# A NEW PROCESSING SYSTEM FOR THE PRODUCTION OF IMPROVED REFUSE DERIVED FUEL AND RECYCLABLES FROM MUNICIPAL SOLID WASTE

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## ABSTRACT

The University of Alabama in Huntsville (UAH) has been developing a new process for treatment of municipal solid waste (MSW) that can produce a higher quality refuse derived fuel (RDF) while simultaneously improving the separation and recovery of recyclable metals, plastics, textiles, and glass. The first step of the process is to presort to remove large bulky items. Moisture is added to the remaining commingled wastes which are then exposed to 4.46 bar (50 psig) saturated steam under pressure for approximately 30 minutes with continuous agitation. The pulp and paper materials, food wastes, and soft yard wastes are transformed under these conditions into a near sterile cellulosic pulp at about 50% moisture by weight. Since the process does not require any shredding or grinding of the wastes, most of the metals, textiles, and certain plastics can be recovered essentially intact for recycling by standard reparation techniques. Most of the cellulosic materials are less than 1.27 mm ($\frac{1}{2}$ inch) particle size, but due to the agitation during processing, significant quantities of glass, ceramics, and other dense items are also present in this fraction. After drying to about 20% moisture content, the dense materials can be separated by air classification yielding a relatively clean boiler fuel. The fuel value is 13,900–18,600 kJ/kg (6000–8000 Btu/lb) (dry), and it contains much less metal, plastic, and textiles than conventional (shredded) RDF. The fuel should produce less potentially toxic stack emissions and less ash. The fuel has low sulfur and nitrogen content, and when blended with many coals would result in a reduction of both sulfur and NOx emissions from coal-fired power plants. The dry fuel also has a low density making it suitable for pneumatic transport and potential co-firing with pulverized coal without modification of the fuel handling system. Although the fuel is derived from MSW, it is exposed to sterilization conditions during processing and consequently is stabilized when dried, reducing odors and the potential for spoilage or spontaneous combustion, thus making long term storage possible. Details of the process, materials recovery, and fuel properties are presented in the paper.

## PROBLEM STATEMENT

### Background

A major problem facing the United States is disposal of municipal solid waste (MSW).

The Environmental Protection Agency has promulgated new rules which revise minimum Federal criteria for municipal solid waste landfills (MSWLFs) (Federal Register, October 9, 1991). These new rules (40 CFR part 258), effective October 1993, impose additional design requirements, monitoring requirements, operating criteria, location restrictions, etc., on MSWLFs. The response of the MSWLF operators to these regulations will vary, but they will at least result in sharply increased tipping fees and in some cases outright refusal to accept certain wastes as an effective means of extending the lifetime of a MSWLF.

Resource recovery is a feasible approach to minimizing waste committed to landfills and energy recovery is often the most cost effective. Bone dry biomass typically contains about 18,600 kJ/kg (8,000 Btu/lb). The waste currently going to landfills can be converted to useful thermal energy or power with no net impact on the environment, but removal of non-combustibles and synthetic materials (plastics/textiles, etc.) for recycling or alternate disposal is an important step in enhancing energy content and reducing aerial emissions and toxic ash. Table I provides the composition of a typical residential MSW.

**TABLE I TYPICAL COMPOSITION OF RESIDENTIAL MSW**

| Components | % by Weight |
|---|---|
| Moisture | 20 |
| Paper products | 50 |
| Food wastes | 5 |
| Ferrous metals | 7 |
| Nonferrous metals | 2 |
| Glass | 7 |
| Plastics | 6 |
| Other | 3 |

There are several ways to convert MSW to a usable fuel. Mass burn is the most common, but pyrolysis and anaerobic digestion are also possible. Mass burning or direct combustion of as-received refuse in a waterwall furnace is the most immediate alternative available to many municipalities and is the one most often chosen even though there are many economic and technical difficulties. Mass burn typically entails collection of garbage, separating the large heavy components and burning it on a specially designed grate. Because it requires enormously complex equipment, separation and recovery of recyclables can only be accomplished if economics justify, otherwise all contents, glass bottles, tin cans, batteries, etc. are passed through the furnace and into the flue gases or ash. Resource recovery is usually limited to separating ferrous metal objects from the bottom ash after firing. In addition to limited capability for resource recovery, ash and stack emissions will contain a certain amount of hazardous compounds as a result of burning plastics, rubber, batteries, etc.

