Design and development of desiccant seed dryer with airflow inversion and recirculation

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Abstract A desiccant seed dryer has been developed to dry seed in deep bed at safe temperatures for good shelf life and germination. The dryer consists of two chambers viz., air conditioning control unit and seed drying chamber. It operates in seed drying mode and desiccant regeneration mode. It has provision for recirculation of the drying air to minimise the moisture removal from drying air. Also, it has provision of airflow inversion through deep seed bed for uniform drying. Moisture removal from drying air has been done using silica gel desiccant. Chilly ‘Punjab Surakh’, Chilly ‘Punjab Guchhedaar’, Paddy, Coriander, Fenugreek and Radish seeds was dried with hot air at 38 °C from initial moisture content of 26.9 to 5 % (wb) in 2 h, 46.52 to 4.19 % (wb) in 4.25 h, 13.3 to 2.61 % (wb) in 4 h, 13.4 to 10.08 % (wb) in 3 h, 12.4 to 8.22 % (wb) in 4¼h and 10.6 to 6.08 % (wb) in 4 h respectively. The statistical analysis based on paired *t*-test showed that seed drying in this dryer has no adverse effect on seed germination.

Keywords Seed dryer · Desiccant · Hot air · Moisture content · Seed germination · Regeneration

Introduction

Seed with lower moisture content and higher germination rate fetch higher market price. To achieve low moisture content, normally seed are dried at 55–60 °C air temperature; but at these temperatures seed germination level falls (Tang and Sokhansanj 1993; Correa et al. 1999; Kumar et al. 2011). A number of studies (Gowda et al. 1990; Sarada et al. 1994; de Valentini et al. 1999; K’Opondo et al. 2011) have reported that the drying air temperature should not be above 40 °C for good seed germination. However, drying air at temperature below 40 °C is not able to dry seed to low moisture content due to higher relative humidity of drying air. Othmer (1979) found that low moisture content of seed can be achieved at low drying air temperature by dehumidifying air. Therefore, drying of seed to low moisture content without losing its germination requires seed drying at low temperature with dehumidified air.

Different studies have been reported for seed drying at low temperature with dehumidified air using either vapour compression dehumidifier (Adapa et al. 2002) or desiccant dehumidifier (Danzieger et al. 1972; Graham et al. 1983; Sturton et al. 1983; Kundu et al. 2001; Zhangyong et al. 2002; Dhaliwal et al. 2006, 2009; Ondier et al. 2010).

A cabinet dryer was developed for low temperature (25–45 °C) drying of alfalfa using vapour compression dehumidifier (Adapa et al. 2002). It employed recirculation of air to conserve energy and a moving tray arrangement to achieve uniform and faster drying. Chopped alfalfa was dried from 70 % moisture content to 10 % moisture content in 5 h and 4 h in the fixed tray drying and in the moving tray drying, respectively. The main drawback of this dryer was that there was loss of dehumidified air to the environment due to opening and closing of manual butterfly valves used to maintain the drying air temperature.

Seeds of corn, wheat, and oats were dried by intimately mixing them with desiccant (Graham et al. 1983; Sturton et

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al. 1983). The drying of corn, wheat, and oats using desiccants based on drying kinetics and seed quality was found to be promising. Similar study for drying of corn and soybean seeds have been reported by Danzieger et al. (1972) and Zhangyong et al. (2002), respectively. Kundu et al. (2001) carried out investigations on sorption drying of mustard, sunflower, soybean and groundnut oilseeds in fluidized bed of seeds and silica gel under different conditions of drying air temperature, bed height, feed rate, initial moisture content and flow rate of hot air. The drying results were found to be satisfactory based on drying kinetics.

