# Combustion Studies on Manure

by

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## ABSTRACT

This study addresses two major areas. First, existing data is used to determine the tonnage, composition, energy content, and distribution of manure resources in the U.S.. This data is then analysed with respect to the manure resource's economic utility. Secondly, preliminary results for a new combustor design, constructed for this project, are presented.

The survey on manure resources indicates a huge tonnage of manure produced each day. However, costs associated with collection, transportation, and storage are quite high. These costs are compounded by low energy content for the fuel itself. From an economic standpoint, manure to energy conversion is marginal at present. Manure's use in the future as an energy alternative is highly dependent on the cost of other fuels in the nation's energy mix.

The combustor design is somewhat similar to that used in recovery boilers in that it uses a free fall method for combusting manure while hot combustion gases flow upward through it. The ash is collected at the base of the combustor and continuously removed.

Preliminary results indicate that feedlot manure is difficult to burn in this configuration when compared with fine sawdust. Explanations for these observed differences are presented. Finally, proposals for additional study of this combustor configuration are provided.

## ACKNOWLEDGEMENT

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# I. Introduction

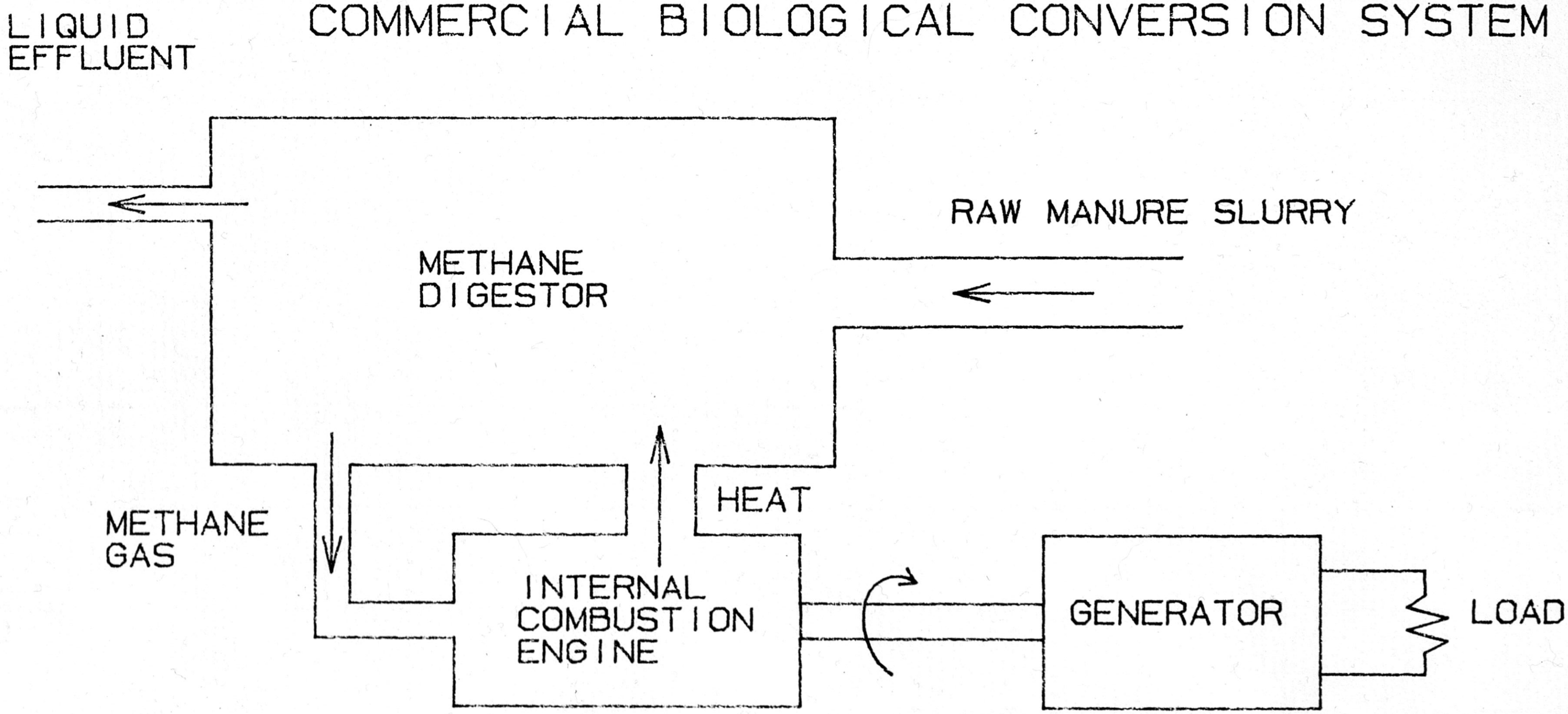
The United States, and the other industrialized nations of the world, share a common quandary. Each comsumes vast quantities of energy, a vital ingredient of continued economic growth without which they would likely collapse. Their cumulative depletion of finite fossil fuel reserves is enormous. This means that unless alternative energy sources are developed, each faces a dismal future.

Recently, interest has surfaced in the United States to find economical methods to convert manure wastes into useable energy forms. Two basic causes form the basis of this interest. First, manure appears to offer a viable supplement to the nation's energy mix in the face of the almost universal realization that conventional fossil fuels are indeed, finite. In addition, manure creates serious water pollution problems in those areas where livestock concentrations are high. Above a certain limit, (approximately 20 tons/acre/year (Gilbertson et al)), the land simply cannot absorb animal wastes without serious long term damage. Application at rates higher than this limit also raises nitrate levels to damaging levels in runoff waters, causing serious environmental impact hundreds of miles downstream. For these reasons, energy conversion appears to offer the possibility of attacking two problems with one solution.

Recent American approaches to manure conversion have concentrated on two areas: gasification (both biological and thermal), and direct combustion. Biological gasification uses a bacterial reaction at an optimal temperature of 318 K (113 F) to produce methane gas which is then combusted for heat and or electricity. Figure #1, on the following page depicts a successful biological gasification system on a 1600 head dairy farm near Gettysburg, Pennsylvania. Thermal gasification employs heating to decompose manure in volatile gases and solid carbon char. The char is further reacted with $O_2$ and $HO_2$ to produce CO, $CO_2$, and $H_2$ By contrast, the direct combustion method involves burning animal wastes directly for heat and, or

FIGURE #1

COMMERCIAL BIOLOGICAL CONVERSION SYSTEM




LOCATION: MASON DIXON DAIRY FARMS
GETTYSBURG, PA.

