1986

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

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Mechanical Engineering

Comments
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Drying Corn with Coal on Iowa Farms

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This article is reprinted from APPLIED ENGINEERING IN AGRICULTURE (Vol. 2, No. 2, pp. 241-245, 1986)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

ABSTRACT

A study was conducted to determine the feasibility of using Iowa coal as a fuel source for on-farm corn drying. Two furnaces tested operate at 50 to 55% efficiency. Two existing on-farm systems were described. A cost analysis showed energy costs for coal were less than for propane, but heating system costs are about equal and do not favor a shift to coal.

INTRODUCTION

A total of 11.2 x 10^9 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 10^8L (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 10^9t (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 Birlingmair, 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.

Article was submitted for publication in September, 1985; reviewed and approved for publication by the Electric Power and Processing Div. of ASAE in June, 1986. Presented as ASAE Paper No. 83-3511.

Journal Paper No. J-11266 of the Iowa Agriculture and Home Economics Experiment Station, Ames; Project 2540.

Research supported by the Iowa Energy Policy Council, Engineering Research Institute, and Iowa Agriculture Home Economics Experiment Station.

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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 that fed 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 evalute 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

TABLE 1. COAL-FIRED FAN-FURNACE UNITS FOR CROP DRYING (HALL, 1957)

Brand	Manufacturer	Heat output		Coal feed rate		Input to
		MJ/h	Btu/h	kg/h	lb/h	fan kW
Stokermatic	Rheem Mfg. Co. New York, NY	514	0.49×10^6	14 to 28	31 to 62	3.7
BCR	BCR Product Columbus, OH	475	0.45×10^6	20	44	3.7

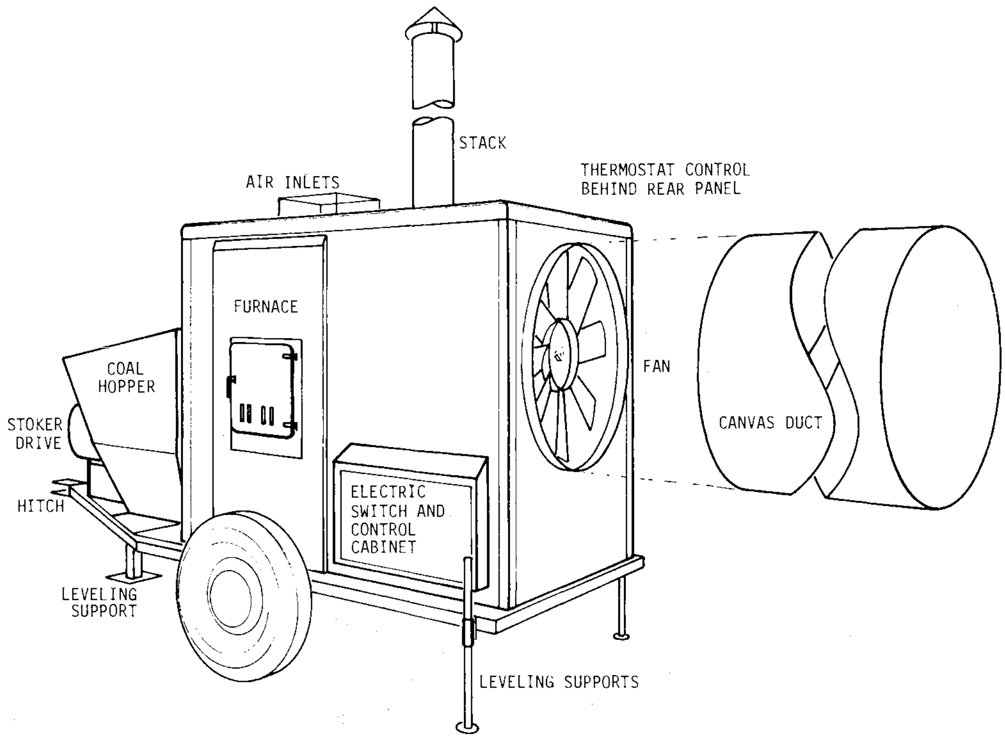

Fig. 1—BCR furnace.

TABLE 2. TEST FURNACE SPECIFICATIONS

Model designation, manufacturer	Feed	Approx. grate area m^2	(ft^2)
Burn-All Versatile Products, Inc. Albert Lea, MN	hand, through 635 mm (25 in.) wide by 914 mm (36 in.) door	0.61	6.6
Stokermatic Sorenson Energy, Inc. Salt Lake City, UT	underfire stoker	0.57	6.1

