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Pre-Drying of Cereal Grains Using Exhaust Air

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There is need to dry grain quickly and effectively after harvest and before storage to retain maximum quality and to attain moisture content sufficiently low to minimise infestation by insects, micro-organisms (bacteria, fungi etc) and to prevent germination. Drying systems require substantial investment and to optimise their performance, efficient control systems are vital to minimise energy usage. This study, involved cycling of exhaust air from drying trays to pre-dry fresh grain. The drying temperatures used were 40^0 C and 60^0 C. Highest drying capacity of 3.17kg/hr occurred when pre-drying wheat with a moisture content of 21.657 % db, using a drying temperature of 60^0 C. The lowest capacity of 0.54 kg/hr was recorded when no pre-drying was carried at 40^0 C. The highest heat utilisation factor (HUF) of 87.6 % was obtained when pre-drying 17.158 % (db) wheat at 40^0 C and the lowest (26.67 %) when no pre-drying was carried on drying 21.657 % (db) wheat at 60^0C. The highest drying efficiency of 72.29 % was obtained when drying 21.657 % (db) wheat at 60^0C and the lowest (22.44 %) when no pre-drying was carried on 21.657 % (db) wheat at 60^0C. Highest thermal efficiency of 33.86 % was obtained when pre-drying 21.657 % (db) wheat at 60^0C and the lowest (7.56 %) obtained when no pre-drying was carried on drying 19.56 % (db) barley at 40^0C. The average power consumed when using a drying temperature of 40^0C and 60 ^{0}C was 1.25 kW and 1.775 kW respectively.

Good energy utilisation of pre-drying systems is supported by high HUF, overall thermal and drying efficiency, which is more than double for conventional systems. By using low temperature drying, the desired small thermal and moisture gradients can be achieved.

Key words: Drying, Efficiency, Energy, heat utilization and moisture content

Introduction

Drying has been used as to preserve food and grain crops since early civilisation **(**McLean, 1989). Though this practice of artificial drying dates back more than 100 years ago, most of the developments in grain drying have occurred in the last three decades (Brook,1992)**.** With the development of Combine harvesters, drying by natural means has been made obsolete. Drying by Sun and wind has been replaced with artificial drying. With sharp increase of energy prices over recent years, it is therefore necessary to look into ways to reduce energy consumption (Dickinson,1980).This can be achieved through use of efficient drying processes in order to reduce the total drying costs and application of heat recovery methods. Drying processes and technologies should be continuously improved in response to changing economics and technology.

Martono (1990) designed build and tested a small-scale manually operated grain dryer using propane gas as a source of heat. When operating the dryer at 60^0C, he reported a drying capacity was 66.7 Kg/hr, fuel consumption of 1.43 Kg/hr and drying rate of 2.8 %/hr. Using the same dryer, Alamirew (1992) carried out a feasibility of using photovoltaic cells for forced air ventilation. The power generated by the photocells was used to drive the fan. He obtained a drying capacity of 30.9 kg/hr; moisture reduction of 2.26 %/hr and fuel consumption of 2 kg fuel wood/hr. Based on the two projects, Nellist (1998) investigated the effect of temperature on throughput and evaluated the operation of the dryer with the objective of improving its performance. He reported moisture reduction of 2.19 %/hr, drying capacity of 67.33 kg/hr and power consumption of 3.925 kWh when using drying air at 73^0C.

The high energy requirements for drying and high exit air temperature from the small scale mechanised continuous dryer, made it desirable to carry out a thorough investigation on drying energy requirements, throughput, efficiency and possible ways of improvement.

The basis of exhaust air re-cycling is that at a given temperature and relative humidity, air has a limited capacity to pick up moisture from a product. In practice, it does not become 100 % saturated in passing through a dryer and has a potential to absorb more water vapour. On second or subsequent passes through the dryer, the air makes a close approach to saturation. This re-cycling of air that could have gone to waste improves the economics of grain drying and forms the basis of this study.

Materials and Methods

Preparation

The grain (wheat) was cleaned before drying or moisture content analysis to remove dust, chaff etc using the Westrup air screen cleaner. Moisture content analysis was carried out before wetting using the oven method. The grains were then wetted to predetermined moisture content by adding known amount of water.