MANURE TONNAGE: 12 TONS PER DAY

conversion to electromechanical forms. Each of these methods has advantages and disadvantages depending on the type of operation they are applied to and the final form of energy required.

However, direct combustion is far more efficient in converting the available energy in the manure to usable forms. For that reason. most of the commercial interest has concentrated on direct combustion.

National Energy Associates of Imperial, California has commenced construction of a 17-megawatt electric generating facility supplied by a portion of the 1,850 tons of manure that accumulates in California's Imperial Valley each day (Forbes 3/86). William Parish, founder of National Energy Associates expects to produce electricity at 2 cents a kilowatt-hour from manure that costs $5.50 per ton. In Hereford, Texas, Valley View Corporation is planning a 40-megawatt electric power plant fueled by manure and based on fluidized bed technology but, using the circulating bed concept.

## II. Project Objectives

This research project had two main objectives. The first was to quantify and qualify the manure resources in the United States in terms of their economic recoverability. The second was to design a simple, low cost, steady state manure combustor to obtain preliminary combustion results.

## III. The Manure Resource

### Quantity and Distribution

Van Dyne et al (1979) estimated the amount of livestock and poultry manure voided in the United States to be 112 million tons on a dry basis in 1974. About 47 percent was produced by beef cattle on pasture and range, 23 percent from dairy cattle and 30 percent from other livestock and poultry. These figures were compiled by multiplying the appropiate inventory number by the relevant manure

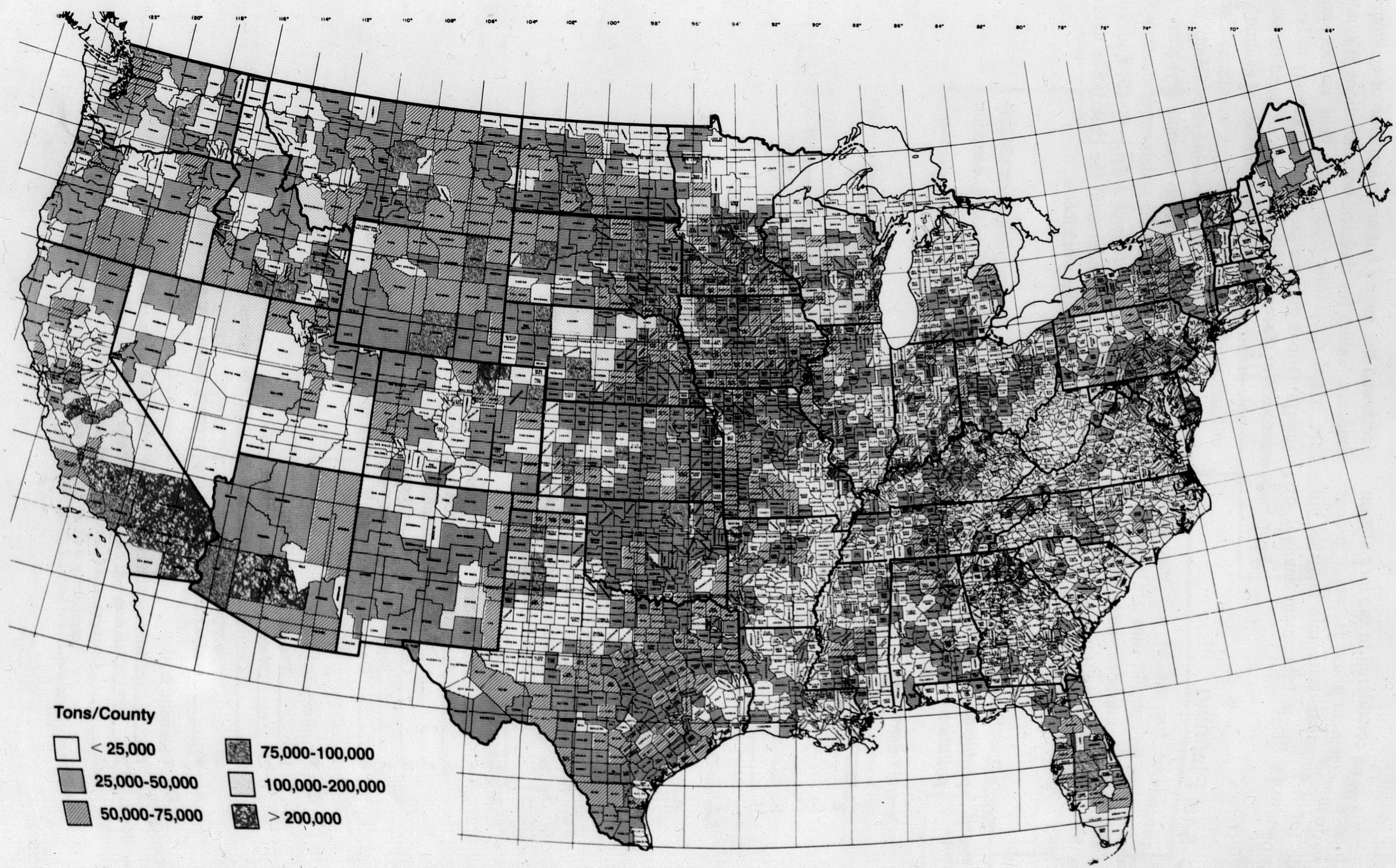



**Figure 2.**—Manure production by livestock and poultry after losses from storage and waste-handling systems in the continental United States, 1974.

production coefficient for each species. By themselves, they provide little indication of the availabity of manure for combustion.

However, the distribution map included in the same study by Van Dyne provides data on manure concentrations throughout the United States. States in the North East, Middle Atlantic and Upper Midwest show manure concentrations centered around dairy operations, while those in the Mid-West, South-West and Far West show the highest overall manure concentrations resulting from highly localized feedlot operations.

