FEASIBILITY OF DRYING WHEAT WITH VARIOUS SOLID HEAT TRANSFER MEDIA

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Investigations on drying wheat using different sand grades and alternative solid media including granular salt and steel balls are described. Wheat was dried, with the lowest energy consumption, from 17.0 to 14.5% moisture content (WB) using a 20–40 grade sand with a sand-to-wheat mass ratio of 4:1 and an initial sand temperature of 100°C in a drying interval of 2 min. Steel balls were found unsuitable for wheat drying due to their higher density and thermal conductivity. Granulated salt was more energy efficient than other solid media at initial temperatures greater than 120°C.

INTRODUCTION

In conventional dryers air is used as the heat and moisture transfer medium because it can be easily handled and does not by itself contaminate the grain. The low heat transfer coefficient of air coupled with the resistance to moisture diffusion within grain results in extended drying time and relatively low drying efficiency. A heated solid heat transfer medium is an alternative method of improving drying efficiency. Research conducted by various investigators on solid medium drying were summarized by Mittal et al. (1983).

Earlier experiments conducted by Mittal et al. (1983) revealed that hot sand having a 12–30 grade rating was effective in reducing the moisture content of wheat from 17.0 to 14.5% wet basis (WB) without damage to its milling quality. A 12–30 grade describes sand grains which pass a 12-mesh screen and are retained on a 30-mesh screen. Sand-to-grain mass ratios (SGMR) ranging from 3:1 to 5:1 were found to be effective in removing moisture from wheat with sand temperatures ranging from 90 to 110°C with a residence time of 2 min. The grain moisture removed was found to be proportional to the initial sand temperature. Various investigators have used other heat transfer media such as steel plates (Chancellor 1968; Finney et al. 1963; Hall and Hall 1961), granular salt (Benson 1966; Raghavan et al. 1974) and steel balls (Lapp 1973) in grain drying experiments. However, no work has been reported on the relative effectiveness of these heat transfer media and various grades. This paper describes the work on wheat drying using different sand grades and alternative solid media.

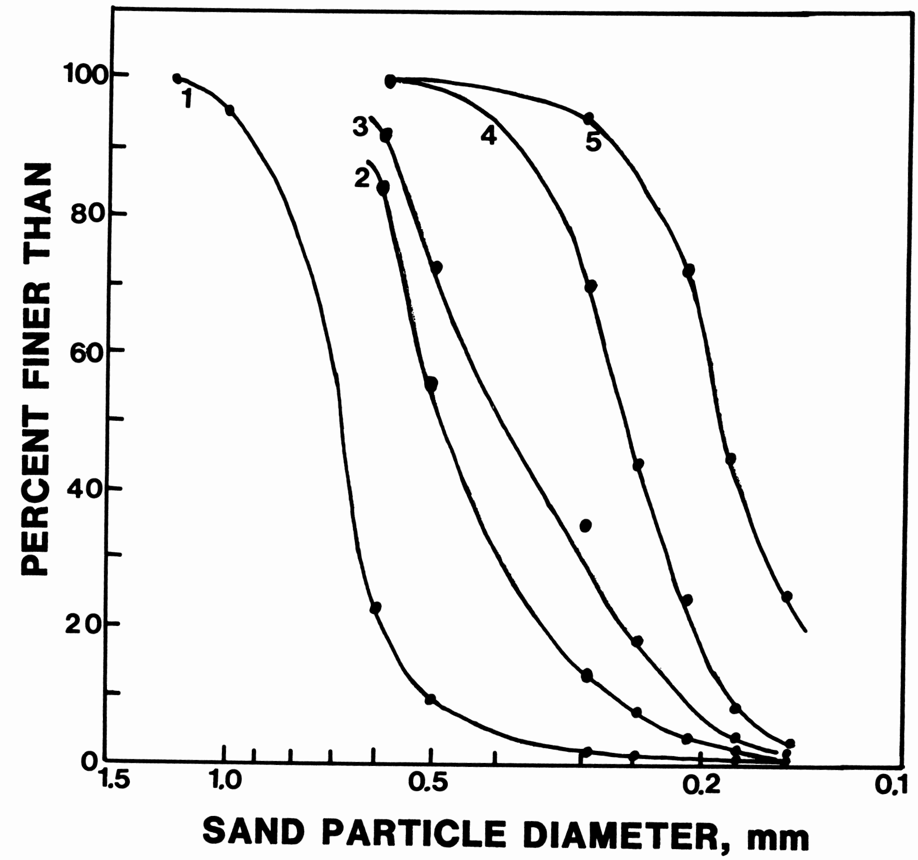

Figure 1. Sieve analysis of different sand grades, 1, 12–30 grade; 2, 20–40 grade; 3, 30–50 grade; 4, 40–60 grade; and 5, 60–100 grade.