To avoid dehumidified air loss to the environment during forced circulation air drying, closed circulation dryers have also been reported (Dhaliwal et al. 2006, 2009; Ondier et al. 2010). Ondier et al. (2010) developed a dryer for thin-layer drying of long-grain rice and medium-grain rice from initial moisture content of 19.6 % and 17.5 % respectively. Air at low temperatures (26–34 °C) was used to dry rice to desired moisture content of 12.5 %. It was found that dehumidification of the drying air had greater potential for increasing drying rates at 26 °C than at 30 °C and 34 °C. Low drying air temperatures and relative humidities had no adverse effects on quality of rice. Dhaliwal et al. (2006) developed a desiccant seed dryer for drying seed in thin layer using recirculation of drying air. The air was recirculated through a desiccant bed of silica gel to dehumidify the drying air. Onion seed was dried from initial moisture content of 8 % to final moisture content of 4.5 % with 40 °C drying air in 7 h. This dryer occupied more space due to its spread out components. To make it compact, Dhaliwal et al. (2009) developed a compact desiccant thin layer seed dryer that worked on same principle. It was tested for drying carrot and farm fresh brinjal seeds to moisture content of 5 % (wb) without lose in germination.

The closed circulation dryers discussed above were designed for thin layer drying. These dryer are not able to dry seed in deep bed as in deep-bed seed drying, the seed in lower layer of the bed gets over dried in the process of achieving required moisture content in top layer of the bed (Chakraverty 2008). This over drying of seed in the lower layer of seed bed tends to impair its germination (Bewley and Black 1985). The present work was taken up to develop desiccant seed dryer for deep bed seed drying. It has a provision of air flow inversion through seed bed for uniform deep bed drying and was tested for chilly, paddy, coriander, radish and fenugreek seeds.

Materials and methods

Description of desiccant seed dryer A desiccant seed dryer of 2 kg capacity shown in Fig. 1, has been designed and fabricated at Punjab Agricultural University, Ludhiana,

Fig. 1 Photograph of desiccant seed dryer

India. It has two chambers viz., air conditioning control unit and seed drying chamber, so as to have airflow inversion. The air conditioning control unit supplies drying air at low temperature and low relative humidity to seed drying chamber and the drying chamber holds seed to be dried. The seed drying chamber and air conditioning control unit are connected using an arrangement of G.I. pipes of 50 mm diameter. A single-phase 1 hp electric air blower was used to circulate air through the seed dryer. To control the direction of air flow in two chambers, eight gate valves were fitted in GI pipes arrangement.

The details of the air conditioning control unit and seed drying chamber are given below:

Air conditioning control unit: As shown in Fig. 2, the air conditioning control unit consists of desiccant bed, heat exchanger, air distributor and electric air heater. This unit is made of galvanized iron (G.I.) sheet having length 350 mm, width 310 mm and height 550 mm. Desiccant bed is designed to dry 2 kg of seed in 6 h. The design details of desiccant bed are given in Appendix-A (Dhaliwal et al. 2009). The desiccant bed has length 350 mm, width 310 mm and height 250 mm. The crystals

Fig. 2 Schematic of air conditioning control unit and seed drying chamber

of silica gel are used as desiccant. The silica gel crystals are supported on wire mesh.

The heat exchanger is of 'tube-and-fin' type (Fig. 3). The design detail of heat exchanger is given in Appendix-A (Dhaliwal et al. 2009). It has 24 copper tubes of 16 mm diameter each, arranged in 8 columns and 3 rows. Distance between two consecutive columns of pipes is 40 mm and between consecutive rows is 50 mm. These pipes are connected in such a manner that there is a single entry and a single exit of water. These pipes have 16 identical parallel copper fins of 295 mm × 160 mm in size and consecutive fins spacing is 15 mm. For good thermal contact, pipes and fins are brazed together.

The air distributor has three pipes of 1.25 cm diameter and 28 cm long, and each pipe has 13 holes of 3 mm diameter on the lower side for proper distribution of air. For air heating, a 200 W electric air heater consisting of 10 heating strips inclined at 45° with horizontal was used.