Seven western states acount for the majority of feedlot manure produced. In Table #1, raw manure output for these seven states is computed using data supplied by (Whetstone et al) along with inventory and bodyweight figures from Jule Andrews of the USDA office in Austin, Texas. According to Whetstone, beef cattle produce 5.7 pounds of dry manure each day for every 1000 pounds of animal weight. Jule Andrews indicated an average weight for beef cattle of 900 pounds. From these figures, a production coefficient of 0.00257 tons per head per day was used to calculate the output in each state based on the animal inventory provided.

Similar data for the largest dairy states was not available at the time this was written.

Dairy and feedlot operations although, both sources of collectible manure, possess significant differences with respect to their utility for direct combustion in manure fired units. Dairy operations are usually small as compared to feedlot operations, which may approach 50,000 head or more. Most dairy operations operate with a collection system in place and remove fresh manure daily. Feedlot operations, by contrast, scrape the manure off the pen floor at the conclusion of each 5-6 month fattening period. For that reason, feedlot manure tends to be both dryer and more ashy than dairy manure.

**Table #1**

Raw Manure Output for the Seven Major Beef Producing States

| State | Cattle (1000's) | Manure (tons dry wt.) |
|---|---|---|
| Arizona | 239 | 613 |
| California | 433 | 1,110 |
| Colorado | 615 | 1,577 |
| Iowa | 500 | 1,283 |
| Kansas | 1,300 | 3,335 |
| Nebraska | 1,200 | 3,078 |
| Texas | 1,850 | 4,745 |

Table 2

Chemical Analysis of Cattle Feedlot
Manure Supplied by Valley View Energy Corporation (August,1985)
(Manure D)

| | As Received | | After Drying (As Fired) | |
|---|---|---|---|---|
| Proximate | Wet Basis % | Dry Basis % | Wet Basis % | Dry Basis % |
| Moisture | 24.6 | -- | 10.8 | -- |
| Ash | 31.92 | 42.34 | 36.44 | 40.85 |
| Fixed Carbon | 3.48 | 4.61 | 5.15 | 5.78 |
| Volatile | 40.0 | 53.05 | 47.61 | 53.37 |
| Ultimate | | | | |
| Carbon | 21.98 | 29.15 | 27.3 | 30.60 |
| Hydrogen | 2.67 | 3.55 | 3.08 | 3.45 |
| Nitrogen | 1.69 | 2.25 | 2.07 | 2.32 |
| Chlorine | 1.02 | 1.35 | 1.13 | 1.26 |
| Sulfur | 0.46 | 0.61 | 0.60 | 0.67 |
| Oxygen | 15.66 | 20.75 | 18.58 | 20.8 |

Analysis Provided by Dickinson Laboratories, INC

P.O. Box 5247

Bryan, Texas 77805-5247

Table 2

Continued

| | | | | |
|---|---|---|---|---|
| Heating Value | | | | |
| As Received | | | | |
| (KJ/KG) | 8515 | 11297 | 10677 | 11969.8 |
| (Btu/lb) | 3671 | 4869 | 4602 | 5159 |
| Calculation 'Boie' Eq(kJ/kg) | | 12677.8 | | |
| Chemical | $CH_{1.45}O_{0.53}N_{0.066}Cl_{0.012}S_{0.0078}$ | | | |
| | $CH_{1.34}O_{0.51}N_{0.065}Cl_{0.014}S_{0.0082}$ | | | |
| Formula | | | | |

## Composition

Manure consists of four main constituents of significance in direct combustion. They are moisture, ash (soil and other included inert materials), fixed carbon, and volatile solids. Table #2 provides a proximate analysis of a sample of feedlot manure. Although the constituent values for this sample fall about in the center of a wide spectrum of all samples tested, scatter is particularly severe for manure samples, so it cannot be considered representative of the manure resource in general.

The amount of ash, on a percentage basis, has a huge effect the heating value of manure on a per pound basis. Impossible to remove economically, it acts as thermal mass while contributing nothing to the heating value. Ranging from a low of 10 percent to a high of over 70 percent on a dry basis, ash content is the most significant factor affecting manure's utility as fuel. For that reason, the factors that affect ash content deserve consideration.

Variations in ash content generally are connected to differences in collection systems, weather during exposure, and biological breakdown resulting from storage. As the following data indicates, each of these variables can have profound effects on the final ash content of the manure samples studied.

Sweeten (1981) found that as initially voided, feedlot cattle manure normally contains 15 percent ash on a dry weight basis. Hansen et al. (1976) in a study of unpaved Colorado feedlots found and average ash content of 37.14 percent with a range of between 30.7 and 42.9 percent. The sampling was made above the obvious soil interface and at two week intervals during the 6 month production period. Sweeten, in the same study found 20-30 percent ash on a dry basis for surfaced feedlots and values of between 30 and 70 percent for unsurfaced feedlots under the same weather conditions. This data clearly indicates that soil contamination in feedlot operations can double or triple ash content

Biological degradation appears to occur in parallel with soil contamination on

Table 3

Chemical Analysis of Cattle Feedlot (Manure B)
in 1983 and the Same Manure 2 Years Later (Manure C)
Used by Madan (1984)

| | Composted | | Composted Manure | |
|---|---|---|---|---|
| Proximate | Wet Basis % | Dry Basis % | Wet Basis % | Dry Basis % |
| Moisture | 18.02 | -- | 12.76 | -- |
| Ash | 34.10 | 41.59 | 64.13 | 73.52 |
| Fixed Carbon | 9.12 | 11.12 | 4.45 | 5.09 |
| Volatile | 38.77 | 47.3 | 18.66 | 21.33 |
| Ultimate | | | | |
| Carbon | 27.01 | 32.95 | 11.30 | 12.96 |
| Hydrogen | 4.02 | 4.90 | 1.26 | 1.45 |
| Nitrogen | 0.57 | 0.69 | 1.27 | 1.46 |
| Chlorine | 1.32 | 1.61 | 0.19 | 0.22 |
| Sulfur | 0.64 | 0.78 | 0.27 | 0.31 |
| Oxygen | 14.32 | 17.48 | 8.82 | 10.08 |

Table 3

Continued

| | | | | |
|---|---|---|---|---|
| Heating value (KJ/Kg) | 12395 | 15210 | 3679.8 | 4218 |
| Heating value (Btu/lb) | 5342 | 6555 | 1586 | 1818 |
| Boie HV (KJ/Kg) | | 15467 | | 5348 |

the feedlot surface and continues well after the manure is placed in dry storage. Sweeten, in the preceding study, attributes the 5 to 15 percent increase in ash content for surface feedlots to biological degradration. Table #3 shows results of dry storage for two years of a composted manure. Ash content increased by 77 percent over this period. Ash content appears to increase on a percent basis (as opposed to an absolute basis) as the volatile solids gasify due to bacterial action and slow pyrolysis.