Experimental

After cleaning, wetting and mixing of the grain for three days, its moisture content was then determined using the oven method. Grain of known moisture content was weighed into the six trays as shown in the equipment layout in **Figure 1**. A set of three trays, placed on the air duct (drying trays) simulate a dryer while a set of three trays (pre-drying trays) placed directly on top simulate a pre-dryer. An empty tray placed in-between these two sets of trays (drying and pre-drying) enabled temperature readings for the exhaust air from the drying trays to be taken. It is this exhaust air from the drying trays that is used to pre-dry the grain in the pre-dryer. Exhaust air temperature, grain weight and relative humidity readings were taken every 15 minutes. Temperature readings were read in the positions shown in **Figure 2**. A safe storage moisture content of approximately 13 % (Wb) was chosen, where the drying process was stopped when it was attained. This safe moisture content was determined through continual weighing and computing of new moisture content. In pre-drying system, the grain in the pre-dryer was shifted to the dryer while fresh un-dried grain was put onto the emptied trays to be pre-dried. This process of alternating the set of trays was repeated until a uniform sequence was obtained. When drying without pre-drying, the three trays are filled with the wet grain and dried to the chosen safe moisture content with same readings taken every 15 as in pre-drying. Temperature reading positions are shown in **Figure 2**. The same procedure was done with high and low moisture contents, using high and low drying temperatures. The high temperatures of about 60 ^{0}C were chosen to represent commercial drying of cereal grains and 40-42 ^{0}C to represent drying of grain seed whose embryos are killed by higher temperatures (FAO, 1994)**.** During the whole process, drying air temperature and airflow rates were kept constant. Power consumed in both systems and at the different temperatures, was measured using an electronic wattmeter.

Moisture content determination (BS 4317)

The method used was **BS 4317** identical to **ISO 712** where 5g of the sample with moisture content between 7 and 17% was ground, dried in the oven set at 130 ^{0}C for two hours then cooled in desiccator for about 30 minutes. Grain wetter than 17% was pre-conditioned by heating in the oven set at 130 ^{0}C for 10 min, left in the bench to cool for two hours, then ground and dried in the oven for 2 hours. The grain was finally cooled in a desiccator for about 30 minutes. The moisture content expressed as percentage by mass of the product as received is given by the following formulae **(**Kandala *et al*., 1996**):**

1. Without preconditioning;

$$\frac{(M_0 - M_1)(100)}{M_0}$$ Where M_o is the ground weight and M_1 is the dry weight.

2. With preconditioning

$$\left[\frac{(M_0 - M_1)(M_3)}{M_0} + (M_2 - M_3)\right]\left(\frac{100}{M_2}\right) \text{ OR } (100)\left(1 - \frac{(M_1)(M_3)}{(M_0)(M_2)}\right)$$

Where:
M_o is the ground weight.
M_1 is the final weight after drying.
M_2 is the initial weight before grinding.
M_3 is the pre-conditioning weight before grinding.

Measurement of air velocity

Constant airflow rate was set for the whole experiment. Air velocity was measured on three duct diameters 60^{0} apart downstream of the duct bend using ETA 3000 Anemotherm air meter.

Power measurement

All the connections to heaters, thermostat and the fan were made through the wattmeter. The meter calibrated when all the equipment was switched off. Where a higher drying temperature was chosen, the two heaters were alternately in use and an average power reading was taken when both heaters were on and when one of them was in use.

Temperature measurement

The thermocouples used were chrome (+) - Alumel (-) and were calibrated by inserting them inside a beaker of water and selecting the ones with same temperature readings. The temperature of the drying air was pre-set using a thermostat and by switching on a number of heaters depending on the required drying temperature. A thermocouple placed at the exit of the drying air, before the first tray, was used to monitor any temperature fluctuations in the plenum during the drying process. Temperatures at the various points in the trays were measured as shown in **Figure 2**. The relative humidity of the exhaust air was measured using dry and wet bulb thermometer placed on top of the pre-drying tray as shown in Figure 1

Results and Discussion

Moisture content (MC)

Moisture content changes (% Wb) for the two systems are as shown in **Figures 3, 4 and 5**. In pre-drying system, the top curve, which is at higher moisture content, represents pre-drying of the grain, while the lower curve at lower moisture content represents drying. Moisture content changed in the same pattern when pre-drying high and low moisture grain using high and low temperatures as seen in **Figures 3** and **4**. In **Figure 4**, the starting moisture content in both trays was 21.657 %. After 60 min, the grain (A) that was in the drying tray, had dried to a moisture content of 14.257 %, while the pre-dried grain (B), had dried to 17.153 %. The pre-dried grain (B), was shifted to the dryer and took 30 min to attain a moisture content of 14.28 % while the fresh grain (C) put into the pre-dryer had dried to 18.74 %. Grain (C), was then shifted to the dryer where it took 60 min to attain a moisture content of 13.639 % and 17.182 % for the pre-dried grain. At this point the same sequence is repeated.

