CONTINUOUS DRYING OF WHEAT WITH HOT SAND

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A prototype continuous-flow dryer employing a solid heat-transfer medium was evaluated for drying wheat at different grain flow rates and sand-to-grain mass ratios. Drying capacity, fuel efficiency, and specific fuel consumption were determined. An average drying efficiency of 61% was obtained for grain flow rates ranging from 2.5 to 3.5 kg/min, and the highest fuel efficiency of 41% was observed at a grain flow rate of 3.0 kg/min at a sand-to-grain mass ratio of 4:1.

INTRODUCTION

The fuel crisis has emphasized the need to search for ways and means of decreasing the energy consumption in grain drying. A heated granular-solid transfer-medium has been studied by various investigators to improve drying efficiency (Lengar et al. 1971; Raghavan and Harper 1974; Lapp and Manchur 1974). Heated steel plates, sand and granular salt have been used successfully for quick and efficient drying of corn, oilseeds and paddy rice. Experiments on a model batch dryer by Lapp et al. (1976a,b) were conducted using 12-30 texture sand (0.59- to 1.65-mm particle diameter). Wheat was dried from 17.0 to 14.5% wet basis with sand heated to 100°C and a sand-to-grain mass ratio (SGMR) of 4:1 in 2 min, and with sand heated to 105°C with a SGMR of 4.5:1 in 1 min.

Various investigators have conducted work on continuous-flow dryers using particulate media. Heated salt for drying paddy rice (Lengar et al. 1974; Lapp and Manchur 1974). Heated salt for drying paddy rice (Lengar et al. 1974; Khan et al. 1974) and rapeseed (Lapp and Manchur 1974) were employed. However, no work has been reported on wheat drying and overall efficiency of drying with a solid heat-transfer medium. Therefore, this paper describes the wheat-drying experiments using a prototype continuous flow dryer employing a solid heat-transfer medium, to assess the commercial potential of the process.

EQUIPMENTS AND PROCEDURE

Description of Prototype Dryer

The prototype dryer used for this investigation consists of a rotating 43.2-cm i.d. drum. The total drum length of 3.05 m was divided into a 1.22-m insulated drying section, a 0.61-m screened separating section and a 1.22-m cooling and delivery section. The cylinder was driven by a small gear meshing with a larger gear fitted to the rotating cylinder. The angular speed of the cylinder was varied using a variable speed reduction system driven by a 250-W electric motor. Two hoppers, one for damp grain and one for hot sand, were mounted above the drying section inlet. These hoppers delivered the grain and sand into the metering head. The metering head was used to deliver the desired sand-to-grain mass ratio into the drying section. Adjustable legs were installed on the frame of the machine to control the angle of inclination of the dryer. Further details and the schematic diagram of the dryer are given elsewhere (Lapp and Manchur 1974).

The residence time of the sand and grain in the dryer section was regulated by varying the cylinder slope, the rotational speed or the feed rate. The sand, after screening through the separating section, was recirculated to the sand hopper by a 3.05-m bucket elevator and a 15.2-cm-diameter pipe insulated with fiber glass. The sand hopper contained ten 230-V, 2-kW electric heating elements. These heaters were placed on three separate circuits with circuit breakers on each circuit. A fan of 17-m³/min capacity was installed at the end of the cooling section. The fan helped to cool the grain and removed moisture from the drying section.

TESTING PROCEDURE

The metering head was calibrated by weighing separately the amount of sand and damp wheat delivered over a period of 1 min at various metering head and main gear settings. The calibration curves between the metering head setting and the flow rate at certain main gear settings were found to be linear. The appropriate meter settings were determined from the calibration curves for desired SGMR and grain flow rates. A cylinder slope of 1.1° was used and the residence time of sand and wheat mixture, at a grain flow of 3.0 kg/min in the drying section, was about 1 min when the cylinder rotated at 13 rev./sec. For other grain flow rates, the cylinder rotational speed was adjusted to get 1 min residence time.

The wheat was conditioned to an initial moisture content of approximately 17% by the addition of water. Each lot was stored at room temperature in sealed containers and mixed daily for a brief interval for at least 5 days before drying. This procedure insured uniform distribution of moisture throughout the grain sample. The moisture content was measured with a Halross moisture meter. The air oven drying method was also used for checking the meter results by keeping the oven temperature at 130°C for 19 h (Anonymous 1981).

Some of the heaters in the sand-heating hopper on the prototype were turned on for about 10 min to preheat the sand prior to each drying trial. The desired sand flow rate was set on the metering head dial and hot sand was allowed to flow through the dryer to preheat the machine. The desired wheat flow rate was then set on the metering head and the observations were recorded.

Sand temperatures were measured at three different locations in the dryer during drying tests. The initial sand temperature (T₃) was measured at the sand discharge port of the metering head. The temperature of sand upon completion of the drying process (T₄) was measured in the sand-collecting hopper beneath the separating section. The temperature (T₅) of sand re-entering the sand-heating hopper was also measured. The temperature of wheat at the outlet of the rotating cyli-
Amount of power consumed (W)

\[ P = \frac{\text{amount of energy supplied}}{\text{time}} \]

It is expressed as:

\[ P = \frac{\text{work done}}{\text{time}} \]

The fuel efficiency is defined as the ratio of the theoretical energy required to evaporate the grain water to the total amount of energy supplied. It is expressed as:

\[ \lambda_f = \frac{w T}{h T} \]

where

\( \lambda_f \) = fuel efficiency
\( w \) = mass rate of water removed from
\( h T \) = latent heat of vaporization of water from wheat, 2560 kJ/kg.