Environmental factors also play a large role affecting ash content. Hansen found that manure collected from a muddy feedlot after a wet Colorado winter showed much higher ash content than that collected from the same feedlot following relatively dry weather. Two possible explanations can be used to account for this. First, soil contamination is likely to be higher during wet weather than dry. Second, the rate of biological degradation is likely to be higher during periods of high manure moisture content. Weather is of particular importance to the feedlot operations where manure is exposed for up to 6 months. Dairy operations generally would be immune to direct weather affects because of the frequency of collection and the prevalence of protected collection surfaces.

## Economic Considerations as They Affect Direct Combustion

Manure is a relatively low energy fuel on a mass basis as compared to other fuels commercially consumed today. For that reason, economic factors will likely determine the success and extent of commercial ventures that use manure as a primary fuel in energy conversion cycles. This study will look at the economic factors that come into play between the location of initial production and the combustion unit, itself.

Collection at the farm level is a necessary first step. This limits economical manure to those operations where the animals void in relatively small area. Feedlot, dairy, swine, and variety of poultry operations are likely to satisfy this condition. Areas that produce a surplus of manure above what the land can safely absorb often have to pay disposal and or storage costs to remove their surplus. In these areas, direct combustion will be particularly attractive from an economic standpoint.

The second step involves hauling the manure from farm to combustion unit. Manure's low energy values, on a per kilogram basis, would limit economically feasible hauling to short distances. Large scale power plants (20-40 megaWatt size) would likely be feasable only in areas of concentrated feedlot operations. In the dairy areas, where manure is concentrated at the farm level as opposed to a regional basis, combustion units would likely have to be located on the farm itself to be economically feasable.

To sum up, economic realities would seem to limit manure combustion to small, low capitalized on-site units at least for the near future. Large, highly, capitalized central power plants would be extremely vulnerable to small price swings in the overall energy market. Small simple units would offer the capability of rapid change without out massive loss should manure's competitive economic edge disappear under pressure from falling prices of the more traditional fuel sources.

## IV. Combustor Design and Analysis

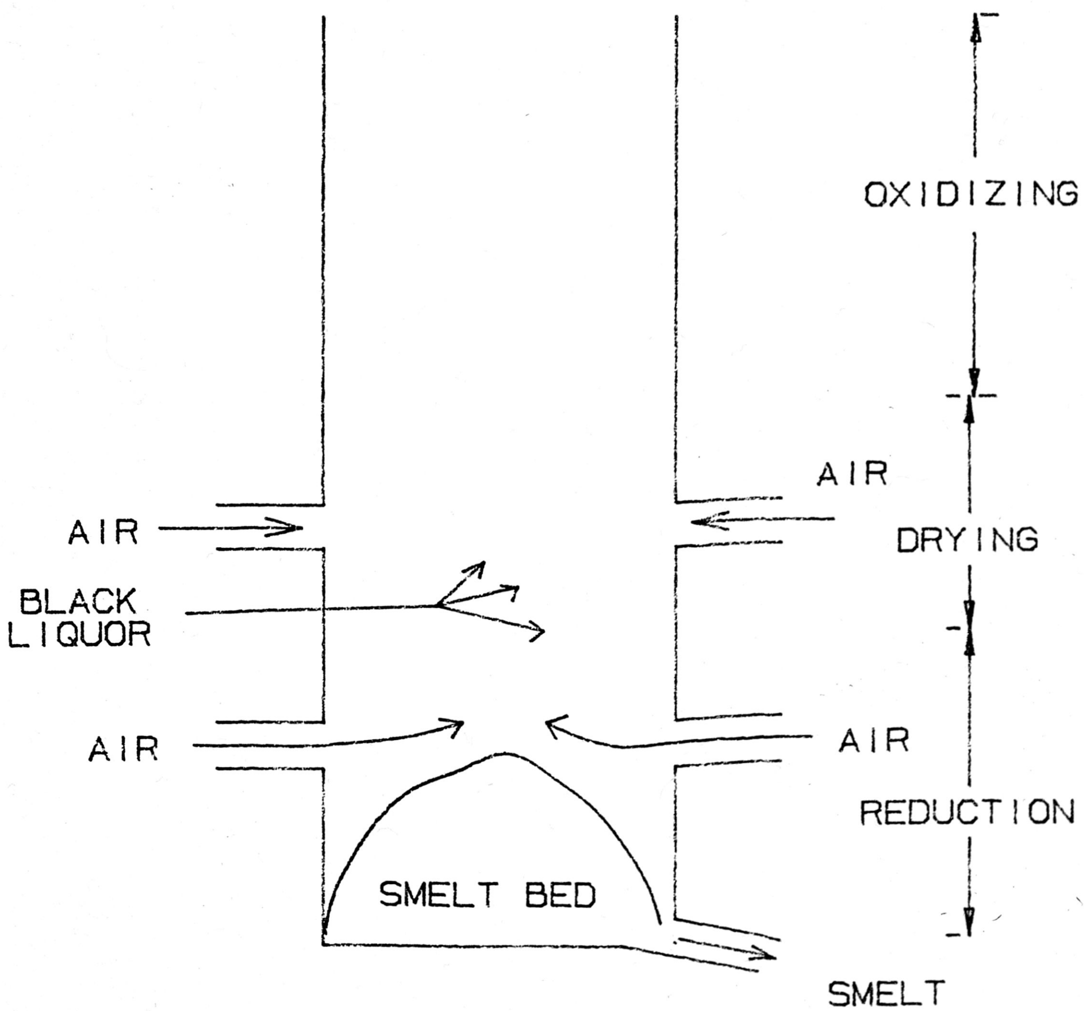
After considering the above economic aspects, it was decided to concentrate on a small scale steady state combustor for heat generation. However, before discussing the design aproaches it will be instructive to discuss the actual combustion process itself.

