INTRODUCTION

Drying of high-moisture content cereal grains at commercial handling and storage centers, and on farms, has been practiced in Canada for many years. Drying at terminal elevators has been a common practice, whereas on-farm drying has generally been undertaken only in critical years of wet harvesting season and primarily to reduce the moisture content to permissible levels for safe storage in farm bins. Marketing constraints and limited drying capacities at terminal elevators has increased the need for on-farm drying, particularly during wet harvest seasons. Drying grain on the farm can be advantageous to permit earlier harvesting, to extend harvest hours, to reduce field losses, and to reduce in-storage deterioration.

There is a risk of grain damage due to overheating affecting germination, feed and milling qualities, and on-farm drying as a general practice has not been encouraged. Seed viability is a major concern and regulations of the Canadian Grain Commission do not permit seed grain temperatures to exceed 100°F (43.3°C). Conventional methods of grain drying use air as the heat transfer medium because air can be handled easily and it does not by itself contaminate the grain. Air, however, does not have a high heat transfer coefficient and this, coupled with a resistance to moisture diffusion within grain kernels, results in extended drying times. The process of air-drying, regardless of the type of dryer used, is an inefficient process.

Attempts to accelerate drying rates and to increase drying efficiencies have been undertaken by other investigators. A conducted heat process for drying paddy rice in Thailand has been reported by Chancellor (2) in which he used a steel plate heated to 200°F (93.3°C) with which he was able to dry about 1,000 pounds (454.55 kg) of paddy rice from 24 to 14% in about 4 h. He suggested the use of granular medium, such as sand, to reduce excessive localized heating. Kahn (3) has reported that hot sand has been used traditionally for uniformly roasting wheat, rice and corn in India and that it has also been used for partial drying of rice during the parboiling process in the Philippines. Kahn (3) has investigations in progress at the International Rice Research Institute at Los Banos in the Philippines, using heated sand in a process for accelerated drying of paddy rice. He reported reducing the moisture content from 32 to 18% in 30 sec using sand heated to 460°F (237.8°C) and mixed with rice in a 20:1 weight ratio. Benson (1) holds a United States patent to apply an agitated bed of heated salt to puff-cooked cereal kernels in short times. Raghavan and Harper (4) reported that an agitated salt bed heated to 450°F (232.2°C) in a bench-model drum dryer effected the drying of corn from 21-14% during a residence interval of 30 sec or less in laboratory tests.

Laboratory tests, construction, and evaluation of a prototype continuous-flow dryer using sand as the heat transfer medium to dry rapseseed and sunflowers are described in this report.

EXPERIMENTAL MATERIALS, EQUIPMENT AND PROCEDURE

An experimental continuous-flow dryer using heated sand with a mixing and flow system similar to that used by the International Rice Research Institute in the Philippines was built in 1972. Operation of this machine showed that sand could be heated, mixed with grain, conveyed in a rotating drum and again separated from the grain by a rotating screen, all in a continuous-flow drying sequence. No attempt was made to control temperatures or mixing ratios, to determine capacity or to effect cooling after drying during the operation of this experimental machine.

A small bench-model dryer consisting of a rotating 18-inch (45.72-cm) length of 12-inch (30.48-cm) diam indent cylinder was then built to assess the potential of drying in the laboratory. This drying cylinder was insulated with fiberglass and contained access ports for introducing and removing sand and grain mixtures. Central sections in both ends of the model drying cylinder were open to permit the escape of moisture liberated during drying. Sand was heated in an electric oven, mixed in defined weight ratios with grain, placed in the model for timed intervals, then removed and separated by hand-screening. Sand heated to 450°F (232.2°C) was mixed in sand-to-rapseseed weight ratios of 2-1/2:1, 5:1 and 8:1 and placed in the model for residence interval of 2 min.

Successful operation of a grain dryer using sand as a heat transfer medium appeared feasible, and a prototype continuous-flow dryer was designed and built. The prototype, as shown schematically in Figure 1, consists of two hoppers, one for seed and one for sand, a rotating cylindrical drum with a screened separating section and a 4-ft (1.22-m) cooling and dry seed delivery section. A conventional bucket elevator is used to return hot sand from the separating section to the sand hopper for reheating. The sand hopper has a capacity of 2 ft³ (0.056 m³) and heating is effected by an 10 kw calrod heaters mounted in the hopper. A low-capacity fan discharges into the dry-grain delivery end of the cylinder to effect seed cooling and moisture expulsion from the dryer. Three basic parameters to be controlled by the machine are: 1) temperature of the sand,
In machine operation, high-moisture seed and hot sand are mixed in controlled ratios by calibrated hopper gates and introduced directly into the drying section. Residence time in the drying zone is controlled by varying the rotation speed and the slope of the cylinder. Mixing and propulsion of sand and seed in the drying area is assisted by small and gently curved spiral flights attached to the interior of the cylinder in the drying section. Silica sand having a texture that will pass through a 40-mesh, and be retained by a 60-mesh screen, has been used in all drying trials completed with the prototype.

RESULTS AND DISCUSSION

During drying trials in the bench model dryer with sand at 450°F (232.2°C), the sand-to-rapeseed ratio of 2-1/2:1 reduced the moisture content of rapeseed from 17.6 to 13.3%, the ratio of 5:1 from 19 to 12% and the 8:1 ratio from 16 to 9.3%. Some rapeseed popping, estimated to be approximately 10%, occurred during the 8:1 ratio trial. Test analysis conducted by the Faculty of Agriculture's Cereal Chemistry Laboratory showed that the quality and quantity of oil recovered after these drying trials was unaffected by any of the treatments. An analysis of one sample of dried rapeseed meal showed a decrease in protein content of approximately 10% when compared to meal from rapeseed that had not been dried.