MATERIALS AND METHODS

A model batch dryer was used for these investigations. The main component of the dryer was an insulated drying bucket, 29.3 cm inside diameter and 22.9 cm deep. The bucket was equipped with a removable lid containing three small holes for temperature measurement, escape of moisture and preheating. The bucket was preheated with a small propane torch. This bucket assembly was mounted on a yoke supported by a stand. The yoke had adjustments for selecting the operating position of the bucket. A 186-W gear-head electric motor rotated the bucket through a matched pair of step pulleys and a V-belt. Bucket rotational speeds of 24, 32 and 40 rev/min were possible.

The desired initial moisture levels for the grain were achieved by the addition of a precalculated quantity of water. The wheat sample and water were then uniformly mixed for 30 min in a rotating drum. After mixing, the grain was stored for 4 days in a refrigerator. This procedure resulted in uniform moisture distribution throughout the sample. The grain sample was

TABLE I. MECHANICAL SIEVE ANALYSIS OF DIFFERENT SAND GRADES

Sand grade	Modulus of fineness	Effective size (D_{10}, mm)	Uniformity coefficient (D_{60}/D_{10})
60–100	0.81	—	—
40–60	1.27	0.18	1.50
30–50	1.76	0.21	1.99
20–40	2.02	0.27	1.89
12–30	2.76	0.51	1.37

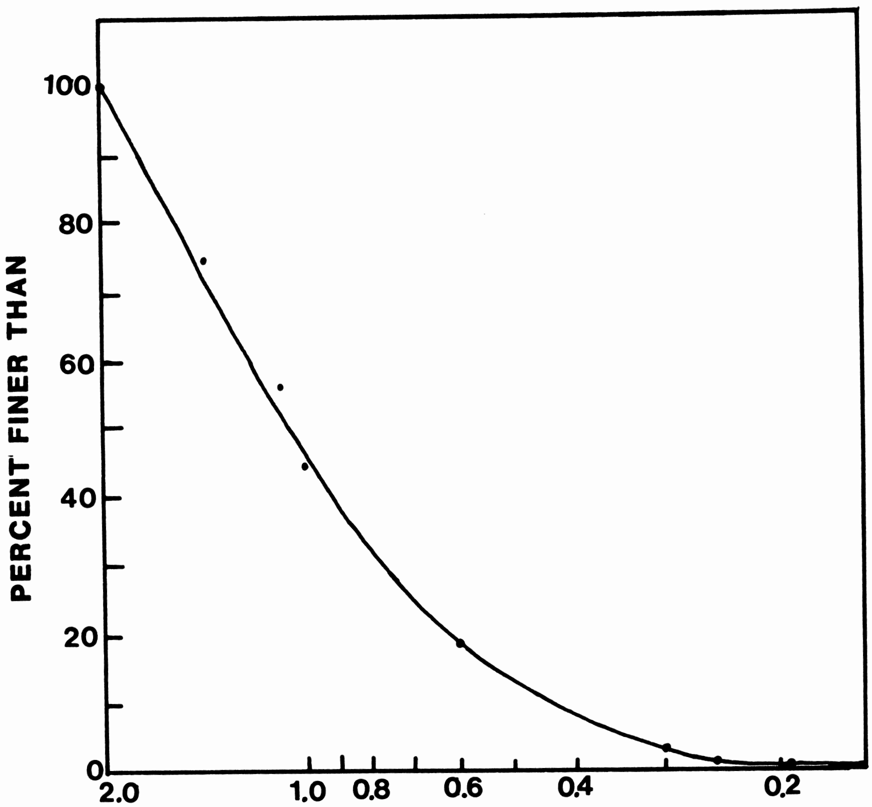

Figure 2. Sieve analysis of salt.

