Development of a Biomass
Energy System for Drying Corn

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W. F. Buchele, P. W. Claar, II
and S. J. Marley

Department of Agricultural Engineering
Iowa State University
Ames, Iowa 50011

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ABSTRACT:

During the past year, the following research efforts have been carried out:

(1) Evaluation of the design specifications and operation of the ISU-AE incinerator furnace.

(2) Evaluation of existing furnace types for application to burning agricultural residues.

(3) Design of a direct-fired furnace fueled by corn plant residues.

This report will provide a summary of the progress that has been made during the past year. Research has been carried out to provide the design parameters for a new furnace prototype.

EVALUATION OF COMBUSTION PROCESS WITH THE EXISTING INCINERATOR FURNACE:

The first phase of the study was the evaluation of the design specifications and operation for the existing cornstalk fueled, direct-fired incinerator furnace owned by Iowa State University.

A series of tests were made with cornstalks having varying moisture contents (25-60% M.C.). Also, these cornstalks were supplied to the furnace at varying rates (3, 6, and 10 lb/min).

From these tests, several important findings and conclusions were made. First, the combustion process could not be maintained at high feed rates using the higher moisture fuel. This incomplete combustion occurred because there was inadequate time to dehydrate, volatilize, and burn the remaining carbon in the fuel. The problem became more aggravated with increasing feed rates.

Second, to improve combustion, the firebox was lined with refractory material. Firebrick is necessary to radiate the heat from the fire back into the fire. This design feature decreases the time needed to dehydrate and volatilize the fuel. In addition, the higher temperatures allow the particulate matter in the exhaust gases to be completely burned and sustain the burning of the remaining carbon in the fuel.

Third, the firebox grate became covered with slag, a glassy-like, silicon material, after approximately one hour of operation of the furnace. This, in turn, caused a decrease in the combustion rate and efficiency. Slag forms from agricultural residues at approximately 1500°F. As it flows over the grate and down the grate openings, the slag cools and solidifies, thereby closing the grate openings. This, in turn, will prevent primary air from entering the combustion zone. Therefore, it is extremely important that the slag is instantly frozen to prevent its flowing. It should be noted that most agricultural residues contain a large amount of silicon and are covered with soil particles during the harvesting operation. Slag is considered to be frozen if it is below the fusion temperature range of 1450-1500°F.

Fourth, a sufficient supply of primary and secondary air is needed for the complete combustion of fuel. Air is needed to supply oxygen to the fuel and to remove or wipe away the layer of carbon dioxide that forms on the surface of the burning charcoal. Further, the cool air entering is used to freeze the molten slag.

Fifth, the agricultural residues may need to be processed into a fuel form. It may be necessary to crush cornstalks and other materials so that the exposed surface area is increased. This process will allow for a more rapid combustion of the fuel.

In conclusion, the furnace must be designed to provide adequate residence time, temperature and air turbulence. These criteria are necessary for complete combustion of the fuel at the desired heat release rate.

A table containing the chemical analysis of the cornstalk ashes is included, along with a paper, as part of this report.

EVALUATION OF EXISTING COMBUSTION ART:

The next phase of the study consisted of reviewing the available literature for the combustion of agricultural residues and other biomass. Also, furnace manufacturers were contacted to obtain technical literature on their products.

From this literature search, very little information was obtained for burning crop residues. Most of the work has been done in Germany by Dr.-Ing. H. W. Orth, Dr.-Ing. A. Stehler, Dr. E. M. Hofstetter and in Oregon by Mr. T. R. Miles.

From the evaluation of existing furnace types, four appeared to have potential design merit. They were: (1) the cell furnace, (2) the vortex furnace, (3) furnace with gasification chamber, and (4) furnace with sloping firegrate.

The cell was originally developed to burn the crushed sugar cane plant (bagasse), and later modified to burn hogwood. This furnace is a firebrick lined cylinder with a primary and secondary air supply. The principle of this furnace is described in Figure 1. Steam boilers are mounted on top of the furnaces for electricity generation. Severe problems arise from slag due to the field dirt in bagasse. The major manufacturers of these furnaces are:

- (1) Bigelow - Liptak Corp., Detroit, Michigan
- (2) M. H. Detrick Co., Chicago, Illinois

The vortex furnace consists of two chambers, one above the other. The lower chamber dehydrates and gasifies the fuel. The volatile gases are then burned completely in the upper chamber. The remaining carbon in the fuel is burned in the lower chamber. The Lamb-Cargate (New Westminster, British Columbia) unit is shown in Figure 2. Also, Miles developed a mobile vortex unit to burn grass straw in the state of Oregon.