A series of performance evaluation trials using the prototype to dry rapeseed have been completed. Typical drying results for rapeseed are contained in Table I. Further machine development and evaluation is in progress.

1. The prototype flow system for mixing, drying, separating, delivery of dried seed and recirculation of sand functions well. Further aeration of the dried grain may be required to ensure that seeds are cooled to a safe temperature level prior to placing the grain in storage.

2. Sand hopper design must be such that sand flow will be continuous and uniform past all calrod heaters. Static sand adjacent to heating elements will result in excessive local temperatures and heating rod failure.

3. Drying efficiencies were calculated on the basis of the heat utilized to remove water (output) divided by the heat available for drying (input). Singh and Muir (4) give this relationship as follows:

\[
\text{Drying efficiency} = \frac{W_{\text{fg}}}{M_s C_p \Delta T}
\]

Where:  
- \( W_{\text{fg}} \) = latent heat of vaporization of water;  
- \( M_s \) = weight of sand circulated through the machine during the drying interval;  
- \( C_p \) = specific heat of sand;  
- \( \Delta T = T_1 - T_2 \) = temperature drop of the sand through the drying section.

A sample calculation applied to trial number 3 in Table I follows.

When applied to the prototype dryer the formulas can be written:

\[
\text{Drying efficiency} = \frac{W_{\text{fg}}}{M_s C_p \Delta T}
\]

Where:
- \( W \) = weight of water to be removed.

TABLE I  TYPICAL DRYING RESULTS FOR RAPESEED

<table>
<thead>
<tr>
<th>Trial No.</th>
<th>Sand to rapeseed wt ratio</th>
<th>Sand temperature ( ^{\circ}\text{F} )</th>
<th>Moisture content (%)</th>
<th>Capacity (bu/h)</th>
<th>Drying efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4:1</td>
<td>350</td>
<td>11.5</td>
<td>9.0</td>
<td>8.5</td>
</tr>
<tr>
<td>2</td>
<td>4:1</td>
<td>250</td>
<td>11.5</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>2.5:1</td>
<td>340</td>
<td>14.0</td>
<td>9.5</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>2.25:1</td>
<td>430</td>
<td>12.0</td>
<td>9.8</td>
<td>5.0</td>
</tr>
<tr>
<td>5</td>
<td>1.5:1</td>
<td>325</td>
<td>13.1</td>
<td>9.8</td>
<td>6.1</td>
</tr>
<tr>
<td>6</td>
<td>4:4:1</td>
<td>325</td>
<td>12.5</td>
<td>9.1</td>
<td>14.5</td>
</tr>
<tr>
<td>7</td>
<td>3:1</td>
<td>335</td>
<td>12.5</td>
<td>9.1</td>
<td>14.5</td>
</tr>
</tbody>
</table>

Residence time for all trials was 30 sec.  
T1 is sand temperature entering the drying section.  
T2 is sand temperature leaving the drying section.  
No insulation was installed on the exterior of the rotating drying section when results were obtained for trial numbers 1 and 2. This lack of insulation was considered to contribute to the lower drying efficiencies obtained for these trials.
solid heat transfer medium. Small steel balls, for example, were used in the laboratory and were about equal in drying effectiveness to sand. However, difficulties were experienced in obtaining a screen separation from rapeseed since the seeds and steel balls were almost equal in size. A magnetic separator would have to be added to the machine to insure complete separation if steel balls were used.

5. High temperatures employed will disqualify the principle from application to the drying of seed grain. Oilseed crops that are processed for oil recovery are heated to high temperatures well above 200°F (93.3°C) during the crushing process. McKnight and Moysey (5) reported that rapeseed could be heated to at least 200°F without loss in quality of the oil extracted.

CONCLUSIONS

1. The principle of using a solid heat transfer medium, as far as the authors are aware, is a new approach to grain drying in Canada.

2. The process gives definite promise of becoming a viable method of rapidly and efficiently drying grain that is not be used for seeding.

3. The principle is expected to have immediate application to the drying of rapeseed and sunflowerseeds. Future applications may well include faba beans, soybeans and wild rice.

4. The fire hazard associated with the use of conventionally heated air-dryers will be reduced by the use of sand as the heat transfer medium since no open flame is present in the drying area.

5. The system provides no opportunity for grain contamination other than small-textured sand grains that may pass through the dryer. The separation of sand from grain in the screened section has been remarkably complete and no sand has been noted in any of the grain dried by the prototype to date.

SUMMARY

A prototype continuous-flow grain dryer employing hot sand as the medium to effect heat transfer and drying has been built and operated. The dryer contains drying, separating and cooling sections in a continuous-flow system. The machine functions well in introducing controlled mixtures, drying, separating, recirculating hot sand, expelling moisture and delivering dried grain.

Oilseeds at initial moisture contents ranging from 11.5 to 15 percent have undergone moisture reductions from 3 to 4.5 percent during a residence time of 30 seconds. Sand temperatures entering and leaving the dryer averaged 315 degrees Fahrenheit (157.2 degrees Celsius) and 185 degrees Fahrenheit (85.0 degrees Celsius), respectively. Drying of oil seeds using hot, fine-textured sand was effected rapidly at efficiencies ranging from 45 to 55 percent.

ACKNOWLEDGMENTS

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REFERENCES