TABLE II. PROPERTIES OF SOLID MEDIA

Properties	Wheat	Sand†	Granulated Salt‡	Steel† (1% C)	Air† (0°C, 1 atm.)
1. Specific gravity (at 20°C)	1.30§ (10% MC)	1.4–1.7	2.165	7.83	0.0013
2. Specific heat kJ/(kg.K)	1.811¶ (15% MC)	0.800	---	0.502 (20°–100°C)	1.005
3. Thermal conductivity W/(m.K)	0.457‖ (20°C, 15% MC)	0.33	---	48.4	0.0242

†Perry and Chilton (1973).
‡Chemical Rubber Co. (1984).
§Hahn (1983).
¶Muir and Viravanichai (1972).
‖Chandera and Muir (1971).

removed from the refrigerator and held at room temperature for 24 h prior to drying. The grain was held in air-tight plastic bags and/or containers while stored in the refrigerator or at room temperature.

Five sand grades (12–30, 20–40, 30–50, 40–60, and 60–100) were selected to determine the effect of sand grade on wheat drying. Mechanical sieve analyses of these sand grades were conducted according to the ASAE Standard, S319 (Hahn 1983) and the results are recorded in Fig. 1. A set of nine sieves (16, 18, 30, 35, 50, 60, 70, 80, 100 mesh U.S. sieves) was used and shaken for 5 min. Two replications were completed for each sand grade. The modulus of fineness, effective size and uniformity coefficient were calculated for each grade using the method of Agriculture Canada (1971). These properties are tabulated in Table I. Drying tests were conducted using SGMR of 4:1 and 5:1. An initial sand temperature of 100°C and a residence time of 2 min were used in these tests. The residence time was the time for which the sand and grain mixture remained in the batch dryer.

Sand, granular salt and steel balls were used to compare the drying performance of alternative media. Values of experimental variables included initial temperature of the medium (100, 120, and 140°C) and medium-to-grain mass ratios (MGMR) of 4:1, 6:1 and 8:1. Wheat at an initial moisture content of approximately 17% with a residence time of 2 min was used in the drying trials. The three media were 12–30 grade sand, 1.12-mm-diameter steel balls and granulated salt. The granulated salt passed through a 10-mesh sieve, and had a fineness modulus of 3.05 and an average particle diameter of 1.83 mm. The results of the mechanical sieve analysis of the salt are shown in Fig. 2. Thermophysical properties of these media are recorded in Table II. A rotating drum speed of 24 rev/min was used in all experiments. A randomized factorial experimental design was used with three replications. The average performance parameter values were plotted. The ANOVA procedure of the Statistical Analysis System (SAS) (Barr et al. 1976) was used for the analysis of variance.

A 500-g sample of Neepawa wheat was selected as a base and the mass of solid media was varied to give the desired MGMR. The predetermined mass of solid media was poured into a tray and heated in an electric oven to the required temperature. The drying bucket of the batch dryer was preheated at the desired temperature with a small propane torch prior to each set of drying trials to minimize the heat losses. The wheat and solid media were placed into the bucket while it was in a vertical position. The lid was then replaced and the bucket lowered to its horizontal running position and operated for the selected residence time. The temperature inside the container was monitored continuously. When the residence time elapsed the bucket was dumped and the media were screened from the wheat.

The moisture content of the wheat was determined by the oven-drying method. The oven temperature was held at 130°C for 19 h (Hahn 1983). Dried wheat samples were sent to the Grain Research Labora-