In the case where pre-drying was not carried out, moisture content changes in each tray are as shown in **Figure 5**. From the graph, it takes 75 min for the average moisture content in trays A to fall to 14.191 % and 180 min for it to fall to 14.917 % when using drying temperatures of 60 and 40^0C respectively. At 40^0C, the moisture gradient is very small compared to 60^0C, which is desirable, to avoid over-drying of bottom layers and moulding of top layers of grain.

From data obtained and the three graphs it can be seen that pre-drying systems take shorter time to dry same quantity of grain to same moisture levels under same drying conditions, temperature and relative humidity. Moisture gradients in pre-drying systems are also lower than in conventional systems.

Temperature changes

The temperature changes for both systems are as shown in **Figure 6** and **Figure 7**. In pre-drying, the difference in temperature of the inlet (heated drying air), and the outlet air is high indicating that much of the energy in the drying air was used up in the drying process. From Figure 7, the difference between inlet air temperature to the pre-dryer or the outlet air from the dryer and the exit air is much larger than the inlet and outlet temperature difference for the dryer. Exit air temperature is a main determinant of drying and heat utilization efficiency, which is lower and near ambient when pre-drying is carried out using low temperatures. Similar to moisture gradient, high temperature gradients can be observed in high temperature drying. This is not desired for the same reason of over-drying the bottom layers of grain.

Drying rate (D_C)

In pre-drying of low moisture grain, the drying rate, initially increases at an increasing rate then decreases exponentially at the beginning of the drying operation as in **Error! Reference source not found.**8. When high moisture content grain is pre-dried the drying rate in the pre-drying tray at the beginning of every lot initially increases then decreases at decreasing rate like in the drying tray. This could possibly be due to moisture deposit on the upper trays or the wet zone, which finally dries up, and the grain in the tray dries exponentially as expected.

Power consumption

1. Drying air set at 40 ^{0}C.

Power = 1250 W or 1.25KW.

2. Drying air set at 60 ^{0}C.

$$Power = \left(\frac{0.25 \times 0.46}{2}\right) \times 10 \times 500 \ W$$

= 1775W or 1.775 kW.

Thermal efficiency (E_T)

The overall thermal efficiency was computed using the following formula (Hall, 1980)**:**

$$Overall\ thermal\ efficiency = \frac{(Water\ evaporated)(Latent\ heat).}{(Fuel\ Used)(Net\ heating\ value\ of\ fuel).}.$$

$$but\ \frac{(Water\ evaporated(Kg))(Latent\ heat\ (KJ/Kg)).}{(Fuel\ used\ (Kg))(Net\ heating\ value\ of\ fuel(KJ/Kg)).}$$

$$= \frac{(Water\ evaporated\ during\ the\ drying\ process\ (Kg))(Latent\ heat(KJ/Kg)).}{(Drying\ air\ mass\ flow\ rate\ (Kg/Min))(Specific\ enthalpy\ (KJ/Kg))(Time\ (min))}$$

Latent heat of water at 40^0 C and 60^0 C given as 2399.5 and 2358.9 KJ/Kg respectively (Hall, 1980). An average of 2380 KJ/Kg was used in the computation of results.

The known values of ambient and drying air conditions (temperature (T_a) and relative humidity) are used to compute the specific enthalpy of the drying air. The mass flow rate of the drying air is obtained by measuring the cross-sectional area of the duct at the point of exit and the air velocity. The following measurements were obtained:

1. Diameter of the duct/tray = 20 cm and cross-sectional area = 0.03 m^2.
2. Depth of a single tray = 4.5 cm.
3. Average air speed = 0.5 m/s.
4. Drying time = 225 minutes.
5. Weight of water evaporated = 0.17 kg.