Seed drying chamber: The rectangular seed drying chamber is made of 26 gauge thick G.I. sheet having length 210 mm, width 160 mm and height 420 mm (Fig. 2). It has a seed container made of 26 gauge aluminium sheet of length 160 mm, width 110 mm and height 315 mm with wire mesh base having 144 holes in 1 cm² area. A removable wire mesh is provided on the top of seed bed to avoid the flow of seed with drying air. This is because as the drying proceeds the seed gets lighter and tend to flow with drying air. The seed container is insulated with 25 mm thick thermocol. The seed drying chamber is placed on a digital electronic balance which directly indicates the weight of seed in the seed container during drying. The seed drying chamber is connected at the top and bottom with

Fig. 3 Fin and tube type heat exchanger

G.I. pipes using the rubber pipe in the form of bellows which do not affect the weight indicated on the balance. The dryer operates in two modes viz. seed drying mode and desiccant regeneration mode. In seed drying mode, drying air is recirculated between the air conditioning control unit and seed drying chamber as shown in Fig. 4. The hot air entering air conditioning control unit is first cooled in heat exchanger to enhance the adsorption capacity of desiccant. For uniform air distribution in heat exchanger, air passes through an air distributor provided before heat exchanger. The cooled air then passes through desiccant bed for dehumidification. From there it is heated in electric air heater to desired temperature before it is supplied to seed drying chamber for seed drying. In the seed drying chamber, the direction of air flow through seed bed is changed from 'top-to-bottom' to 'bottom-to-top' after every half an hour to achieve uniform drying of seed. The hot air after removing moisture from seed in seed drying chamber re-enters the air conditioning control unit to start a new cycle. As the air is being re-circulated (closed loop) in the dryer, the desiccant only needs to remove moisture which is picked up by drying air from the seed bed. The system is designed in such a way that the desiccant gets saturated after one seed drying batch and needs to be regenerated for drying next batch.

In desiccant regeneration mode, the desiccant is regenerated with hot air in open loop (Fig. 5). The hot air is sucked from solar air heater. Air heated in solar air heater is then brought to desired temperature using thermostatically controlled supplementary electric air heater before supplying to desiccant bed. The air after desorption of moisture from desiccant is exhausted to atmosphere.

The flow rate of air was measured by an orifice plate having 2.5 cm orifice diameter fitted in a 5 cm diameter pipe. Pressure drop across the orifice plate was measured with U-tube water manometer. A temperature controller was used to control the temperature of air by switching the electric air heater. For regeneration of desiccant, temperature sensor (Iron-Constantan thermocouple) is provided in the airflow just before desiccant bed for controlling air temperature. For controlling temperature of air during seed drying, one temperature sensor (Iron-Constantan thermocouple) is provided at the top and one temperature sensor at the bottom of seedbed. The top sensor is used when the airflow is from top-to-bottom while the bottom sensor is used when the airflow is from bottom-to-top.

Testing The desiccant seed dryer was tested both in laboratory and in an industry (M/s Plantsmans Landscapes and

seeds, Patiala, Punjab, India) to dry Chilly, Paddy, Coriander, Fenugreek and Radish seeds.

During drying in laboratory, two varieties of chilly seeds namely ‘Punjab Surakh’ variety and ‘Punjab Guchhedaar’ variety were tested for drying. Seed of ‘Punjab Surakh’ were rewetted overnight before drying due to its low initial moisture content (7 % (wb)). After rewetting, 2 kg seed with initial moisture content of 26.9 % (wb) was loaded in dryer. Chilies of ‘Punjab Guchhedaar’ were procured and seed were extracted from chilies using machine based on wet extraction principle (Appendix B). After wet extraction, 1.69 kg seed with initial moisture content of 46.5 % (wb) was loaded in dryer. The flow rate of drying air through seed bed was 0.106 m³/s. During the experimental run, the air flow was reversed every half an hour. For air flow from bottom-to-top, the valves X1, X2, X4, X6 and X8 were closed while the valves X3, X5 and X7 remained open as shown in Fig. 4. To reverse the air flow (top-to-bottom), the valves X3, X5 were closed and X2, X4 were opened while keeping other valves in same position. Water at 25 °C was circulated through the heat exchanger. The temperature at the inlet of seed drying chamber was maintained close to 38 °C. For moisture content determination, samples of the seed at five levels in seed bed were collected after every 2 h. The moisture content was determined by Oven method (AOAC 2000). Five samples of seed were collected before and after drying to determine germination of seed. The paired *t*-test was used to determine adverse effect of seed drying on germination.

