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Abstract
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Keywords
Mechanical Engineering, Coal-fired drivers, Grain drying, On-farm corn drying

Disciplines
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Comments
Drying Corn with Coal on Iowa Farms

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ABSTRACT

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INTRODUCTION

A total of 11.2 x 10^6 MJ (1.06 x 10^13 Btu) was used for on-farm corn drying in Iowa for the bumper crop of 1981. About 88% of this energy was derived from burning 4.17 x 10^6 L (110 million gal) of propane (Iowa Crop and Livestock Reporting Service, 1984). Except for some Iowa coal burned for electrical energy production and very small amounts of energy contributed by alternative sources including refuse and biomass combustion, solar, wind, and hydroelectric, all this energy was imported into the state.

Recoverable reserves of Iowa coal have been estimated at 2.96 x 10^9 t (3.262 million tons) (Landis and Van Eck, 1965), and present production is about 0.55 x 10^6 t/year (600 000 tons per year) (Peterson and Biringmair, 1982). Because of an interest in utilizing this in-state energy reserve as a substitute for imported energy, a project was undertaken which had the objective of determining the feasibility of using Iowa coal for on-farm corn drying. This report describes a coal furnace testing experiment, coal-burning dryers on two farms, and a cost analysis of coal as an energy source for on-farm corn drying.

Coal-fired dryers

No recent reports of drying systems that use coal fuel were found in the literature. Hall (1957) lists two coal-fired, portable fan-furnace units for grain drying, as described in Table 1.

Both used heat exchangers and stokers. Neither brand is currently available from the manufacturers listed. Evidently both of these fan-furnace units originated with a design developed by Bituminous Coal Research, Inc. in 1951 (Lawler et al., 1954). The “BCR Crop Dryer” was a trailer-mounted, fan-furnace unit designed to supply heated air under pressure to a structure containing a crop to be dried (Fig. 1). The furnace employed an underfire stoker to an fcc coal from an integral hopper. The design was tested at several farms and experiment stations and then marketed in the early 1950s. Sorenson Energy, Inc., of Salt Lake City, UT has recently produced, under license, a number of units based on the BCR design. This machine is called the Stokermatic Crop Dryer. Tests of this recent Stokermatic are described later in this report.

FURNACE TESTS

The objective of the furnace tests was to evaluate thermal efficiency, particulate and sulphur dioxide emissions, and operational characteristics of some coal furnaces currently being marketed. Two furnaces with nominal input ratings of 500 MJ/h (474 000 Btu/h) were tested. Table 2 lists furnaces specifications. Both furnaces are heat-exchanger types. The Burn-All uses gravity-induced draft, whereas, the Stokermatic uses an adjustable-rate forced draft system for underfire air. Neither furnace has adequate provision for control of overfire air.

Furnace test setup

Furnace testing was carried out at the Iowa State University Coal Preparation Plant, Ames, IA. Arrangement of the furnace setup and associated instrumentation is shown in Fig. 2. The stack extended through the building ceiling. A 3.7-kW (5-hp) centrifugal blower pulled ambient air through the furnace heat exchanger and then through an
instrumented flow tube.

The stack was equipped with a barometric damper to provide draft similar to what is expected in practice, and three sampling ports. One port was used for Orsat analysis sampling. A second was used for carbon dioxide, carbon monoxide, and oxygen sampling. Sampling for particulates and sulphur dioxide was done at the third port. Type K (chromel-alumel) thermocouples were used for temperature measurement in the stack, on the furnace, and in the flow tube. Blower flow was calculated from pressure drop measured across an orifice plate in the flow tube.

**Furnace firing**

A total of 14 tests were conducted using coal from the Iowa Fuel and Minerals mine, Pella, IA. Both raw crushed coal and cleaned stoker coal were burned. Table 3 lists coal properties.

The Burn-All furnace was hand-charged with 12 to 14 kg (26 to 31 lb) of coal every 20 min. This rate slightly exceeded the nominal 500 MJ/h (474 000 Btu/h) input rating. Although firing with up to 180 kg (400 lb) at a time is possible, frequent firing allowed near steady-state operation and contributed to even burning. Excess airflow to the combustion chamber had to be adjusted for satisfactory combustion and could not be varied from this rate without hindering furnace operation. Two different damper settings were used to vary the heated air flow rate.