Resource recovery prior to incineration has significant advantages such as reduced ash, reduced toxic and hazardous emissions, more high value products, and a fuel with more uniform chemical and physical characteristics. Almost all large-scale resource recovery facilities produce a Refuse Derived Fuel (RDF) which involves shredding of the MSW to facilitate recovery of components by physical characteristics and to enhance fuel properties. Separation of valuable constituents is accomplished by various mechanical, magnetic or aerodynamic separation techniques. Because the physical characteristic of some materials are not sufficiently distinct, this method of preparation cannot classify some light materials and the RDF will still contain a high percentage of non-combustible inorganics and toxic combustibles. In addition, hardened steel objects and flammable and explosive materials can cause severe wear or damage to the shredder and other materials, such as rugs, mattresses, wire, plastic sheets, and milk bottles can sometimes cause operational problems. For use as a fuel, the RDF may require two shredding operations to attain the desired size reduction a requirement which is accompanied by increased capital and operating cost.

Since the early 1970's, electric utilities have been interested in using MSW as a boiler fuel for power generation primarily because it dilutes the $SO_2$ emissions and because it is potentially cheaper than coal [1]. Fluff RDF is made by additional processing to produce a low ash and fine fluffy material with a heating value near that of western lignite. Fluff RDF can be co-fired with coal in a utility suspension-fired boilers at rates up to 20% of the total heat input [2]. However because of the variability of the contents, high ash content, high moisture content, slagging, high corrosion potential, and higher air flow rates, utilities are reluctant to seriously consider RDF as a utility boiler fuel, except in dedicated boilers specifically designed for this purpose [3].

The University of Alabama in Huntsville (UAH) has developed a technique for classifying MSW for pre-incineration resource recovery that appears to have significant advantages over current approaches. The UAH process transforms the paper, food and soft yard waste into a sterile, damp cellulosic pulp with low ash content. When dried, the pulp is transformed to a fluff which appears to have advantages over conventionally prepared RDF for firing in utility suspension burners. For spreader-stoker firing, the fluff can be pelletized to provide the density necessary for achieving uniform fuel distribution on the grate.

The UAH process is a simple one, consisting of exposing raw MSW to saturated steam in a pressurized container and agitating for about 30 minutes. The steam is used to provide the heat and moisture for expansion process that pulps the cellulosic components. After steam processing and some drying, the recyclables are readily recovered by conventional solid separation techniques. The organic waste becomes a light, fluffy combustible material that is comparable in some ways to ASTM RDF-3, except that its physical appearance is more like cellulosic insulation or paper mache. The UAH-RDF is also sterilized during processing which eliminates putrefaction and odor, making it possible to store the fuel for long periods before use. Cans, most plastic bottles and other non-biomass objects remain essentially intact in this process, but glass bottles are broken by the agitation and most plastics are melted into amorphous lumps resembling stones or pebbles. Because of the large density and size variations of the combustibles and non-combustibles, the fuel component can be readily separated by screening and air separation. The large solid objects can be further separated for resource recovery and recycle, if economics warrant. The cellulosic end-product is about 20% moisture content at this point and further drying can be undertaken to improve the "as fired" HHV if economics warrant.

The UAH-RDF process differs markedly from conventional methods of producing ASTM RDF-3. The conventional fluff processing sequence involves removal of large objects, size reduction by shredding, magnetic separation, screening and/or air classifying. As a result, the moisture and ash content are high, and variable, thereby limiting its use as a boiler fuel. The UAH process also requires an initial sort to remove large objects but because the process involves no shredding the ash content should be significantly lower and the resultant particle size and moisture content should be more uniform than the RDF-3. Furthermore, since most plastics are removed along with other objects, the chloride emissions are significantly lower than conventional RDF.

Recoverable recyclable components include most of the ferrous and non-ferrous metals, textiles, and certain plastics, notably polyethylene terephthalate (PETE) and polypropylene (PP). The paper labels and food wastes are removed from ferrous cans, and aluminum can labels are partially delaminated. Textiles are typically dirty, but may be washed and dried for sale to rag markets. The PETE bottles are typically shrunken by about 30% and are flattened, but the PP film labels, glue, and high density polyethylene (HDPE) base cups, if originally present on the bottle, are all removed. Thus, the PETE bottles are more valuable for recycling. The PP films, laminates, and molded items are also of higher value for recycling due to the removal of other plastics. Most other plastics are melted due to the heat of the process and are recovered as amorphous lumps of mixed plastics, however these mixed plastics have recycling potential to be extrusion molded into new products.