Manure combustion involves a three step process with significant overlap between steps. As the particle heats up, water vapor evaporates first. Then at 200 degrees Centigrade, pyrolysis (gasification) of the volatile solids begins to occur. Finally, at about 600 degrees Centigrade, the volatile gases begin to combust.

The initial design was based on a "Black Liquor" recovery combustor used at paper mills

FIGURE #3

BLACK LIQUOR RECOVERY UNIT



to recover molten NaS from a mixture of NaS and lignin. Figure #3 illustrates a typical recovery furnace. Black liquor is sprayed in at the top by an oscillating nozzle. As the liquid droplets freefall through the hot combustion gases, process water is evaporated and pyrolysis occurs. It is thought that up to 70 percent of the organic material (between gasified during this process. The remainder falls onto the smelt bed where reduction of alkaline material takes place. The bed temperature is thermostated near the fusion temperature of the smelt (1000 K) allowing liquid NaS to be drawn off for reuse.

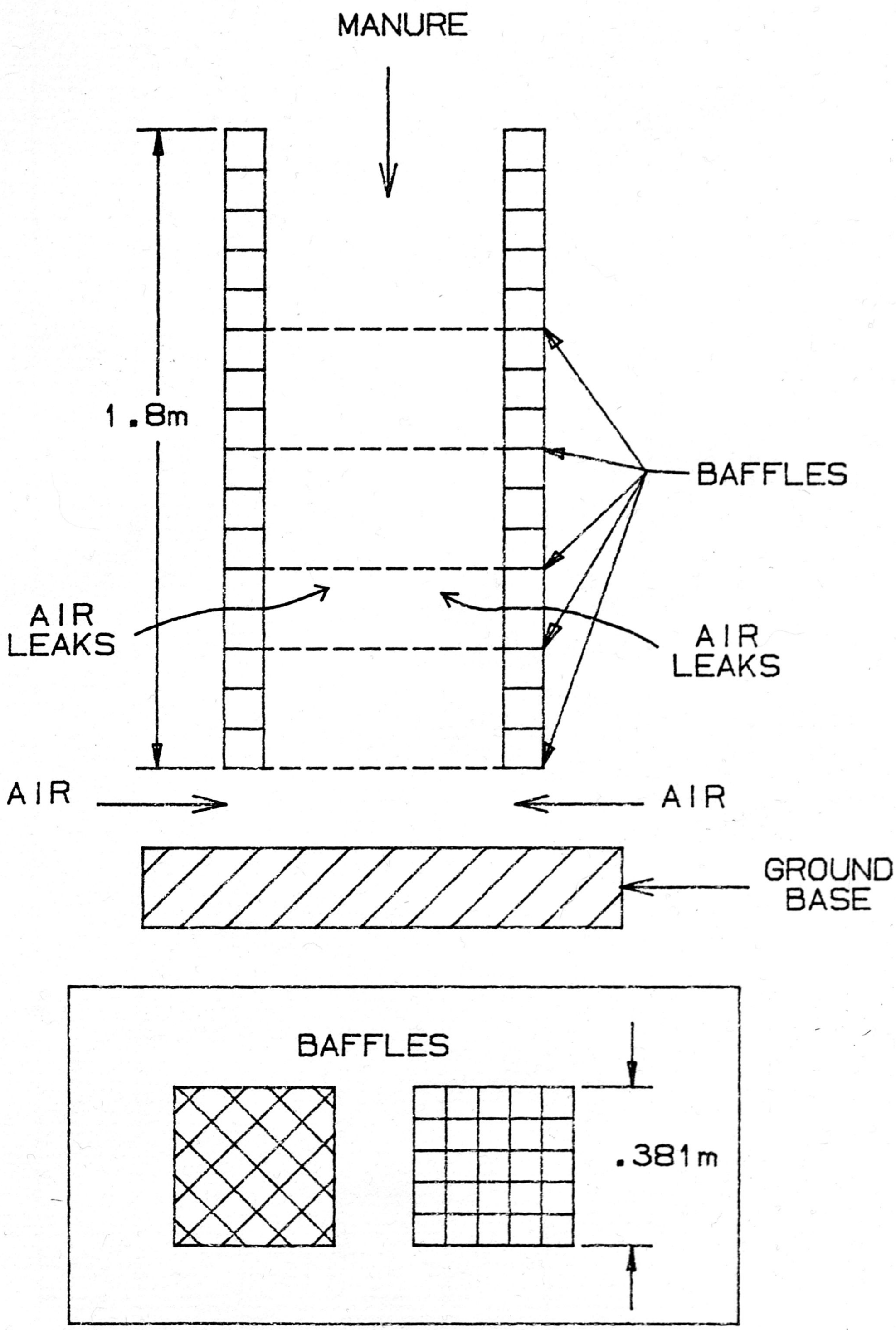
Figure #4 details the initial design. Basically, a "chimney" constructed of standard firebricks, it had steel grates suspended across the flow at different heights to slow particle freefall and to provide a surface for combustion. Air entered through the base and the manure was fed from the top.

The procedure for combustion experiments went as follows. A wood fire was built between the first and second grate (about 9 kg of wood). When the wood fire created sufficient draft and temperature (600 to 800 Centigrade when measured at the top) manure was fed from the top in an attempt to attain steady state combustion from the manure alone as the wood burned away. Eleven burns were made using this basic configuration with minor changes in grate placement and draft flow. Manure combustion was poor at best and at no time was steady state combustion of the manure alone attained.

Several observations were made to explain this. It was noticed that the medium to large size particles fell through the gas flow with almost no weight loss and no apparent gasification. This was attributed to anemic flow velocity (too slow to measure accurately), the short distance each particle fell through the flow, and cool air leakages through the brick intercises. Combined, each of these factors had an adverse effect on moisture evaporation and gasification. Drag forces due to low flow velocity were insufficient in slowing particle freefall for the majority of particles. This,

FIGURE #4

COMBUSTOR DESIGN #1



along with the short fall distance limited residence time to a fraction of a second. Cool air filtering in through the brick intercises compounded the problem by lowering flow temperatures and thereby lengthening the time of gasification for each particle. Finally, it was noticed that those small particles (mean diameter less than one millimeter) that did become entrained, exited the stack smoldering and remained hot for a minute or more. This was an indication that combustion was incomplete and that even the small particles needed either a higher temperature, longer time in the flow, or both, to gasify completely.

