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Retention of Gasification-Combustion Products by Corn

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ABSTRACT

Shelled corn was dried in layers of 5.1 cm (2 in.) 10.2 cm (4 in.), and 15.2 cm (6 in.) using air heated with the exhaust from a corn-cob fueled gasification-combustion updraft furnace. The drying air entering and leaving the grain layers was sampled for particulate content to determine the percentage of total particulates trapped by the grain during drying. It was determined that an average of 25% of the total particulates in the drying air were retained by the grain. The large majority of those particulates retained were found in the bottom 5.1 cm (2 in.) of the grain layer.

INTRODUCTION

The gasification-combustion of corncobs as a means of providing an alternate energy source for grain drying shows great promise. Increased energy efficiency and reduced cost will result if the exhaust gases from a gasification-combustion process may be passed directly through the grain being dried without using a heat-exchanger. The technology for such a system is available and the economics are very promising. However, the effects of this type of process on the quality of grain need to be carefully evaluated. Specifically, the objectives of this study were to:

1. Determine the extent to which particulates in the exhaust from a corn-cob gasification-combustion unit are trapped by grain.
2. Determine the effect of the depth of grain being dried on trapping efficiency.

LITERATURE REVIEW

Drying grain is an energy-intensive practice that presents an ideal situation for the use of biomass, provided it can be shown that direct utilization of this energy source is technically and economically feasible and does not adversely affect grain quality. Investigators who have examined the gasification-combustion process for agricultural applications include Payne (1980), Payne et al. (1979, 1981), Morey and Thimsen (1981), Richey et al. (1981, 1982) and Bozdech (1980). These writers indicate that such a system is technically feasible. Loewer et al. (1982a, 1982b) have indicated that using gasification-combustion for drying corn with cobs as the fuel is economically feasible.

Grain quality, however, may be adversely affected if the products of the gasification-combustion process are trapped by the grain in sufficient quantities and concentrations. Thus, the quantity of particulates contained in exhaust from a biomass gasification-combustion process is also an important consideration. Barrett et al. (1983) analyzed the emissions from three different cob-fueled gasification-combustion systems. After the exhaust was sufficiently diluted to provide a proper drying temperature, the concentration of particulates ranged from 5.3 mg/m^3 to 17.2 mg/m^3, the average being 11.1 mg/m^3. This compares favorably with preliminary tests performed by the authors using the biomass unit described by Payne (1980). Barrett also examined the particle size of the particulates collected from one of the furnaces under consideration. It was determined that 90 percent of the particulates were less than one micron in diameter.

Payne (1980) observed that particulate emissions increased in proportion to the second power of the gasification rate for his range of test conditions. He estimated that the biomass gasification-combustion unit, when operated at its maximum gasification rate, could potentially deposit 0.1 g of particulates per kg of corn at 15% moisture content (wb). He considered this to be relatively low when compared to the levels of particulates naturally present in the grain or generated during handling. Naturally occurring levels were estimated to be approximately 1 g of particulates per kg of corn and soybeans, and 0.5 g of particulates per kg of wheat. Therefore, the process in question could potentially increase dust concentration on the grain by 10 to 20 percent. Barrett, et al. (1983) found that collection efficiencies of a 3-foot layer of corn were from 26 to 60% of the total particulates contained in the drying air produced by a biomass gasification-furnace using cobs as fuel. Particles collected from the airstream after passing through the grain were smaller than those collected before entering the grain.

The chemical composition of the products of combustion are also important in terms of grain contamination. Sizemore et al. (1983) provide a discussion of this aspect of particulate deposition along with a review of other studies in that area. However, chemical composition will not be addressed in this paper.

EXPERIMENTAL DESIGN

The hypothesis associated with this study was that depth of grain above 5.1 cm would not significantly influence trapping efficiency of grain as related to particulates in the exhaust gases from the gasification-

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combustion process. An experimental design was established so that particulates were passed through a grain depth of 5.1 cm. Trapped particulates were determined by sampling the drying air before and after it passed through the grain. These tests were repeated for grain depths of 10.2 cm and 15.2 cm. If there was no significant statistical difference amoung these depths with regard to total particulates trapped by the grain, the hypothesis would be accepted.

In designing the test series, it was determined that all extraneous sources of variability could be reduced to the following two time-related considerations: (a) the relative order in which the various tests were performed on a given test day, and (b) the relative order of the test sets over the days required to complete the experiment. These two parameters were incorporated into a Latin-square so as to take into account variations in operating characteristics associated with weather, fuel quality, and atmospheric dust levels. The selected treatments were depths of grain. The Latin-square design was replicated twice giving a total of six tests for each grain depth.