Woody biomass is mechanically reduced to a mulch. The glass and ceramic components are broken during processing, and along with other dense contaminants, are separated from the cellulosic pulp by air classification. This mostly glass fraction can be mechanically reduced in particle size to be marketed as an aggregate for construction materials.

The original concept of processing MSW with steam was introduced in 1982. A prototype unit was fabricated from using a modified rendering vessel as the processor. This system was described in Reference [4]. Since the first unit was constructed, research at UAH has continued and improvements have been made to reduce steam and water consumption, reduce processing time and to improve the quality of the cellulosic product, e.g. reduced moisture and mineral content [5]. The previous efforts have been directed at producing a cellulosic material suitable for enzymatic or acid hydrolysis conversion to sugar for fermentation into a variety of fuels and chemicals. Use as a compost for soil conditioning is another application currently being explored.

Only recently has steam classification been considered as a means of producing RDF boiler fuel. Discussions with Alabama Power Company (APC) has indicated the material is too light and fluffy for grate burning, however, it appeared suited for use as a fuel in utility boilers using suspension burners. As a first step in characterizing its fuel properties, small samples of MSW have been collected, processed and subjected to laboratory analyses. These analyses have provided the HHV, ultimate analysis, ash content, moisture content and ash chemical analysis. No attempts have been made to further characterize the material as a boiler fuel, or to expand the sample size to a wider range of MSW sources. Also, the research effort there for has focused on the steam processor unit operation. Elements required to establish economic feasibility i.e. capital cost, operating cost (including energy balance) and revenues from sale of recovered materials have not yet been addressed.

## DESCRIPTION OF UAH PROTOTYPE FACILITY

### Description

A postulated process flow sheet for the UAH-RDF is presented in Figure 1. Although only one line is illustrated, two or more parallel process lines may be employed to assure continuous flow of fuel to the boiler. Also, when detailed characteristics of the material are taken into account, the individual unit operation may vary in type and sequence to achieve a higher quality product. Before waste enters the RDF processing line, the delivery trucks will dump loads on the tipping floor so that components that cannot be processed because of size or harmful effects can be visibly identified and manually removed. Such unacceptable or hazardous wastes include telephone or other wire, steel bands, bedsprings, carpets and textiles, car batteries, large tree trunks, combustible liquids such as gasoline, kerosene and process solvents, pressurized tanks, tires, bulk pesticides and insecticides, and automobile components.

A prototype facility at UAH has been under operation that includes some, but not all, unit operations of a full scale facility. In this prototype a conveyer system transports the material to the processor which, is simply a modified 10 $m^3$ (353 $ft^3$) concrete mixer removed from a standard truck frame and mounted on a stationary frame. The mixer drum is rotated by means of a sprocket and chain which is driven by a hydraulic pump and motor. The hydraulic system is powered with an air cooled diesel engine. The modifications to the concrete mixer include welding the side-wall inspection door closed. In addition, a 2.5 cm (1.0 in) pipe was inserted through the front bearing assembly and connected internally to four sparging lines affixed to the wall of the drum at 90 deg. and connecting exter-