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

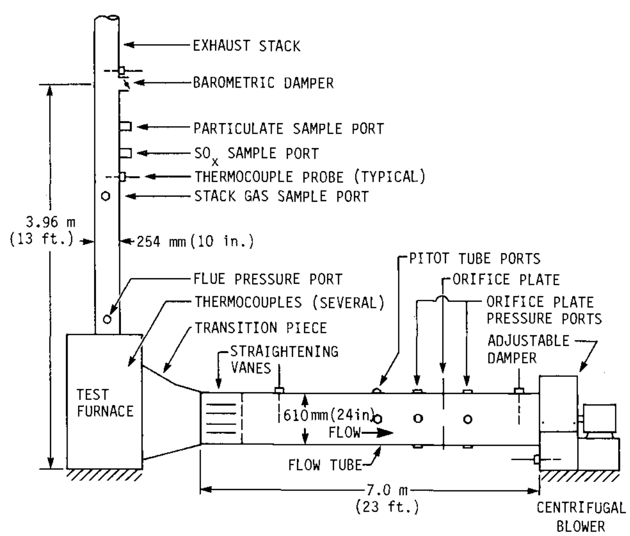

Fig. 2—Furnace test setup.

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)

Size range, mm	Raw coal 51 to fines	Cleaned coal 38 to 6.3
carbon, %	70.30	75.02
hydrogen, %	4.62	4.30
oxygen, %	4.02	4.55
nitrogen, %	1.16	1.41
sulphur, %	7.24	3.99
ash, %	12.66	10.74
pyrite (included in ash), %	4.15	1.72
gross higher heating value, MJ/kg	28.4	29.6
g SO_2 per MJ heating value*	5.10	2.69

*Including all S

TABLE 4. FURNACE FIRING TEST RESULTS

Furnace	Firing rate lb/h	kg/h	MJ/h	Fuel moisture, %	Excess air, %	Heated airflow, L/s	ft^3/min	Efficiency, %	Emissions Particulate, g/MJ	SO^2, g/MJ	Stack temperature, °C	°F
Burn-all												
1. Raw coal	50.0	22.7	569	11.8	33	3142	6658	49.7	1.16	1.53	481	897
	60.2	27.3	679	11.8	−15	3124	6620	54.3	1.15	2.02	508	946
Average					9			52.0	1.15	1.78	495	923
2. Cleaned coal	50.0	22.7	575	14.4	60	3964	8399	57.1	1.97	2.53	483	901
	50.0	22.7	561	16.5	79	1977	4189	44.6	1.55	2.97	464	867
	60.2	27.3	696	13.7	59	3129	6630	49.1	1.42	2.21	523	973
	60.2	27.3	701	13.0	49	1949	4130	47.8	3.07	—	542	1008
Average					62			49.7	2.00	2.57	503	937
Stokermatic												
1. Raw coal	29.5	13.4	329	14.0	135	2723	5770	50.0	1.19	2.74	331	628
	39.0	17.7	431	14.3	105	2718	5759	50.2	0.93	—	398	748
	53.6	24.3	616	10.6	56	2662	5641	50.1	0.53	3.12	428	802
Average					87			50.1	0.88	2.93	407	765
2. Cleaned coal	30.2	13.7	347	14.3	167	2723	5770	60.1	1.10	1.84	346	655
	39.2	17.8	458	13.0	117	2690	5670	56.9	0.66	1.86	412	774
	39.2	17.8	446	15.2	122	2713	5749	50.4	0.69	1.52	412	774
	45.2	19.3	482	15.2	104	2690	5670	54.1	0.77	1.68	402	756
	62.2	28.2	715	14.1	81	2647	5609	51.2	0.44	1.80	466	871
Average					118			54.5	0.73	1.74	407	765

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.

SO_2 emissions

Emission of SO_2 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

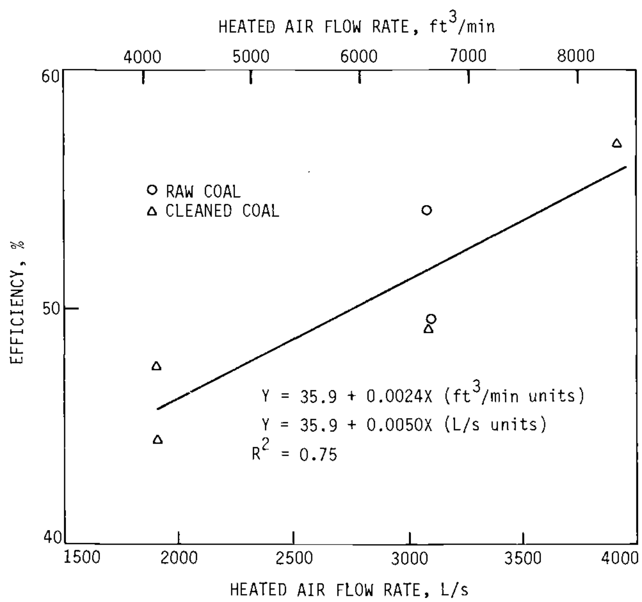

Fig. 3—Efficiency vs. heated air flow rate for Burn-All furnace.