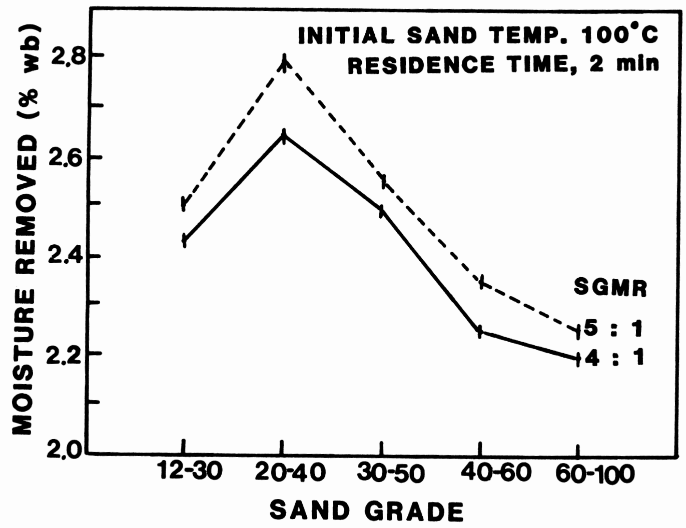

Figure 3. Effect of sand grade on wheat drying (vertical lines show 95% confidence intervals).

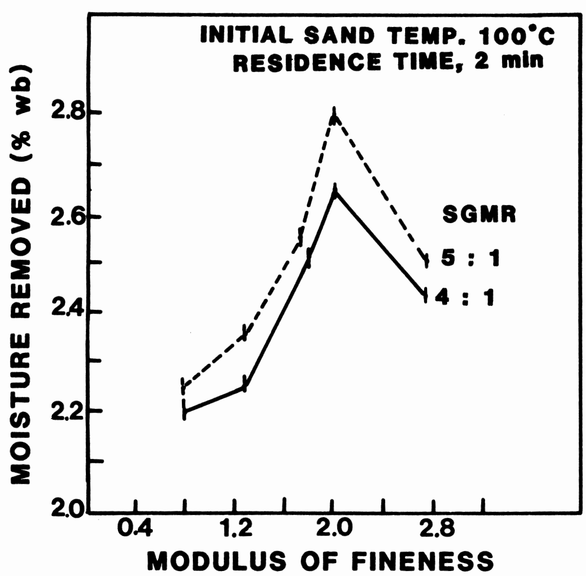

Figure 4. Effect of modulus of fineness of sand on wheat drying (vertical lines show 95% confidence intervals).

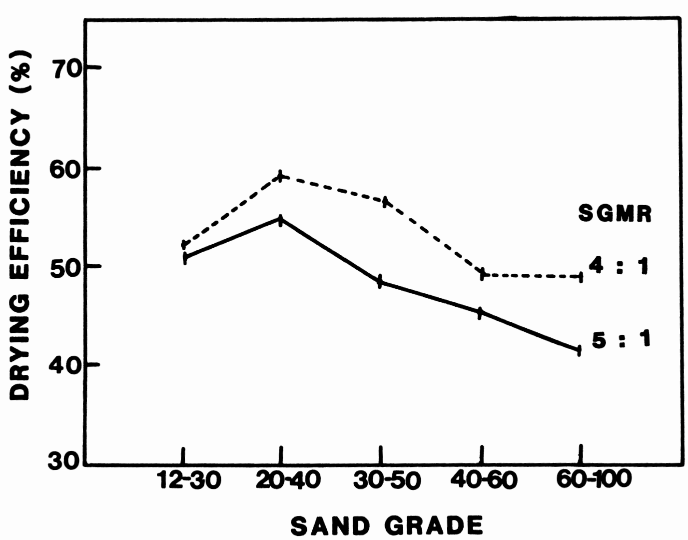

Figure 5. Effect of sand grade on wheat drying efficiency at an initial sand temperature of 100°C and 2 min residence time. (Vertical lines show 95% confidence intervals.)

tory of the Canadian Grain Commission in Winnipeg to assess the effect of drying on the gluten quality for baking purposes.

Drying efficiency was calculated as follows:

Drying efficiency =

$$M_w \cdot h_{fg} / (M_s \cdot C_p \cdot \Delta T)$$

where M_w = mass of water removed (kg), h_{fg} = latent heat of vaporization (2560 kJ/kg), M_s = mass of media (kg), C_p = specific heat of media (kJ/(kg.K)), and ΔT = temperature change of media during drying (K).

RESULTS AND DISCUSSION

Effects of Sand Grade

Drying results using different sand grades are presented in Figs. 3 and 4. The quality tests conducted by the Grain Research Laboratory of the Canadian Grain Commission showed that the baking quality was unaffected using different grades of sand. It can be concluded from these results that for conditions tested the 20–40 sand grade is the most energy efficient for wheat drying.

