_2 (e) temperature at U_2 and (f) bed inclination on the blower energy consumption when dried with and without the use of spirals.

Figure 6 (a) shows that at the input velocity of U_1 (= 1.1 $m.s^{-1}$) and temperature 60°C, the blower energy consumptions were (6.16, 5.44, 4.72, 4 and 3.28) kW.hr in the vertical bed and (4.86, 4.32, 3.78 and 3.24) kW.hr in the 15°inclined beds for bed inventories (2.5, 2, 1.5, 1, 0.5) kg, respectively when dried without the use of spirals. The energy consumption decreased by around 50% when the bed inventory was reduced from 2.5 kg to 0.5 kg. i.e. using higher load in the dryer is found to be more economical compared to using lower load during drying. Similar trend, as shown in figure 6 (d), is observed for the input velocity U_2 (=1.6 $m.s^{-1}$)



(a)



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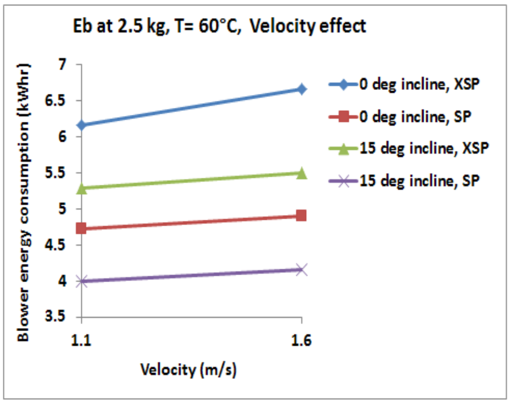

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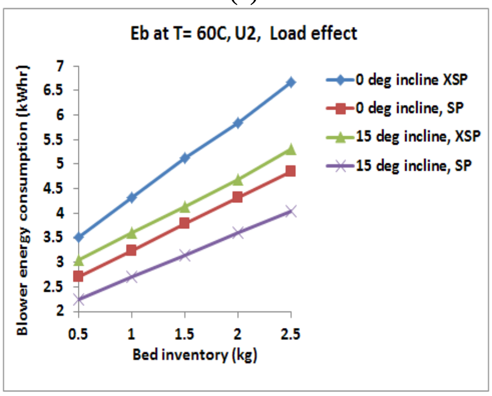
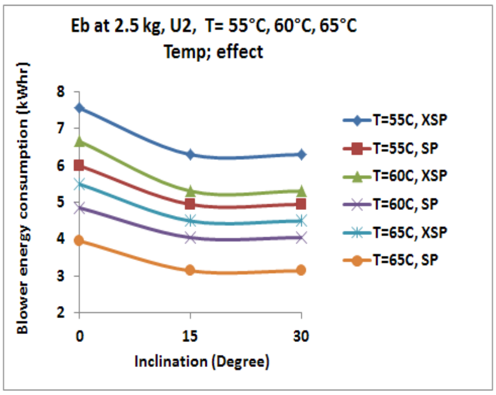


(d)



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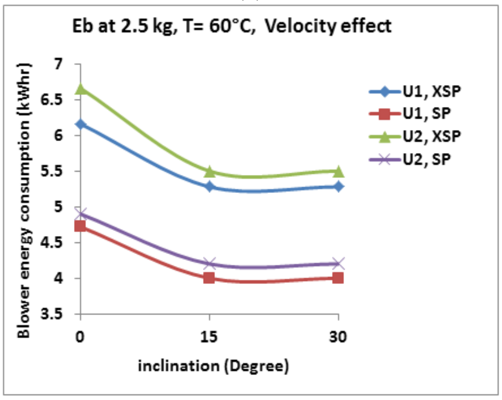


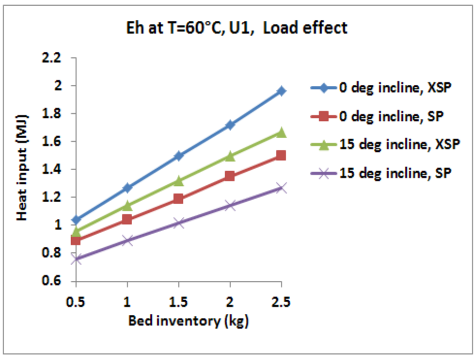
(f)