At this point it was decided to radically change the design to increase gas velocity and prevent leakage of ambient air through the sides. Additionally, the objective was simplified. Instead of trying for steady state combustion, it was decided to measure the contribution made to the wood fire by manure combustion. The second and final design was constructed with this in mind.

Design number 2 is illustrated in figures 5 and 6. The height was increased to 3.62 meters while the crossection was reduced to only 15.2 cm. The air intake was enclosed as shown to reduce wind related velocity and pressure oscillations. A single baffle was installed at the base of the column to support the mass of wood and provide an air inlet. Finally, foil was wrapped tightly around the column's exterior to prevent cold air leakage. A single thermocouple was placed 31 cm below the top of the column and in the center of the flow. Overall heat transfer through the walls of the column was minimal as all surfaces were sealed and the fire brick offered excellent thermal resistance. Exterior surface temperatures never exceeded 75 C, even when interior temperatures were 800 C and above.

Combined, these improvements increased flow velocity to the point that feeding through the top resulted in greater than 50 percent blowback. For that reason, it was decided to inject manure through the side at the 1.21 meter level. The feeder consisted of a plunger enclosed in a 5.08cm diameter steel pipe that extended

FIGURE #5

## COMBUSTOR DESIGN #2

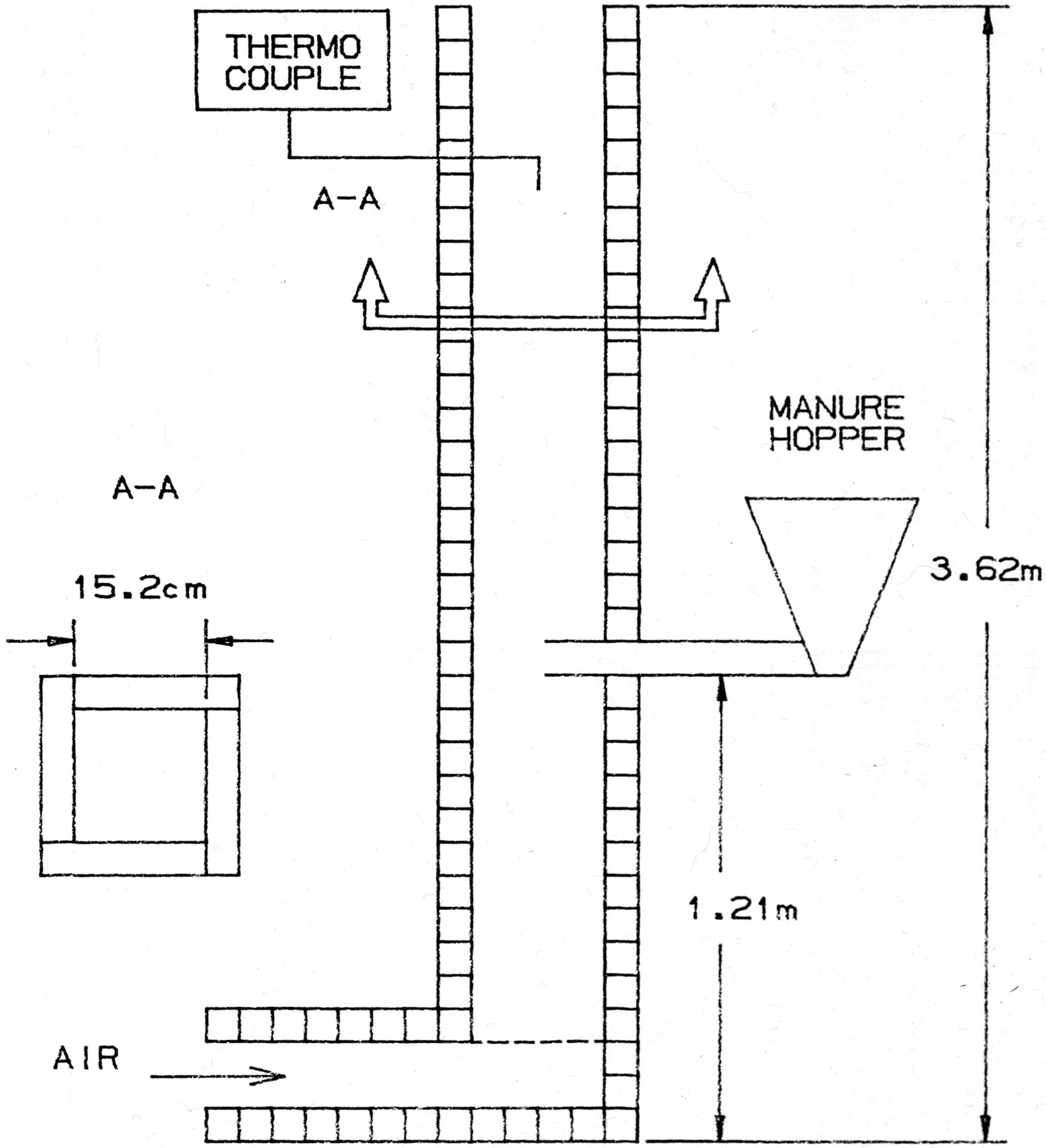
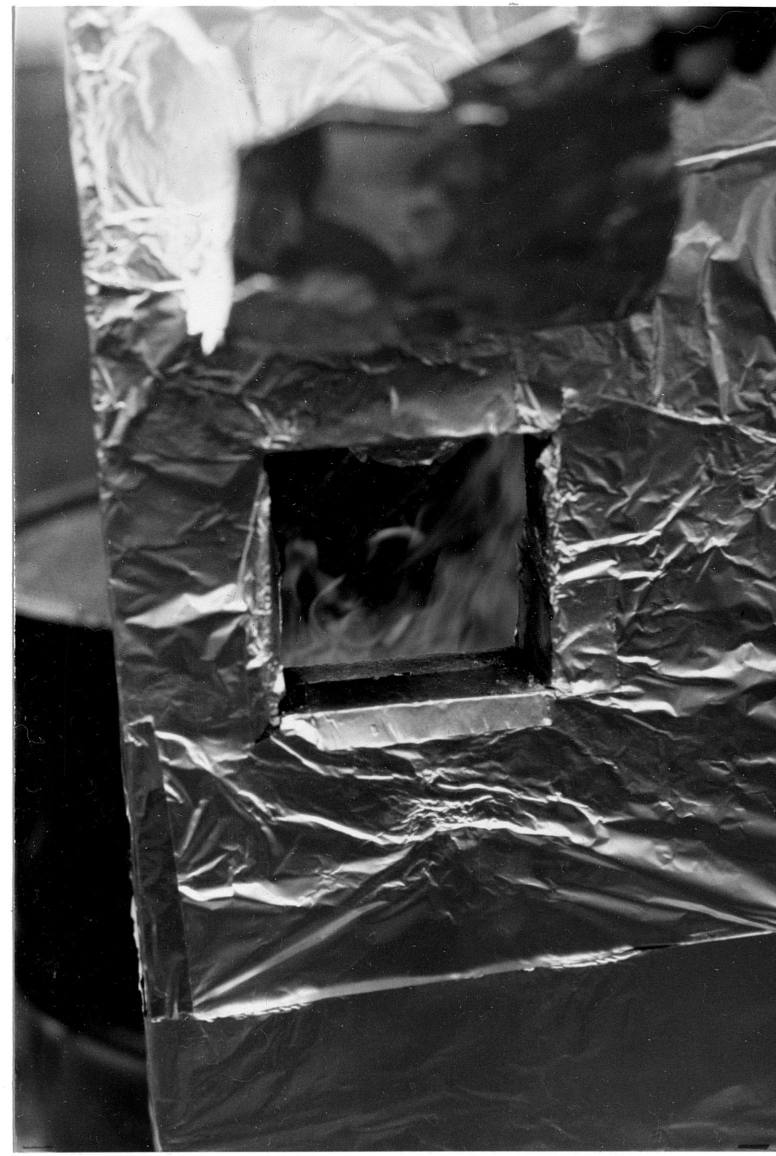