Increasing the fineness of the sand did not lead to increased drying over the entire range of grades tested. Very finely graded sand probably created a physical barrier against the escape of moisture from the grain kernels to the air in the sand voids and to the surrounding air. Finely graded sand is less permeable than coarse sand. Hence, less air was available for moisture removal. These physical characteristics may explain the occurrence of an optimum grade of 20–40 for wheat drying.

An analysis of variance indicated highly significant differences at 95% level in performance parameters (percentage moisture removed and drying efficiency), among different graded sand treatments. A comparison between the different treatments also showed highly significant differences at 95% level in the performance parameters, except between 60–100 versus 40–60 and 30–50 versus 12–30 sand grades. Drying efficiency was also found to be highest for the 20–40 sand grade as shown in Fig. 5.

Alternate Heat Transfer Media

Figure 6 presents the relationship between the initial solid medium temperature and the percentage points of moisture removed. At 100°C sand removed more moisture than either salt or steel balls. At 120°C there was no significant difference in drying between steel balls and salt, but at 140°C salt removed more moisture than steel balls. The hygroscopic property of salt probably decreased the

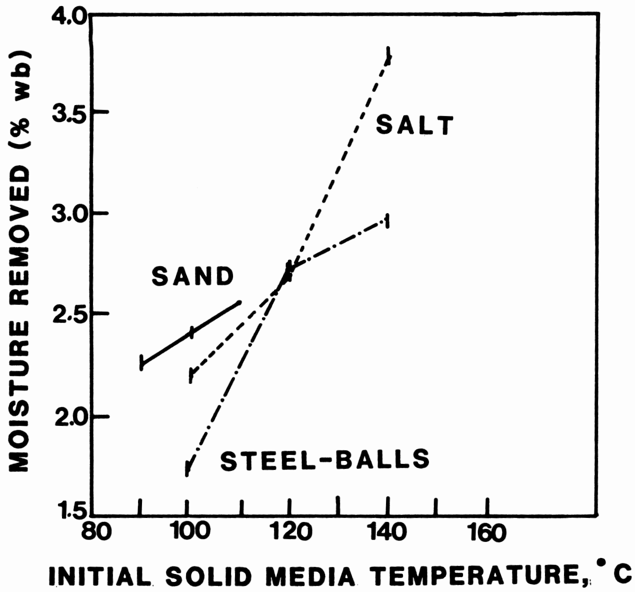

Figure 6. Relationship between initial temperature of solid drying media and the percentage of moisture removed from wheat at MGMR of 4:1 and 2 min residence time. —— sand, ----- salt, -·-·- steel balls. (Vertical lines show 95% confidence intervals.)

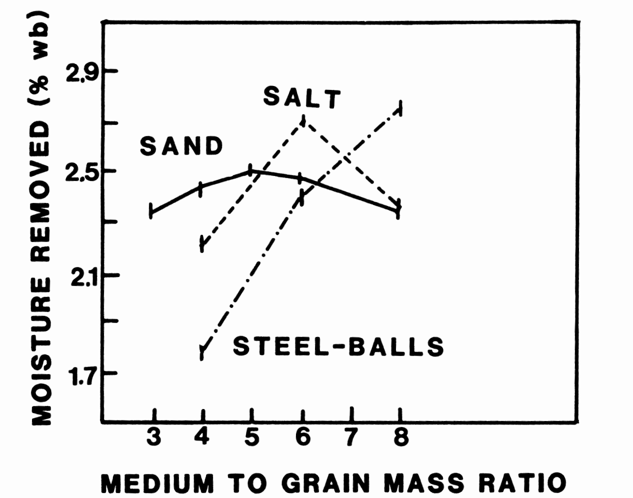

Figure 7. Percent moisture removed from wheat using different medium to grain mass ratios of different drying media, at an initial sand temperature of 100°C and 2 min residence time. —— sand, ----- salt, -·-·- steel balls. (Vertical lines show 95% confidence intervals.)

drying capacity at the lower temperatures.