Fig. 6 plots showing the effect of (a) load at U_1, (b) temperature at U_1, (c) velocity, (d) load at U_2 (e) temperature at U_2 and (f) bed inclination on the blower energy consumption

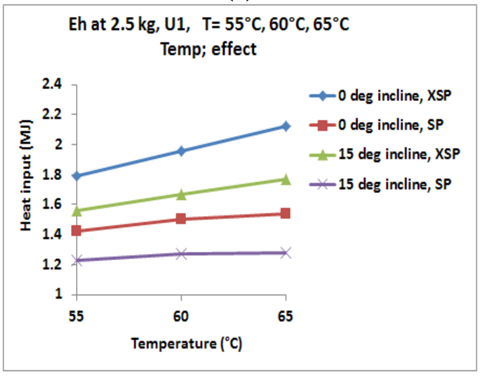
Figure 6(b) shows the effect of temperature on the blower energy consumption. The figure indicates blower energy consumptions of (6.96, 6.16 and 5.36) kW.hr for the vertical bed and (6.08, 5.28 and 4.48) kW.hr for the inclined beds at air temperatures of 55°C, 60°C and 65°C respectively for a bed inventory 2.5 kg. The blower energy consumptions are inversely proportional to the air temperature. The blower energy consumption decreased by 25 % when the air temperature was increased from 55°C to 65°C. When the temperature was high the blower energy consumption was low. Figure 6(e) indicates similar trend in results for the air velocity U_2. Since drying at temperature leads above 65°C would lead to dis-coloration, cracking and non-uniform drying, drying at higher temperatures were not attempted and the optimal temperature for paddy drying was considered as optimal.

Figure 6 (c) shows the effect of air velocity on the blower energy consumption. The blower energy consumptions of 6.16 kW.hr for the vertical bed and 5.28 kW.hr in the inclined beds at U_1 and 6.66 kW.hr in the vertical bed and 5.31 kW.hr in the inclined beds at U_2 for a bed inventory 2.5 kg load when paddy was dried without spirals. The figure indicates that the blower energy consumptions is directly proportional to the velocity. The blower energy consumptions increased by 8 % when the air velocity was increased from U_1 to U_2. The blower energy consumptions reduced by 15 % when the bed inclination was increased from 0° to 15°. The blower energy consumption in all cases reduced by 26 % when spirals were used during drying compared to the drying without spirals.

Figure 7 shows the plots of effect of (a) load at U_1 (b) temperature U_1 (c) velocity and (d) load at U_2 (e) temperature at U_2 (f) bed inclination during drying of the paddy with and without the use of spirals.



(a)



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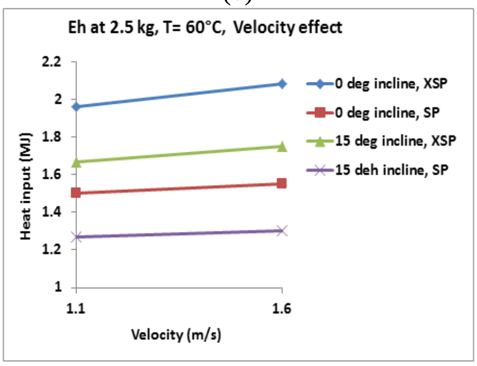

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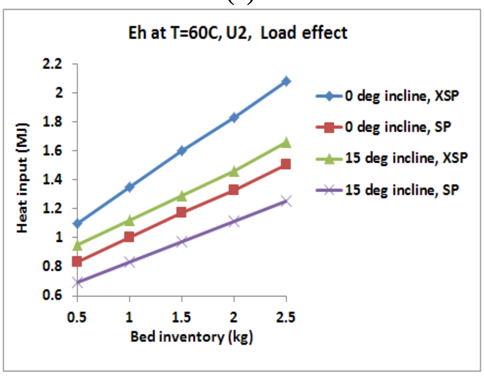