Fig. 4 Schematic of desiccant seed dryer showing air flow path in seed drying mode

During drying in industry, paddy seed (2.26 kg) with initial moisture content of 13.0 % (wb), Coriander seed (1.22 kg) with initial moisture content of 13.5 % (wb), Radish seed (2.04 kg) with initial moisture content of 10.3 % (w.b.) and Fenugreek seeds (2.06 kg) with initial moisture content of 12.2 % (wb) were loaded for drying test. The testing procedure was same as that of drying test in laboratory. In this, the seed samples for moisture content determination were collected after every hour.

The desiccant was regenerated after each batch of seed drying. During regeneration, the valves X2, X3, X4, X5 and X7 were closed while valves X1, X6 and X8 were kept opened as shown in Fig. 5. The air temperature at the inlet of desiccant bed was maintained at 80 °C. The flow rate of regeneration air through desiccant bed was 0.106 m³/s. The regeneration was done for 4 h as per Singh and Singh (1997).

Results and discussion

Figure 6 shows the variation in moisture content with drying time of chilly (‘Punjab Surakh’ and ‘Punjab Guchhedaar’), paddy, coriander, fenugreek and radish seeds. For chilly seeds, results showed a high rate of moisture removal at the initial stages of the drying process followed by a gradual leveling of the drying curve. This higher rate of moisture removal at the initial stages is due to surface moisture and it ends where all surface is no longer wet. The gradual leveling

Fig. 5 Schematic of desiccant seed dryer showing air flow path in regeneration mode

of the drying curve is due to the inability of the moisture to be conveyed from the centre of the seed to the surface at a rate comparable with moisture evaporation from the surface of seed to the surroundings. Similar results on seed drying are reported in literature (Dhaliwal et al. 2006, 2009; Ondier et al. 2010). For Punjab Surakh chilly seed, the moisture content was reduced from 26.9 to 5 % (wb) in 2 h and was finally reduced to 2.8 % (wb) in 7 h. Its germination remained same (70 %) before and after drying. For Punjab Guchhedaar chilly seed, the moisture content was reduced from 46.52 to 4.19 % (wb) in 4.25 h and 3.75 % (wb) moisture content was achieved in 6.25 h. Its germination

before and after drying was 78.3 %. Based on paired *t*-test, the *p*-value of Chilies seeds of ‘Punjab Surakh’ variety and ‘Punjab Guchhedaar’ variety are 0.3 and 0.5 respectively. The *t*-test shows that the germination of seed before and after drying does not differ significantly because $p > 0.05$. This concludes that drying does not impair seed germination of chilly.

Seeds of paddy, coriander, fenugreek and radish were dried from initial moisture content of 13.3 to 2.61 % (wb) in 4 h, 13.4 to 10.08 % (wb) in 3 h, 12.4 to 8.22 % (wb) in 4.25 h, 10.6 to 6.08 % (wb) in 4 h respectively (Fig. 6). For these seeds, gradual levelling of drying curves and absence of constant rate period is observed. The absence of constant rate period is due to no surface moisture as the drying started at lower moisture content level. The average germination of paddy, coriander, fenugreek and radish seeds before drying was 72 %, 82 %, 80 %, 50 % and after drying was 80 %, 87 %, 86 %, 56 %, respectively (Table 1). Based on paired *t*-test, the *p*-value of Paddy, Coriander, Fenugreek and Radish seeds are 0.0005, 0.0003, 0.0001 and 0.0023 respectively. The *t*-test shows that the germination of seed after drying increased because $p < 0.05$. This concludes that drying does not impair germination of the seed.