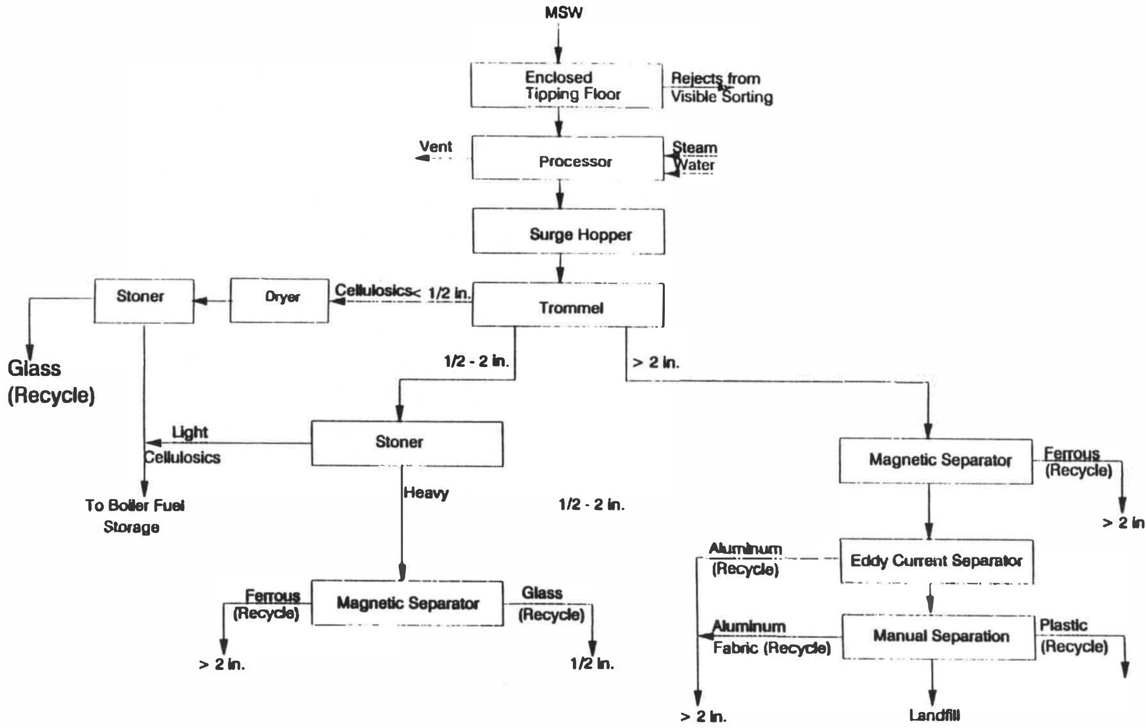

FIG. 1 FLOWSHEET FOR PROTOTYPE UAH RDF PROCESSOR

nally to the 469.4 kg/hr (30 bhp) steam supply through a rotary union. This arrangement allows the mixer to be rotated in either direction while simultaneously injecting steam into the drum interior. Two standard concrete mixer helical flights spaced at 180 degrees along the interior wall provide agitation of the contents. By changing the direction of rotation of the drum, they also provide movement of the contents in either direction relative to the mixer axis for loading and unloading. The standard concrete mixer openings and chutes were removed and replaced with a flat steel plate with a bolt-on door which was welded on the rear of the mixer drum. The doorway, which is about 80 cm (31.5 in) in diameter, is sealed with a gasket between the door and the end plate and is secured with twelve 1.9 cm (0.75 in) bolts. The door was equipped with a 3.8 cm (1.5 in) threaded nipple and rotary union to which are connected a 510 kPa (75 psig) pressure relief valve and a 3.8 cm (1.5 in) gate valve for venting the unit. The drum exterior was coated with ceramic insulation to reduce heat loss.

After depressurization, the door is removed, and the drum rotation is reversed to discharge the contents out of the unit and onto a belt conveyor that transfers the processed materials to a triple-deck vibratory screener. The materials are separated on the vibrating screens into 5.1 cm (2 in) or larger, 1.3–5.1 cm (0.5–2 in), and less than 1.3 cm (0.5 in). The different fractions are transferred to separate storage containers. Figure 2 illustrates the production of material from the screen for nine repetitive tests using a typical residential MSW sample [4].

The fractions less than 1.3 cm (0.5 in) and between 1.3–5.1 cm (0.5–2 in) are continuously conveyed from the vibrating screener to stoners for further separation. These fractions contain most of the cellulosic materials, but they are also contaminated with about 15–20% glass by weight. Approximately 72.0% of the screen output, by weight, is associated with the fraction less than 1.3 cm (0.5 in) and 22.3% with the intermediate fraction. In addition to the glass, the smaller size fraction contains melted plastic that resembles stones or pebbles. A dryer is used to remove water from the cellulosic material to make it separate more readily from the stoner, further reducing the ash and chlorine content. The moisture content of the cellulosic RDF is approximately 20% at this point.

The intermediate fraction contains larger pieces (1.3–5.1 cm, 0.5–2 in) of cardboard, paper and other cellulosic components that are too large to be fully penetrated by the steam and water, thus remaining intact. These pieces are separated from the heavier glass and metal objects in a stoner. They can be further reduced in size by recycling back into the processor for further classification. Since the larger pieces of biomass retain less moisture, grinding to reduce size also offers the possibility of reducing the overall moisture content of the RDF when blended with the small fraction, but this approach has not been explored.