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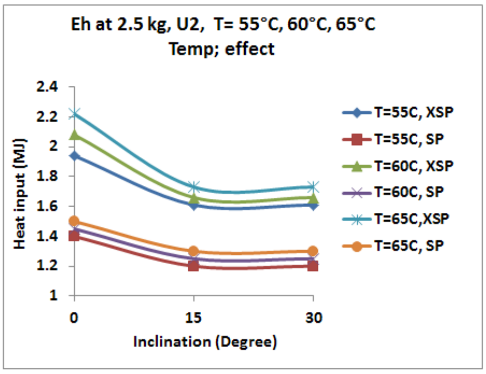

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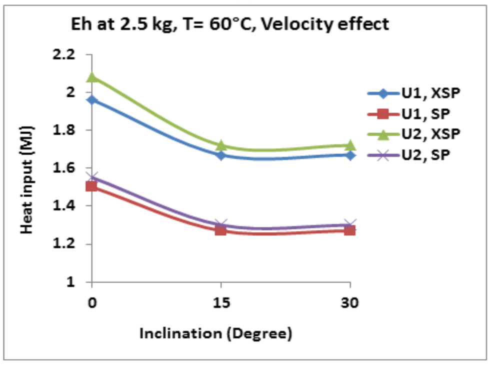

(f)

Fig. 7 Plot of heat input vs. (a) load at U_1 (b) temperature U_1 (c) velocity and (d) load at U_2 (e) temperature at U_2 (f) bed inclination, during drying

Figure 7 (a) shows that at the input velocity of U_1 (= 1.1 $m.s^{-1}$) and temperature 60°C, the heat input values were (1.96, 1.72, 1.5, 1.27 and 1.04) MJ in the vertical bed and (1.67, 1.5, 1.32, 1.14 and 0.96) MJ in the 15°inclined beds for bed inventories (2.5, 2, 1.5, 1, 0.5) kg, respectively when dried without the use of spirals. The heat input decreased by around 50% when the bed inventory was reduced from 2.5 kg to 0.5 kg. i.e. using higher load in the dryer is found to be more economical compared to using lower load during drying. Similar trend, as shown in figure 7 (d), is observed for the input velocity U_2 (=1.6 $m.s^{-1}$)

Figure 7 (b) shows the effect of temperature on the heat input. The figure indicates heat input values of (1.79, 1.96, 2.12) MJ for the vertical bed and (1.56, 1.67, 1.77) MJ for the inclined beds at air temperatures of 55°C, 60°C and 65°C respectively for a bed inventory 2.5 kg. The heat input values are inversely proportional to the air temperature. The heat input increased by 16 % when the air temperature was increased from 55°C to 65°C. Heat input is directly proportional to the temperature. Figure 7 (e) indicates similar trend in results for the air velocity U_2.

Figure 7 (c) shows the effect of air velocity on the heat input. The heat input values of 1.96 MJ for the vertical bed and 1.67 MJ in the inclined beds at U_1 and 2.08 MJ in the vertical bed and 1.68 MJ in the inclined beds at U_2 for a bed inventory 2.5 kg load when paddy was dried in without spirals. The figure indicates that the heat input is directly proportional to the velocity. The heat input increased by 8 % when the air velocity was increased from U_1 to U_2. The heat input reduced by 17 % when the bed inclination was increased from 0° to 15°. The heat input in all cases reduced by 26 % when spirals were used during drying compared to the drying without spirals.

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 was investigated. The hydrodynamic behavior of the system was investigated with and without spirals inside the dryer column. The pressure drops were lower for the dryer when spirals were used. Due to the proper motion of air flow the heat transfer rate increased and drying efficiency of the dryer increased with the use of spirals in the fluidized bed. The energy consumptions were lower for the inclined bed compared to the vertical bed dryer. The blower energy consumption reduced by 25 % with 10 °C increase in the air temperature and increased by 8% with increase in air velocity. The results indicate highest drying efficiency and minimum energy consumption for the inclined fluidized bed dryer with spirals.

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