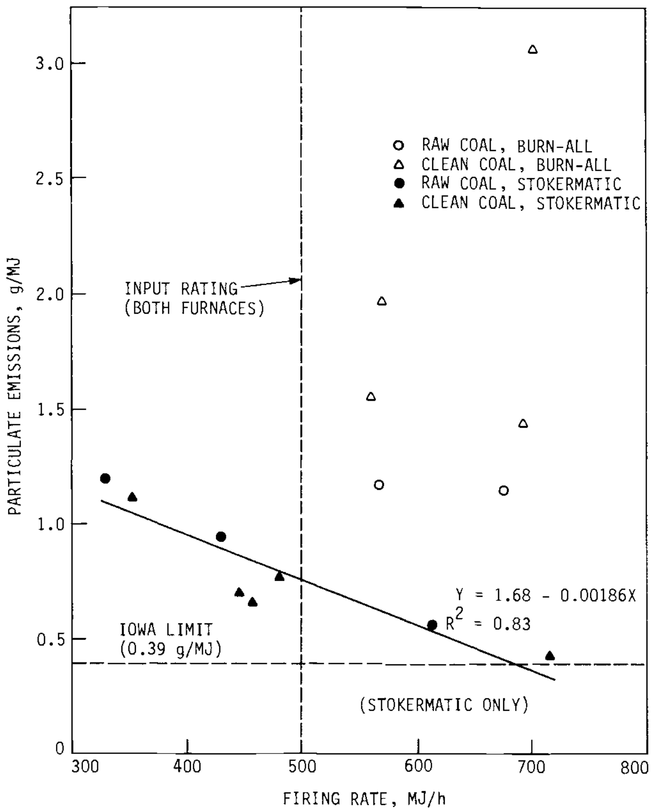

Fig. 4—Particulate emission vs. firing rate.

amounts are the reverse of what was expected. They represent 35% (raw) and 95% (clean) of the SO_2 that would be produced if all sulphur in the fuel was emitted as SO_2 in the flue gas. These reversed results suggest either a large experimental error or incomplete combustion of raw coal because of low excess air.

State laws limit SO_2 emission for a furnace of this size to 2.95 g/MJ (6 lb/10^6 Btu) input. Although two individual tests exceeded this limit, the average of every test series (including the raw coal series for each furnace) was less than this limit. As in the case of particulate emission, furnaces used for on-farm drying are exempt.

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 could operate for several days without resupply of fuel. Ash removal is required for each furnace on about 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 63.6-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 407 t (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

TABLE 5. COST ANALYSIS ASSUMPTIONS

Heater fuel	Propane	Stokermatic cleaned Iowa coal
Nominal input rating, MJ/h	3165	500
Efficiency, %	85	55
Heat value of fuel	25.09 MJ/L	29.6 MJ/kg
Initial cost	$ 905 Burner $1225 Tank	$3800 furnace
Life years	10	5
Salvage value	0	0
Interest rate, %	13	13
Capital recovery factor	0.184	0.284
Fuel cost	$0.17/L ($0.66/gal)	$48.40/t ($44/t) 80 km* $61.60/t ($56/t) 161 km $68.20/t ($61/t) 322 km

*Distance from mine

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:

$$\text{ownership cost} = \left(\begin{matrix}\text{original}\\ \text{cost}\end{matrix}\right)\left(\begin{matrix}\text{capital}\\ \text{recovery}\\ \text{factor}\end{matrix}\right) + \left(\begin{matrix}\text{tax, repair}\\ \text{insurance}\\ \text{factor}\end{matrix}\right)\left(1 - \begin{matrix}\text{income}\\ \text{tax rate}\end{matrix}\right)\Bigg) - \left(\begin{matrix}\text{original}\\ \text{cost/life}\end{matrix}\right)\left(\begin{matrix}\text{income}\\ \text{tax rate}\end{matrix}\right)$$

$$\text{net fuel cost} = \left(\begin{matrix}\text{total}\\ \text{fuel cost}\end{matrix}\right)\left(1 - \begin{matrix}\text{income}\\ \text{tax rate}\end{matrix}\right)$$

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.

TABLE 6. COST COMPARISONS OF HEATING SYSTEMS FOR CORN DRYING

System		Propane	Propane + 1 Stokermatic	5 Stokermatics
Costs, \$/GJ \$/10^6 Btu) of output				
Ownership		0.32 (0.34)	1.11 (1.17)	3.94 (4.16)
Total fuel	80 km (50 mi)*	7.97 (8.41)	7.08 (7.48)	3.54 (3.73)
	161 km (100 mi)	7.97 (8.41)	7.28 (7.68)	4.50 (4.75)
	322 km (200 mi)	7.97 (8.41)	7.37 (7.78)	4.99 (5.26)
Total	80 km (50 mi)	5.90 (6.23)	6.07 (6.41)	6.42 (6.77)
	161 km (100 mi)	5.90 (6.23)	6.21 (6.55)	7.09 (7.49)
	322 km (200 mi)	5.90 (6.23)	6.27 (6.62)	7.43 (7.84)

*Distance from mine

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.

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