The Stokermatic furnace was fired at rates from 13.4

**TABLE 3. TEST COAL ANALYSIS (MOISTURE FREE)**

<table>
<thead>
<tr>
<th>Size range, mm</th>
<th>Raw coal</th>
<th>Cleaned coal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>51 to fines</td>
<td>38 to 6.3</td>
</tr>
<tr>
<td>carbon, %</td>
<td>70.30</td>
<td>75.02</td>
</tr>
<tr>
<td>hydrogen, %</td>
<td>4.62</td>
<td>4.30</td>
</tr>
<tr>
<td>oxygen, %</td>
<td>4.02</td>
<td>4.55</td>
</tr>
<tr>
<td>nitrogen, %</td>
<td>1.16</td>
<td>1.41</td>
</tr>
<tr>
<td>sulphur, %</td>
<td>7.24</td>
<td>3.99</td>
</tr>
<tr>
<td>ash, %</td>
<td>12.66</td>
<td>10.74</td>
</tr>
<tr>
<td>pyrite (included in ash), %</td>
<td>4.15</td>
<td>1.72</td>
</tr>
<tr>
<td>gross higher heating value, MJ/kg</td>
<td>28.4</td>
<td>29.6</td>
</tr>
<tr>
<td>g SO₂ per MJ heating value*</td>
<td>5.10</td>
<td>2.69</td>
</tr>
</tbody>
</table>

*Including all S
Average to 28.2 kg/h (29.5 to 62.2 lb/h). The excess airflow rate was varied as much as possible without altering the burning rate.

**Furnace performance**

Data collection and analysis followed the format specified in the ASME Boiler-Abbreviated-Test Code (ASME, 1964). EPA method 5 isokinetic sampling was used for particulate determination (Environmental Protection Agency, 1982). Stack gas sulphur was sampled by using proportional sampling and EPA method 6 (Environment Protection Agency, 1982). Test data are listed in Peterson and Birlingmair, 1982. Table 4 is a summary of test results. Furnace efficiency is defined as follows:

\[
\text{furnace efficiency} = \frac{\text{heat added to heated air}}{\text{gross heat input from fuel}}
\]

Gross heat input was calculated by using the gross higher heating value of the fuel.

**Furnace efficiency**

Furnace efficiency averaged 50.4% for the Burn-All furnace and 52.9% for the Stokermatic. Raw coal tests averaged 2.3 percentage points higher in efficiency in the Burn-All tests, but averaged 4.3 percent points lower in the Stokermatic tests. Furnace efficiency was not found to be related to firing rate.

Efficiency increased linearly with heated-air flow-rate for the Burn-All tests. The relationship is shown in Fig. 3. Higher airflow rates evidently reduce heat transfer resistance through the combustion chamber walls and reduce losses from the outer furnace surfaces by causing them to operate at lower temperatures.

**Particulate emissions**

For the Stokermatic furnace, particulate emissions (per unit of heat input) decreased with firing rate. Fig. 4 shows this relationship. Particulate emissions from the Burn-all were higher and unrelated to firing rate. State laws limit particulate emissions for a furnace of this size to 0.39 g/MJ (0.8 lb/10^6 Btu) input (State of Iowa, 1983). Neither furnace met this requirement in any test. Equipment used on farms is exempt from being required to have a Department of Environment Quality permit to operate. Hence, such equipment would not usually have to meet this limit. This particulate emission limit would preclude use of either furnace for drying at a grain elevator.

**SO₂ emissions**

Emission of SO₂ was not found to be related to firing rate. For the Burn-all furnace, raw coal tests average 1.78 g/MJ whereas cleaned coal tests averaged 2.57. The
Discussion of furnace performance

Efficiency of the furnaces is probably being lowered because of a lack of overfire air. An increase of about 15 percentage points could probably be realized by modifications that would allow more over-fire air. A stoker-equipped furnace seems more appropriate for a grain drying operation since the hand-fired furnace must be fired on a 1-to-2-h interval. A stoker-type furnace seems more appropriate for a 24-h interval.

On-farm drying with coal

In this section, two farm systems that use coal will be described, and a cost analysis of a coal-fired system will be presented.

Drying systems using coal

To learn more about the practice of coal-fired corn drying, two farm drying systems using coal were inspected. Both farms were south of Knoxville in south-central Iowa, within a few miles of the coal mining area of Iowa. Both farms use Burn-All furnaces.

The first farm uses a batch stir-drying system. A 7.5-kW (10-hp) centrifugal fan with an upstream propane heater is connected to a 7.3-m (24-ft) diameter bin fitted with a 5-auger stirring system. A drying air temperature of 60°C (140°F) is used. The furnace is located close to the crop drying fan air intake so that all heated air from the furnace enters the fan intake. A small electric fan has been mounted on the furnace to increase draft. This farmer purchases uncleaned lump coal at a nearby mine and hauls it himself. He charges the furnace every 2 h with about 200 lb of coal while he is in the farmyard. The furnace contributes a heat rise of about 20°C (36°F), and the rest of the heat rise is automatically made up by the propane heater. A total of 1780 t (70 000 bu) of corn was dried during fall of 1981. The fire-brick supports and roof of the furnace were buckled—probably as a result of overfiring.