The two-stage furnace has been developed in West Germany to burn large packages of grain straw. The straw is devolatilized in the primary chamber and the combustion gas are burned in the secondary chamber. One of these furnaces has been installed at Lyndhurst Farms, Canning, Nova Scotia. The furnace supplies heat at the rate of 4 MMBTU/HR for drying grain. Orth has extensively investigated the combustion process of this furnace and reported his findings. This German furnace is being marketed by PSW - Gesellschaft zur Herstellung von Verbrennungs - analangen m.b.H. and is shown in Figure 3. Other European straw burning furnaces have been developed and are available commercially in Europe.

The last furnace type uses a sloping firegrate. The fuel moves down over the grate surface by means of gravity or reciprocating grate bars. The sloping grate design is employed to allow a longer residence time for the fuel in the furnace. Furnaces with sloping grates have been used extensively for burning coal or wood.

DESIGN OF THE BIOMASS FURNACE:

The last phase of the study has been to design a furnace for burning agricultural residues, in particular, the corn crop residue. In conjunction with this design, Mr. T. R. Miles (Beaverton, Oregon) a consulting engineer, was retained for his expertise in the area of agricultural residue burning.

The first step in the design process was to determine other applications, besides grain drying, for a furnace for year-round farmstead use. With these other applications, it was felt that the overall economic cost analysis for the furnace could be improved. The decision was based upon the concept that a modularized furnace package could be designed and built. Some possible uses for the furnace are heating water for the farm buildings and generating steam for an ethanol distillery. Also, the furnace should have the capability of burning various agricultural residues and should handle the residue in various forms. The flow diagram, shown in Figure 4, shows the possible uses for the furnace.

After defining the possible farmstead uses, the following design objectives for a furnace were formulated:

(1) Develop the furnace to be comprised of a set of modular components. For example, the same hearth could be used for either direct firing or an air to air exchanger.

(2) Feed the furnace with various forms of agricultural residue. The furnace should be able to handle the residue in both loose form and packaged or bale form.

(3) Meet the federal and local EPA emissions standards.

(4) Prevent slag formation on the grate surface. This may be accomplished by controlling the temperature in the combustion chamber, so that the temperature is below the fusion point of the agricultural residue ash.

(5) Utilize state-of-the-art furnace technology.

- (6) Construct the furnace with simple manufacturing technology,

With the design objective in hand, several design concepts for a furnace were sketched. These concepts are shown in Figures 5 and 6. After careful evaluation and some preliminary testing, these concepts were dropped from further consideration.

AGRICULTURAL RESIDUE FURNACE:

To utilize agricultural residue as a fuel source, a vortex furnace has been conceived and designed. This furnace may be utilized for the following applications:

- (1) Supply the hot combustion gases along with ambient dilution air to a grain dryer.
- (2) Supply hot combustion gases to an air-to-air heat exchanger for grain drying.
- (3) Possible supply of hot combustion gases to generate steam in a recovery boiler or heat water for high temperature uses.

A schematic diagram of the furnace is shown in Figure 7. The possible applications for the furnace and its heat release capacities are also included. The furnace has the capability of burning chopped or baled agricultural crop residue. The furnace has incorporated the best design features from the cell and vortex furnaces described earlier in this report.

The furnace is now under construction and will be operating this coming crop-drying season at an Iowa State University grain bin site.

AMES LABORATORY
ANALYTICAL REPORT FORM

Recd. 2/10/79

Repd. 2/15/79

ANALYTICAL SERVICES GROUP 1

Description of Sample Corn Stalk Fly Ash Requested By P. Claar
Room _____ Bldg. _____
Telephone _____ Act. No. _____
Other Elements Present _____ Group Leader's Approval _____

SAMPLE NUMBER	DETERMINATION REQUESTED	ESTIMATED CONCEN.	ANALYTICAL RESULTS				AVERAGES
	SiO_2		72.7	72.0	} ran on ignited and ground sample		
173	Al_2O_3		5.2	5.4			
	Fe_2O_3		2.29	2.18			
	CaO		4.95	4.98			
	MgO		4.60	4.61			
	Na_2O		0.90	.89			
	K_2O		7.83	7.82			
	TiO_2		0.24	.25			
	P_2O_5		1.12	1.13			
	SO_3		0.45%	0.42%			
	C		0.15	.11			