FIGURE 6

Photographs of Design #2

1) Final Combustor Design



2) Wood Combustion in Progress at 1.21 m level

6.35 cm into the flow through a sealed cavity at a point 1.21 meters above the base.

The procedure followed for design number 2 was similar to that of design number 1. A wood fire was ignited in the first four feet of the column. When the thermocouple near the top of the column indicated 600 C or above, manure feeding was initiated. Subsequent temperature readings were compared and flow and combustion conditions were observed through "windows" at various levels. Temperature data was recorded but not included in this report because the lack of a truly repeatable experiment precludes meaningful comparisons.

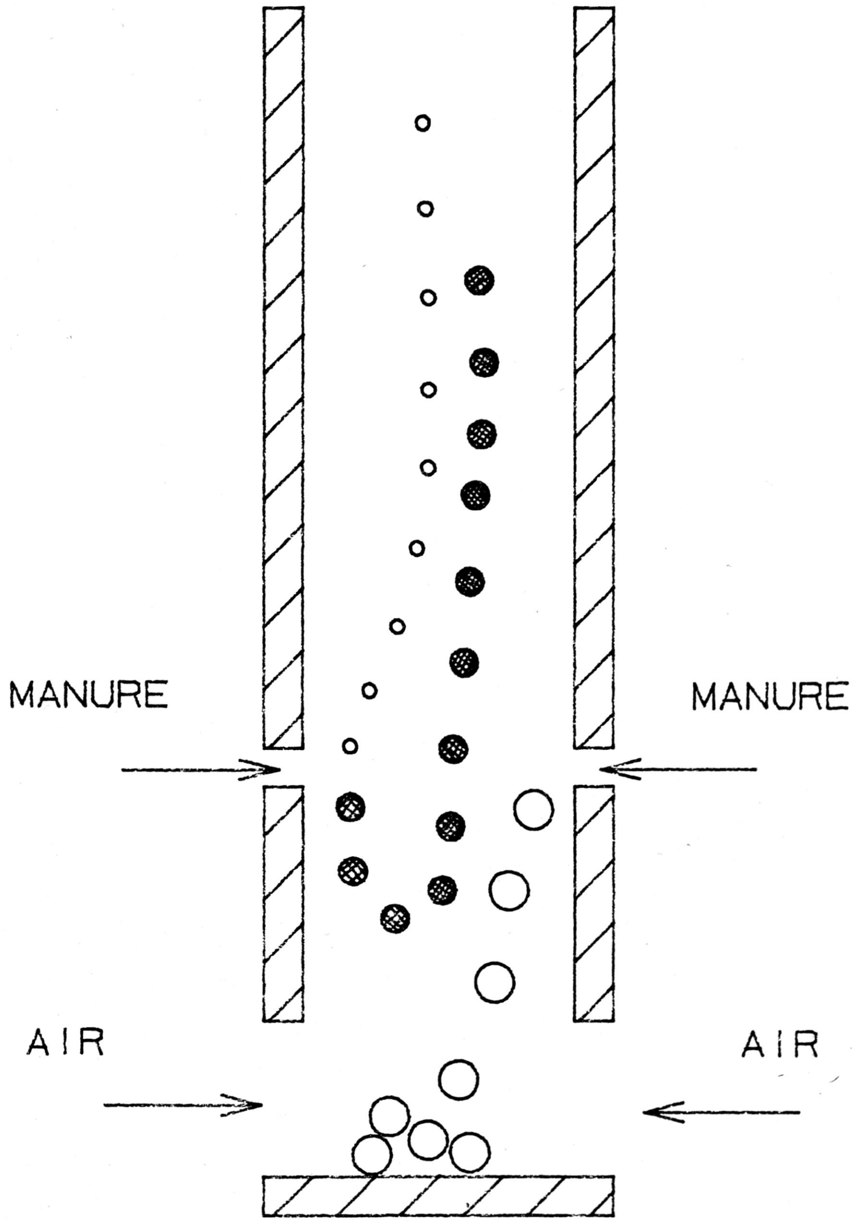
Temperature increases for the manure were inconclusive at best. There was no noticeable temperature spike after feeding began. This would indicate that the manure gases underwent little actual combustion before reaching the level of the thermocouple or that vaporisation of water and gases absorbed most of the heat given off by the manure reaction. At no time were manure solids observed burning with a flame.