Fig. 6 Variation in moisture content with drying time for chilly seeds-Punjab Surakh variety, chilly seeds-Punjab Guchhedaar variety, paddy, coriander, fenugreek and radish seeds

Table 1 Germination of different seeds before and after drying

Name of Seed	% Germination		<i>p</i> -value
	Before drying	After drying	
Paddy	72	80	0.0005
Coriander	82	87	0.0003
Fenugreek	80	86	0.0001
Radish	50	56	0.0023

Conclusions

Low temperature seed dryers are not able to dry seed in deep bed as in deep bed seed drying, the seed in lower layers of the bed gets over dried thereby impairing its germination. To overcome this, an improved desiccant seed dryer has been developed. It works in closed loop and is designed to dry 2 kg of seed in one batch. It has a provision of air flow inversion through seed bed for uniform deep bed drying. This dryer was able to dry seeds of chilly, paddy, coriander, fenugreek and radish in deep bed to the desired moisture content level at 38 °C temperature. The seed germination was not impaired after drying as the drying was carried at low temperature using dehumidified air.

Appendix-A

(a) Design of desiccant Bed

Amount of seeds to be dried	=	2 kg
Initial moisture content of seeds	=	40 % (wb) (assumed)
Final moisture content of seeds	=	5 % (wb) (assumed)
Drying time for seeds	=	6 h (assumed)
Moisture required to be removed from 2 kg (2,000 g) of seeds	=	$2,000 \times (0.040 - 0.005)$ = 700 g
Moisture removal rate from the seeds	=	$700/6$ = 116.7 g/h
Average rate of heat release in desiccant bed	=	$((116.7/1,000) \times 2,400)/3,600$ = 0.0776 kW
Maximum heat release rate in desiccant bed using factor of safety 2	=	2×0.0776 = 0.1552 kW (say 155.2 W)
Singh and Singh (1997) estimated through experimentation on an adiabatic bed that 1 kg of silica gel adsorbs 70 g of moisture.		
Amount of silica gel required to adsorb 350 g moisture	=	$700/70$ kg = 10 kg
Density of silica gel bed (measured)	=	667 kg/m ³ of bed volume
Volume of 5 kg of silica gel bed	=	$10/667 = 0.015$ m ³
Volume of silica gel bed using factor of safety 1.5	=	0.015×1.5 = 0.0225 m ³
Silica gel bed cross-section	=	350 × 310 mm (Assumed)
Therefore, silica gel bed height	=	$0.0225/(350 \times 310)$ = 20.7 cm
Actual silica gel bed height	=	25.0 cm = 250 mm

(b) Design of heat Exchanger

Heat transfer coefficient between air and fins (h)	=	25 W/m ² °C (assumed)
Cooling water temperature	=	25 °C (assumed)
Air temperature	=	35 °C (assumed)

Approximate fin temperature	=	30 °C
Temperature difference between air and fins (dT)	=	$35 - 30 = 5$ °C
Applying, Heat transfer rate (Q)	=	$h \times A \times dT$
155.2 W	=	$25 \times A \times 5$
Required surface area of fins (A)	=	$155.2/(25 \times 5) = 1.248$ m ² = 12,480 cm ²
Assume the following arrangement to satisfy the required surface area of fins		
No of copper fin plates (29.5 × 16 cm)	=	16
No of holes in each fin to pass a piece of pipe of 16 mm diameter (8 columns, 3 rows)	=	24
No of pieces of pipe	=	24
Centre to centre distance in consecutive pieces of pipe in a row	=	4 cm (fixed by copper bends available in the market)
Centre to centre distance in consecutive pieces of pipe in a column	=	5 cm
Fin area available for heat transfer	=	$32 \times 29.5 \times 16 - 384 \times 3.14 \times (1.6)^2/4$ = 14,332 cm ² (required 12,480 cm ²)

Appendix-B

Wet seed extraction principle

The seeds of chillies were extracted from ripe chillies using an axial flow vegetable seed extracting machine (Verma et al. 1992). In this machine, ripe chillies are fed into the cutting chamber of seed extraction machine and sliced into small pieces by the rotating blades and stationary counter blades. The cut chillies enter the crushing chamber where these are further cut and crushed by the curving and crushing blades. Separation of seeds from pulp is accompanied by water sprinkling jets while the pulp is carried axially by the conveying rakes to the waste outlet. The seeds and water escape to seed outlet through the concave openings. A 5 mm concave screen is selected to suit chilly seed size. The discharge from the seed outlet is dropped on a stationary screen placed on a water tub. This screen retains the seed while the water is collected in the tub.

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