The maximum amount of moisture was removed at a 6:1 MGMR using salt and at a 5:1 MGMR using sand. These ratios appear to be optimum for drying wheat as shown in Fig. 7. A large MGMR creates a physical barrier to the escape of moisture. There is less opportunity of heat transfer to wheat since much of the media is in contact with itself. For steel balls the maximum moisture was removed at an 8:1 MGMR. More moisture could possibly be removed at higher MGMR. Steel balls have a low thermal capacity as their specific heat is about 60% that of sand. Therefore, a greater mass of steel balls is required to remove an equal amount of moisture for the same temperature change.

The large difference in density between the steel balls and the wheat (six times) created difficulties in mixing at low MGMR. The higher density steel balls had a tendency to settle at the bottom of the mixture while the wheat remained near the top. The sand density was 10–30% higher than wheat, while salt density was 65% higher than wheat. The differences in the densities among salt, sand and wheat were not large compared with steel balls and thus no difficulty was experienced in their mixing. Sand and salt have the advantage of being commercially available in various grade ratings.

There were some problems in separating steel balls and salt from wheat. The flow characteristics of the steel balls contributed to a slower separation from wheat. A magnetic separating device of some form would probably be necessary to assure complete removal of steel balls. The hygroscopic nature of salt resulted in a separation problem at low temperatures. Salt at high moisture content had a tendency to adhere to the wheat kernels, which further amplified the separation problem. Salt would be suitable for drying at higher temperatures and can be used for the grains which can sustain higher temperatures. It would not be suitable for drying wheat.

The drying efficiencies are shown in Fig. 8. Steel balls gave higher efficiencies at all MGMR. A maximum drying efficiency of 62% at a 4:1 MGMR was achieved. The maximum drying efficiency using salt occurred at a 6:1 MGMR which is comparable to sand. The drying efficiencies of salt and sand at higher MGMR were decreased.

These results show advantages and limitations of various heat transfer media. Sand gave superior drying characteristics when compared with salt at low temperatures while salt was superior at high temperatures. Steel balls were superior to sand or salt in drying efficiency. Due to the low specific heat of steel balls, less heat was required to raise their temperature, but their higher thermal conductivity (140 times that of sand) resulted in a rapid heat transfer to container surfaces and to the surrounding air during separation from grain. The heat required for reheating of the steel balls would result in a lower overall drying efficiency.

CONCLUSIONS

(1) A sand grade of 20–40 removed a greater amount of moisture from wheat than sand grades of 12–30, 30–50, 40–60, or 60–100. A 20–40 grade sand also gave the highest drying efficiency.

(2) Salt, because of its hygroscopic property, was found suitable for drying only at high temperatures and thus could only be used for drying grains which could withstand high temperatures. Salt was more effective than sand and steel balls at temperatures greater than 120°C. It was difficult to separate salt from grain at lower temperatures.

(3) Comparatively less moisture was removed from wheat when steel balls were employed as the solid medium.

(4) A 20–40 grade sand was found to have more desirable characteristics as a solid heat transfer medium for drying

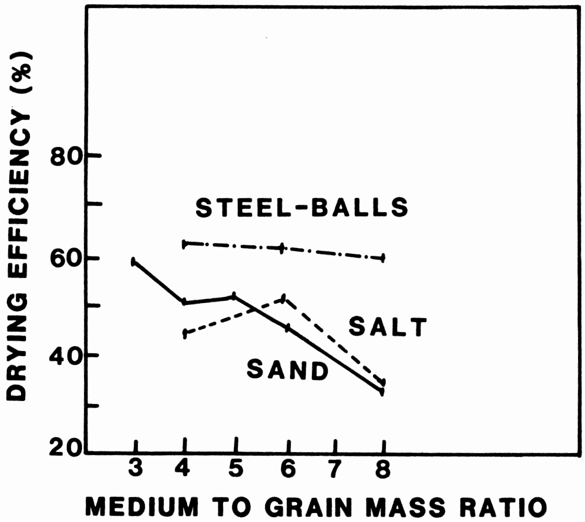

Figure 8. Wheat drying efficiency at different medium to grain mass ratios of various media, at an initial sand temperature of 100°C and 2 min residence time. —— sand, ----- salt, -·-·-· steel balls. (Vertical lines show 95% confidence intervals.)

wheat than either granular salt or steel balls.

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