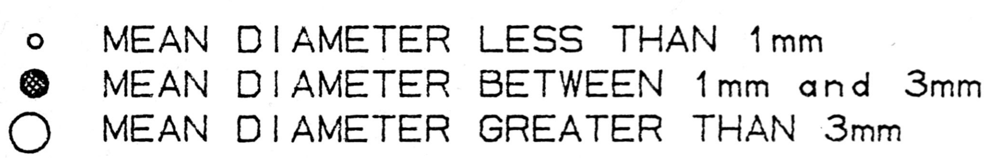
Observed manure flow patterns are illustrated in Figure #7. Large particles (diameter; 0.5 to 5 cm ) fell immediately to the base of the column with no apparent drying and pyrolysis. Medium sized particles (1mmmean diameter0.5cm) dropped 30 to 45 cm before reversing their path and exiting the top of the combustor. Medium particles also exited very hot, indicating incomplete combustion. Those particles with mean diameter under 1 millimeter appeared to be completely entrained and exited the top of the combustor as cool, white ash particles.

One possible explanation of these flow patterns revolves around density changes as the particle gasifies. For example, let us assume constant flow velocity and further assume that particle diameter changes very little during gasification. For the large particles, weight greatly exceeds the drag force induced by the flow and for that reason they fall through the wood fired combustion gases at or near free fall velocity and therefore experience very little gasification. The medium sized particles, which

FIGURE #7

# OBSERVED PARTICLE MOTION AS A FUNCTION OF PARTICLE SIZE



have a larger ratio of wetted area to volume (and weight) than do the larger particles, drop immediately after injection but at a much smaller velocity than do the larger particles. This allows time for gasification to occur, a process that is much faster for the smaller particle. Gasification of the volatile gases and any moisture that is present result in a density decrease for the particle. At some point, the drag force becomes equal to particle weight and downward motion halts. Additional gasification results in further density reduction, causing the medium sized particle to reverse course and exit the top of the combustor. Finally, the small particles, due to their extremely high wetted area to volume ratio, are influenced almost completely by the drag force and for that reason become entrained immediately after injection.

During several of the burns, fine, dry sawdust with an approximate Lower Heating Value of 18,700 KJ/KG (Annamalai, et al), was injected for comparison. Conditions at the sawdust injection point resembled a blow-torch with complete entrainment and almost instant gasification and combustion. Temperature readings jumped 250 C from values indicated prior to injection and the sawdust particles exited the combustor as cool, white ash.

Several explanations can be offered to describe the contrasting results between manure and sawdust. Each involves the time it takes to heat the respective particles to their gasification temperature. Taken together, they will provide the basis of future experiments aimed at encouraging manure to burn in this configuration.

Probably, the most significant explanation of the observed differences is the wide variation of ash and moisture content between manure and sawdust. The composted manure, used for this experiment, tested out at 20.74 percent moisture and 33.71 percent ash on an as received basis. By contrast, clean sawdust usually averages less than 6 percent ash and 15 percent moisture on an as received basis. As a basis for comparison, two particles of the same size will be used. All particles will be modeled as perfect spheres unless otherwise noted. Further, equal values of surface heat flux for both particles will be assumed. For a cold particle, injected into a gas flow of constant temperature To, the parameter of interest is the time it takes each particle to heat to its gasification temperature (assumed for this comparison to be the same for both particles). The manure particle experiences much longer heating times due to the moisture that must be evaporated and the heat required to raise the inert ash to gasification temperature. In effect, the moisture and ash present in manure particle combine to raise its thermal mass to values well above that for the sawdust giving the sawdust a marked advantage in heating time to gasification. Moisture and ash differences are not the only explanations, however.

Size plays a very important role in the time required to heat a particle to gasification temperature. Once again constant surface heat flux is assumed. In addition, for this comparison, density and heat capacity are assumed to be the same for all particles. The amount of heat that enters the particle is dependent on its surface area. The heat required to raise the temperature is dependent on volume and related by density and specific heat capacity (both assumed constant for this analysis). For that reason, large particles, with a small surface area to volume ratio (proportional to 1/D), can be expected to require longer heating times than small particles with a large surface area to volume ratio. The sawdust particles used were between 10 and 20 times smaller than the average manure particle. This almost certainly accounts for some of the differences between the observed combustion characteristics of the two fuels.

## V. Concluding Remarks

Analysis of manure resources in the United States seems to indicate that manure, although quite plentiful, is a marginal fuel from an economic standpoint at present. Three factors that are likely to impact its use as a fuel are, in order of importance: alternative fuel costs, availability of economic collection systems, and the costs associated with safe disposal. Finally, direct combustion of manure hinges on the development of combustors capable of burning this heterogenuos fuel in a reliable, economic manner.

Although the attempts to design a small steady-state combustor were unsuccessful, they did provide valuable data for future attempts. The effective residence time for each particle will be increased by raising flue temperatures, using particles of smaller diameter and extending flue height to provide longer time in the flow. In addition, an easily regulated gas flame will replace the wood used previously to preheat the combustion gases. This should make the experiment more repeatable, thereby rendering the data more meaningful.

## Recommendations

From observations of the present design configuration, several recommendations can be made to increase the repeatability and scientific utility of the present design.

First, an easily regulated and precisely calibrated feeding system must be added to the configuration. Secondly, the cool intake air must be directionalized and protected from ambient wind currents so that air velocity can be measured at the base of the combustor. Thirdly, thermocouples capable of withstanding temperatures of 800 C or above should be placed at even intervals along the column to detect areas of evaporation, volatile gas pyrolysis, and combustion respectively. Each of the measuring instruments should be connected to a strip chart machine for accurate measurements, thus allowing the observers time to directly observe the combustion process itself. Each of these improvements should greatly facilitate data collection and allow much more meaningful comparison of combustion results.

Most importantly, however, an easily regulated gas burner should be installed at the combustor's base to preheat the combustion gases. The fluctuating nature of the wood fire used for this purpose in the initial experiments made it quite difficult to correlate temperature readings to actual manure feeding during the experiment and to the results of other experiments. Finally, quartz windows should be installed in the firebrick wall so that direct observations of the combustion process can be made without altering flow conditions in the vicinity of the area being perused. Combined, these improvements should go a long way toward improving the repeatability of the experiment which is crucial if scientifically valid data is to be obtained.

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