$100 + 20 \pm$

$100 = 0.03$ $LOI = 0.03$

Analyst _____ Analyst's Record Book Reference _____

Remarks Austin Bachman GA 15° 161-176 BR-3-139

AMES LABORATORY
ANALYTICAL REPORT FORM

Recd. 2/16/79

Repd. 2/15/79

ANALYTICAL SERVICES GROUP 1

JAMES S. FRITZ Group Leader

Description of Sample Corn Stalk Fly Ash Requested By P. Claar
Room _____ Bldg. _____
Telephone _____ Act. No. _____
Other Elements Present _____ Group Leader's Approval _____

SAMPLE NUMBER	DETERMINATION REQUESTED	ESTIMATED CONCEN.	ANALYTICAL RESULTS				AVERAGES
	SiO_2		71.6	72.7	} ran on ignited and ground sample		
173	Al_2O_3		4.4	4.2			
	Fe_2O_3		4.66	4.71			
	CaO		5.13	5.17			
	MgO		3.95	3.89			
	Na_2O		1.32	1.25			
	K_2O		4.36	4.45			
	TiO_2		0.23	.21			
	P_2O_5		1.05	1.04			
	SO_3		0.14%	0.16%			
	C		0.15	0.11	1.35	1.38	

$100 + 10 \pm$

$100 = 0.84$ $LOI = 3.78$

Analyst _____ Analyst's Record Book Reference _____

Remarks Austin Bachman GA 15° 161-176 BR-3-139

Pr i c p e s of M U L T I - C E L L Design

← SUSPENSION BURNING

As much as 40% of the fuel burns in suspension. The fuel pile on the solid hearth is free from fines, and open for penetration of air and radiant heat. This permits rapid drying and combustion, resulting in higher burning rates — even without the use of preheated air.

CHUTE →

Fuel enters the cell at the point of greatest turbulence, where fine parts are separated from the heavier particles.

← WHIRLWIND

The whirlwind action of the gases separates the fine particles and holds them in suspension.

← CYCLONIC ACTION

Secondary air is introduced at the restricted throat through tangential ports producing a swirling action that intimately mixes fuel and air.

← PRIMARY AIR

Is introduced to the lower solid hearth area through many small ports in the refractory wall.

← FUEL PILE

Heavier particles drop on to a solid hearth where the air and radiant heat can penetrate the mass because there are no fine particles.

← RESTRICTED

Restricted throat area increases velocity and turbulence of gases at this point.

← AIR DUCTS

A separate dampering and duct system is provided for each cell. This allows for complete isolation of the cell during ash removal, and facilitates control of primary and secondary air.

Figure 1. Dennis-Cell Furnace

Figure 2. Lamb-Cargate Furnace

Type VBA-GBO-H

COMBUSTION PLANT FOR MANUALLY OPERATED LOADING

(for big-bales-straw)

Description:

- 1 = Combustion Plant
(Producer of energy)
- 2 = Loading crane
- 3 = Big bale
- 4 = Lock

Possibilities of application:

Adaption to already existing central heating systems in residential premises, stables, machinery halls, workshops, greenhouses, etc.

Figure 3. German Big Bale Furnace

Figure 4. Material & Heat Flow for Agricultural Residue Furnace

Figure 6. Concept for a Big Bale Furnace

PRIMARY FLUE GAS

427 - 649°C (800-1200°F)

1.1 - 5.2 10³ MJ/HR (1-5 MBTU/HR)

.2 gr/SCF PARTICULATE

F.D.
FAN

VORTEX
AG RESIDUE
FURNACE

SLAGGING GRATE
CAPTURES PARTICULATES
BURNS BALES OR COBS,
CHOPPED STALKS, STRAWS

91 - 450 Kg/HR (200-1000#/HR)

10 - 30% MCWB

DRYER FAN

PRIMARY OR SECONDARY AIR:
GRAIN/CROP DRYING,
SPACE HEATING, ETC.

STEAM/HI TEMP. H.W.
206 Pa - 127°C
(30 PSI - 260°F)
PROCESS/SPACE HEATING
DISTILLATION

SCHEMATIC OF VORTEX FURNACE
SYSTEM FUELED BY AG RESIDUE
for IOWA STATE UNIVERSITY

Figure 7

6/79

THOMAS R MILES
Consulting Engineer
5475 SW Arrowwood Lane
PORTLAND, OREGON 97225