The second farm uses a batch system without stirring. A 7.5-kW (10-hp) axial fan is connected to a 6.4-m (21-ft) diameter bin. The only heat source is a Burn-All furnace located near the fan inlet. The drying fan draws air through the furnace, and all the heated air from the furnace flows into the fan intake. This farmer also hauls mine-run coal purchased from a nearby mine. A 128.6-t (2500-bu) batch is gradually loaded and dried in a 5-day period. The furnace is fired four times a day and holds fire for 8 h through the night. A total of 4071 (16 000 bu) was dried 10 points during the fall of 1981.

Both farmers bought the coal systems to reduce fuel costs for drying, and both said they were achieving this objective. Neither farmer has serious objections to the management time required for the coal systems.

Cost analysis

A cost analysis was carried out comparing costs of heat from three hypothetical systems that could supply heat to a hypothetical farm drying system. This drying system was assumed to operate continuously for a 30-day period each year, and to require a constant heat of 1.71 GJ/h (1.62 x 10^6 Btu/h). During the 30-day period, this dryer could dry about 2450 t (99 800 bu) of corn assuming 10 points of moisture removal, and 1 t = 1000 kg (1 bu = 56 lb) of corn at 15.5% moisture. The heat required for drying was assumed to be 3.71 MJ/kg (1600 Btu/lb) of water removed.

One system used a propane heater only. A second system used a propane heater plus one Stokermatic...
furnace. The Stokermatic furnace was chosen for comparison because a stoker system was judged necessary for continuous operation. A third system used five Stokermatic furnaces. The odd heat input rate of 1.71 GJ/h (1.62 x 10^6 Btu/h) was chosen because it is the output of five Stokermatic furnaces each being fired at a rate of 25 kg/h (55 lb/h) and operating at an efficiency of 55%. Table 5 lists other assumed heater characteristics.

The cost analysis procedure assumed that total heat energy cost = ownership costs + net fuel costs. Ownership costs and net fuel costs were computed as follows:

\[
\text{ownership cost} = \left( \frac{\text{original cost}}{\text{capital recovery factor}} \right) - \left( \frac{\text{tax, repair insurance factor}}{1 - \text{income tax rate}} \right) - \left( \frac{\text{original cost/life}}{\text{income tax rate}} \right) \\
\text{net fuel cost} = \left( \frac{\text{total fuel cost}}{\text{income tax rate}} \right)
\]

The tax, repair, insurance factor was assumed to be 0.045. The income tax rate was assumed to be 0.30. Table 6 lists computed cost values for coal hauling distances of 80, 161, and 322 km (50, 100, and 200 miles). The coal hauling charge was assumed to be $0.08/t-km ($0.12/ton-mile) Peterson and Birlingmair, 1982.

The cost analysis did not charge labor costs to any system. Labor costs would, no doubt, be higher for the systems using the Stokermatic because coal hoppers need to be filled and ashes removed periodically and more management time is required during operation. Costs for additional duct work necessary to connect the Stokermatics were not included. Possible investment and alternate energy tax credits were also not considered. These, if available, would favor the coal fuel systems.

Values in Table 6 show that ownership costs are much lower for the propane system. Total fuel costs, however, are least for the all-coal systems. Energy costs for the coal range from 44 to 63% of those for propane, depending on the coal hauling distance. Total costs per unit of energy output are quite close for all three systems, but propane costs are lowest in all instances. Propane system total costs are about 6% less than the all-coal system costs for an 80-km (50-mile) distance and are about 16% less for a 322-km (200-mile) distance from the mine.

**CONCLUSIONS**

Based on these studies of coal-fueled corn drying, these conclusions may be drawn:

1. The Burn-All and Stokermatic furnaces operate in the range of 50 to 55% thermal efficiency.
2. Particulate emissions average 1.72 g/MJ (3.99 lb/10^6 Btu) for the Burn-All and 0.79 g/MJ (1.83 lb/10^6 Btu) for the Stokermatic furnace. Neither furnace meets the Iowa Department of Environmental Quality limits. However, use for on-farm grain drying exempts furnaces from these limits.
3. Sulphur dioxide emissions average 2.25 g/MJ (5.23 lb/10^6 Btu) for the Burn-All and 2.08 g/MJ (4.82 lb/10^6 Btu) for the Stokermatic. These values are within Iowa Department of Environmental Quality limits.
4. Hand-fired coal furnaces are being used to supply some or all of the heat for corn drying on two farms near Knoxville, Iowa with satisfactory results.
5. Energy costs for heating systems using Iowa coal range from 44 to 63% of propane costs, depending on the hauling distance for the coal.
6. Total heating system costs are about the same for a propane system and a Stokermatic coal system under conditions assumed. Because of added management required for coal systems, however, a shift to coal fuel is not likely at this time.

**References**