The experimental grain drying system was a modification and extension of the biomass gasification-combustion unit designed and constructed by Payne (1980) at the University of Kentucky (Fig. 1). In using this unit for grain drying, the exhaust from the combustion chamber was mixed with sufficient ambient air to arrive at an appropriate drying air temperature and air flow. As the exhaust exited the combustion chamber it passed upward through an eductor fan that provided the airflow for starting the biomass unit. An exhaust duct above this fan controlled whether the exhaust was channeled to the atmosphere (as in the warming-up stages) or diverted into the drying system. After a warm-up period, a centrifugal fan replaced the eductor fan in the system. A calibrated orifice plate was used to measure the total airflow past the exhaust duct which included the added ambient air pulled through the eductor fan and exhaust exit. The diluted exhaust was then transferred to a 35.6-cm (14-in.) diameter duct where it was mixed with more ambient air to provide the desired temperature and airflow rate. The addition of ambient air to this part of the system was controlled by a funnel-shaped valve which regulated the size of the opening in the end of the 35.6-cm (14-in.) diameter duct.

The "drying air" was transported down the 35.6-cm duct past the first sampling point and in to the centrifugal drying fan. The airflow was again measured in the 35.6-cm duct using a calibrated orifice plate. By combining this value with those obtained from the two orifice plates upstream, the proportion of exhaust to ambient air was determined.

The quantity of drying air diverted to the grain bins was controlled by exhausting an appropriate amount of the drying air to the atmosphere. The drying air was transported to the 45.7-cm (18-in.) diameter grain bins by means of a 30.5-cm (12-in.) diameter duct. The drying air passing through the grain was measured by calibrated orifice plates located in the exhaust tubes of the grain bin.

The grain bins were made of 45.7-cm (18-in.) diameter PVC plastic pipes, and the grain was supported by a screen floor. The bins were capped by funnel-shaped exhaust systems which route all the exhaust air through orifice plates for flow measurement purposes. The locations of the thermocouples used to measure the necessary temperatures are shown in Fig. 1.

Air sampling equipment was constructed in close compliance with the ASTM D 2928-71 standard method. A description of the sampling equipment used is given by Payne, 1980 (Fig. 2); one change is that the sampling probes were made of stainless steel rather than of inconnel. This change was possible because of the relatively lower temperatures of the air being sampled.

PROCEDURES AND METHODS

Each test was accomplished by drying the appropriate depth of grain over a period of 1.5 - 2.0 h. A total of six particulate samples were collected during this time period. Two samples were drawn as the drying air exited from each of the two grain bins. Samples of the inlet drying air were taken at the beginning and the end of each test (Fig. 1).

The biomass gasification-combustion unit was operated for at least one hour before being used for drying the grain. The tests were conducted with a constant airflow of 0.302 $m^3/s * m^2$ (51 $SCFM/ft^2$), thus the velocity of air and particulates through the grain was constant for all grain depths. The drying air was maintained at 71°C (160°F) as it entered the grain. Initial grain moisture ranged from 13 to 15% wet basis.

The grain was vacuum cleaned prior to testing to remove particles that could be readily picked up by the air stream. Preliminary experimental tests indicated that vacuum cleaning was both necessary and adequate in terms of sample preparation.

Particulate concentration in the airstreams was determined by drawing a known volume of air from the

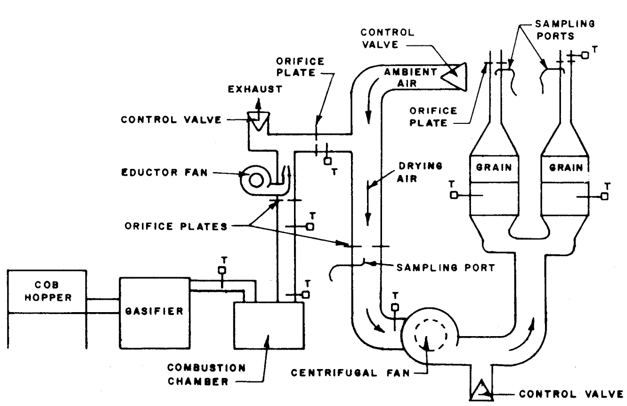

Fig. 1—Drying apparatus showing sampling ports and thermocouples.