The density of air is 1.13 kg/m^3 (Henderson *et al.,* 1997)**.** At 24 ^{0}C, 60 % RH, the specific enthalpy from the psychometric chart = 52 KJ/Kg. Heating the air to 40 increases it's enthalpy to 73KJ/Kg.

Therefore $E_T = \frac{(0.17)(2380)}{(0.03)(0.5)(1.13)(73-52)(225)(60)} \times 100\% = 8.56\,\%.$

The overall thermal efficiencies for pre-drying systems were more than double for the systems with no pre-drying as shown in **table 1**. Though the low values of thermal efficiencies could be attributed to the small grain depths used, the big differences in the overall thermal efficiencies indicates the relative benefits of pre-drying using exhaust or waste air.

Heat utilisation factor (HUF)

The heat utilization factor for pre-drying systems was found to be much higher as expected as shown in table1. This can also be seen from the exit temperature (T_e). Almost all the energy in the waste air gets used up in pre-drying and exits the system with little energy to waste. The high percentage difference therefore signifies good energy utility in the re-circulation. It also implies that by incorporating exhaust air re-circulation, we are able to improve the system performance and cut down costs by more than half.

Drying efficiency (E_D)

The thermal efficiencies were likewise found to be more than double in pre-drying systems as shown in **table 1**. They were computed using the following formula (Henderson *et al.*, 1997):

$$Drying\ efficiency = \frac{Inlet\ air\ temperature - \ Outlet\ air\ temperature.}{Inlet\ air\ temperature - Saturation\ air\ temperature} \times 100\%$$

The average saturation temperatures (T_{sat}) were obtained from the psychometric chart based on the relative humidity (RH) and the ambient dry bulb temperature.

Table 1: Summary of results

TREAT MENT	**CROP**	**MC (%)**	**T_d (^{0} C)**	**RH (%)**	**$T_{sat.}$ (^{0} C)**	**T_e (^{0} C)**	**T_a (^{0} C)**	**Time (min).**	**W_w (Kg).**	**H.U.F (%)**	**E_T (%)**	**E_D (%)**	**W_g (Kg)**	**D_C (Kg/hr)**
Pre-drying.	Wheat.	17.78	40	68	18	26.92	22.0	330	0.54	72.65	18.12	59.44	9.86	1.79
Pre-drying.	Wheat.	17.158	40	54	16	24.23	22.0	565	0.96	87.60	18.84	65.70	17.40	1.85
Pre-drying.	Wheat.	19.332	60	58	20	33.24	26.0	360	1.03	78.70	23.91	66.90	14.50	2.42
No pre-drying.	Wheat.	21.657	40	58	19	35.08	25.5	180	0.15	33.95	9.14	23.44	1.90	0.63
No pre-drying.	Wheat.	21.657	60	58	19	50.80	25.5	135	0.20	26.67	12.23	22.44	1.90	0.84
Pre-drying.	Wheat.	21.657	60	50	18.5	30.00	25.5	180	0.73	86.96	33.86	72.29	9.50	3.17
Pre-drying.	Barley.	19.56	60	50	19	30.80	26.5	225	0.74	87.16	27.47	71.22	9.50	2.53
No pre-drying.	Barley.	19.56	40	55	20	34.93	26.5	210	0.14	37.53	7.56	25.33	1.90	0.54
No pre-drying.	Barley.	19.56	60	55	20	47.30	26.5	135	0.19	37.91	11.99	31.75	1.90	0.84
Pre-drying.	Barley.	19.56	40	60	19.5	27.00	25.0	360	0.62	86.67	19.20	63.41	9.50	1.58
No Pre-drying.	Wheat.	17.158	40	60	19.5	34.13	24.0	225	0.17	36.72	8.55	28.66	2.90	0.77

Conclusion

At the beginning of the drying process, grain in the lower tray (dryer), dried exponentially at a decreasing rate (decay) while grain in the pre-dried grain, dried at an increasing rate before drying exponentially at a decreasing rate (decay). This was observed for all low moisture content grain when drying at both high and low drying air temperatures. The removal of the trays for weighing every 15 minutes could have contributed to the temperature fluctuations of the drying air especially when using high temperatures. This affects the drying time, HUF, drying and thermal efficiencies of the system. The efficiency of the dryer can be improved by reducing the losses due to leakage on the duct and on the trays. Tight fitting trays should be used for this study. The walls of the trays were thin and heat loss could be lost through it. Lagging of the trays will improve this heat loss.

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