The specific fuel consumption is the fuel or heat required to evaporate a unit quantity of water from the grain. This relationship is an indication of the thermal economy of the drying.

RESULTS AND DISCUSSION

An analysis of variance showed significant differences at the confidence level of 0.99 in drying for the different grain flow rates. Significant differences in drying at the 0.95-level were found among different SGMR. The effects of grain flow rate and SGMR on the dryer performance parameters are discussed below:

Drying Capacity

Figure 1 shows the percentage of moisture removed at different grain flow rates and for various SGMR. The moisture reduction during the trials varied from 1.95 to 2.45%. A higher percentage of moisture removal was obtained at a SGMR of 4.5:1 than at other ratios using similar drying and operating conditions. For other grain flow rates of up to 2.7 kg/min more moisture was removed using a 5:1 SGMR than when a 4:1 ratio was used. At higher grain flow rates the SGMR of 4:1 removed more moisture than 5:1. The maximum amount of moisture was removed between grain flow rates of 2.7 and 3.0 kg/min for all SGMR. The percentage moisture content reduction tended to become constant at grain flow rates above 5.0 kg/min for the SGMR of 4:1. Similar behavior is expected for other SGMR.

At grain flow rates above 4.0 kg/min, the sand-grain mixture lost a large amount of heat to the surrounding air and to the dryer components due to the larger mixture surface area and thermal capacitance. Thus, less heat was available to dry grain resulting in a smaller reduction in moisture content. Also, at the higher grain flow rates and SGMR, the mixing of sand and grain was incomplete. A large volume of sand relative to wheat in the mixture resulted in the sand surrounding the wheat kernels. This created a physical barrier to the escape of moisture from the wheat to the surrounding air.

The drying capacity can be enhanced by increasing the drum diameter, rotational speed, length and slope of the drum. Any one or a combination of these parameters can be varied.

Drying Efficiency

Drying efficiencies for different grain flow rates and for various SGMR are shown in Fig. 2. The drying efficiency varied from 42 to 62% to dry wheat from approximately 17.0 to 14.5% moisture content.

The drying efficiency decreased with the increase in SGMR. Drying at higher SGMR was less efficient because of the slower drying rates due to the difficulty in releasing moisture through the surrounding sand. The higher drying rates associated with the use of the lower SGMR permitted better utilization of heat for the evaporation of moisture from the wheat.

The highest drying efficiency was found at a wheat flow rate of 3.0 kg/min, for all the SGMR used. At a SGMR of 4:1, the drying efficiency was nearly constant for grain flow rates between 2.5 and 3.5 kg/min. The average drying efficiency in this range was 61%. At grain flow rates higher than 3.0 kg/min, a moderate decrease in drying efficiency was noted. The drying efficiency tended to be constant at grain flow rates above 5.0 kg/min at a SGMR of 4:1.

A drying efficiency of 51% for drying corn in a continuous flow-tower type grain dryer was measured with a thermometer placed in the collected grain.

Grain samples were taken at 5-min intervals to determine the moisture content of the wheat before and after drying throughout each test. Mean moisture content was then determined from the samples taken. Electrical energy consumed by the motors and heaters was measured using a watt-hour meter.

The variables in a complete randomized experimental design of the study were (i) sand-to-grain mass ratios of 4:1, 4.5:1 and 5:1; and (ii) sand flow rates of 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 and 6.0 kg/min.

Other parameters whose values were constant during the study included a residence time of 1 min, an initial sand temperature of 105°C and wheat conditioned to about 17% moisture content.

The drying efficiency was calculated using the relationship:

\[ \lambda_d = \frac{m_t c_p \Delta T}{h T} \]

where

\( \lambda_d \) = drying efficiency
\( m_t \) = mass flow rate of sand (kg/h)
\( c_p \) = specific heat of sand (0.88 kJ/kg K)
\( \Delta T \) = temperature reduction of sand in drying section (K)

The fuel efficiency is defined as the ratio of the theoretical energy required to evaporate the grain water to the total amount of energy supplied. It is expressed as:

\[ \lambda_f = \frac{w h T}{(3600 P)} \]

\( \lambda_f \) = fuel efficiency
\( P \) = amount of power consumed (W)

The total energy consumption included the energy to heat the sand and to operate the various electrical motors.

The specific fuel consumption is the fuel or heat required to evaporate a unit quantity of water from the grain. This relationship is an indication of the thermal economy of the drying.
Drying efficiencies for wheat at different grain flow rates for various sand-to-grain mass ratios.

Figure 2.

Fuel efficiencies for wheat drying at different grain flow rates for various sand-to-grain mass ratios.

Figure 3.

CONCLUSIONS

1. A sand-to-grain mass ratio of 4.5:1 removed more moisture than a 4:1 or a 5:1 ratio, when 12-30 texture sand at an initial temperature of 105°C was used in a continuous-flow dryer. The maximum amount of moisture was removed at a grain flow rate of 3.0 kg/min under these conditions.

2. An average drying efficiency of 61% was obtained for grain flow rates ranging from 2.5 to 3.5 kg/min at a sand-to-grain mass ratio of 4:1. Lower drying efficiencies were observed for higher sand-to-grain mass ratios.

3. The maximum fuel efficiency of 41% was found at a grain flow rate of 3.0 kg/min using a sand-to-grain mass ratio of 4:1.

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REFERENCES


Figure 4. Specific energy consumption for wheat drying at different grain flow rates for various sand-to-grain mass ratios.