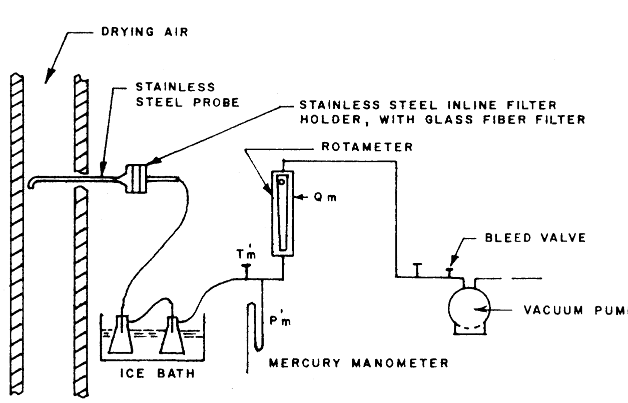

Fig. 2—Particulate sampling train (Payne, 1980).

airstream isokinetically and passing it through a glass filter to collect the particulates. The procedure followed the standard method, ASTM D 2928-71. Samples were taken from the airstream before air entered the grain (inlet) and after it passed through the grain (outlet). For the inlet determination, samples were drawn from 35.6-cm (14 in.) vertical duct on the negative side of the drying fan. The sample was drawn from two different points in the airstream corresponding to radii of 8.9 cm (3.5 in.) and 16.5 cm (6.5 in.), these two points representing the centroids of two equal areas. For the outlet determination, samples were drawn from 10.2-cm (4 in.) vertical exhaust duct at a point 1.2 m (4.0 ft) above the grain. Because of the relatively small diameter of the outlet duct the air-stream was sampled at only one point at a radius of 2.5 cm (1 in.), which is a slight deviation from the standard method. For calibration, the two samplings ports were compared in testing with no grain or other obstruction between them.

The velocity pressure of the inlet airstream was determined using a standard pitot tube. Cheremisinoff and Morresi (1978) suggested that if the velocity of the exhaust entering the probe is changed by more that 10 percent, the measured particulate concentration has little validity. The velocity pressure was used to calculate the velocity at the sampling point and subsequently the appropriate sampling rate according to equation found in ASTM D 2928-71. Once the desired sampling rate was obtained, a Dwyer rotometer was used to meter that rate during sampling. The rotometer was calibrated using a standard recommended practice ASTM D 3195-73 with a Fisher Wet Test Meter. The velocity in the outlet duct was determined by a calibrated orifice plate.

The glass filter pads used for particulate collection were prepared by ashing for 15 min at 500°C and cooling in desiccators until a constant weight was obtained. After the particulates were collected, the pads were again cooled and dried in desiccators until a constant weight was obtained. This weight and the weight as determined prior to sampling were used to determine the total weight of collected particulates.

RESULTS

Results of the tests (Table 1) show that an average of 25.1% of the total particulates were retained on the grain. Duncan's Multiple Range test (alpha level = 0.05) indicated no difference in particulate retention among the 5.1 cm (2 in.), 10.2 cm (4 in.) and 15.2 cm (6 in.) depths. This would confirm the hypothesis that most of the particulates deposited on the grain are trapped in the bottom 5.1 cm (2 in.) or less of the grain.

The statistical tests did indicate significant differences between test days. These were no significant differences between the relative times of day at which the tests were conducted.

TABLE 1. EFFECTS OF GRAIN DEPTH ON PARTICULATE RETENTION

	Average percentage of total particulates retained		
Order* of tests	5.1 cm (2 in.)	10.2 cm (4 in.)	15.2 cm (6 in.)
1	17.2%	18.2%	21.3%
2	12.4%	9.6%	—
3	36.5%	22.2%	24.1%
4	39.0%	32.0%	28.8%
5	6.5%	22.5%	6.1%
6	—	34.1%	36.6%
Avg.†	23.2%	25.8%	26.4%

Average of all test values = 25.1%

*Order of tests refers to the sequence in which tests were conducted in the Latin-square design for each depth. Each percentage listed is an average of all values obtained for that run.

SUMMARY

The updraft biomass gasification-combustion furnace developed and constructed at the University of Kentucky was modified to provide heated air to dry grain for the purpose of testing for particulates deposited on the grain by the drying air. Corn was dried with this system using cobs as fuel. Samples were taken from the airstream before and after passing through the grain to determine the quantity of particulates trapped by the grain. It was found that an average of 25.1% of the total particulates in the drying air was retained by the corn. The tests also indicated that practically all particulates were trapped in the bottom 5.1 (2 in.) of grain. This is important in that it indicates that most of the grain will be contamination free, while the bottom layer may have relatively high concentration of particulates. This finding could also have consequences on the location and concentration of benzo(a)pyrene and other carcinogenic aromatic hydrocarbons.

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