### Operation

The loading operation is initiated by rotating the mixer drum at about 5 rpm in the direction that conveys materials away from the doorway and into the drum. A weighed quantity of MSW is conveyed from ground level via the belt conveyor to a transition chute that directs the MSW into the mixer drum doorway. The maximum capacity of the drum for MSW is about 1364 kg (3000 lb) or about 130 kg/m$^3$ (8.1 lb/ft$^3$), although for most tests, only about 450 kg (990 lb) of MSW has been processed. Typical loading time is about 30 min., for 450 kg (990 lb), and some manual assistance is required for objects larger than the doorway. About 0.15 kg (0.33 lb) of water is added per kg (lb) of MSW, and the door is replaced and secured. The vent valve is opened, and with the drum rotating at about 5 rpm, steam injection is initiated. The open vent valve allows the air and non-condensible gases in the drum and its contents to be displaced with saturated steam while simultaneously heating the vessel and its contents. The vent valve is closed when venting of saturated steam is observed. This usually occurs in about 10–15 min. with a 450 kg (990 lb) batch. Steam injection is continued until the internal pressure of the drum increases to about 375 kPa (55 psig), and then the pressure is maintained at about 375 Kpa (55 psig) for about 30 min. The internal temperature of the drum at this steam pressure is about 150°C (300°F). The contents are agitated throughout the period of steam injection by rotation of the mixer drum at about 5 rpm. After completion of the steam injection, the vent valve is opened and the vented steam is directed into a cold water tank/condenser to capture the heat and condensible vapors. Reversing drum rotation discharges the contents onto a conveyor for the first classification step. The process cycle times are summarized in Table II.

The current process requires about 0.2 to 0.3 kg of steam per kg of MSW (0.2–0.3 lb steam per lb MSW) or about 550–820 kJ/kg (235–355 Btu/lb) of MSW. About 1/3 of this is recovered as condensate during depressurization.

**TABLE II PROCESS CYCLE TIME**

| | Activity | Time |
|---|---|---|
| 1. | Loading MSW | 30 min (450 kg) |
| 2. | Air/Gas Purge | 10 min |
| 3. | Pressurize/Heat-Up | 30 min |
| 4. | Equilibration Time | 30 min |
| 5. | Depressurization | 30 min |
| 6. | Unloading Products | 60 min (650 kg) |
| 7. | Total Cycle Time | 160 min (450 kg) |

## PROPERTIES OF RECOVERABLES

### Recyclables

In the prototype facility, the processed products are separated based on size by vibratory screening, while the individual recyclable components, such as ferrous metals, aluminum, glass, and so on, are separated by other means. By manually sorting the screened fractions, it has been found that 80–90% of the recyclable metals are present in the 5.1 cm (2 in) screened fraction. Repeated sortings have shown that about 7% of the original weight of the MSW can be recovered as ferrous metals from the 5.1 cm (2 in) fraction. Most of the additional ferrous metal was found in the 1.3–5.1 cm (0.5–2 in) fraction, and very little was found in the less than 1.3 cm (0.5 in) fraction. Repeated sortings have shown that slightly more than 2% of the original weight of the MSW can be recovered as aluminum cans from the 5.1 cm (2 in) fraction. Again, most of the additional nonferrous metal was found in the 1.3–5.1 cm (0.5–2 in) fraction, and very little was found in the less than 1.3 cm (0.5 in) fraction.

Repeated sortings have shown that about 5% of the original MSW can be recovered as plastics. Some of the plastics have melted into agglomerates, whereas others are distorted and some remain unchanged because of the temperature of processing. About 60% of the plastics are in the 5.1 cm (2 in) fraction. The remaining 40% of the plastics are found mostly in the 1.3–5.1 cm (0.5–2 in) fraction with a small amount, possibly 0.5%, being present in the less than 1.3 cm fraction. Less than 1% of the original MSW is recovered as glass and ceramics in the 5.1 cm (2 in) fraction. The majority, possibly 80% of the glass and ceramics, is present in the 1.3–5.1 cm (0.5–2 in) fraction. The remainder of the glass is present in the less than 1.3 cm (0.5 in) fraction.

The cellulosic and food wastes are generally distributed 20% in the 1.3–5.1 cm (0.5–2 in) fraction and 80% in the less than 1.3 cm (0.5 in) fraction. Essentially all of the cellulosic pulp can be recovered from the 1.3–5.1 cm (0.5–2 in) fraction upon reprocessing. Other than the recovery of the glass, the 1.3–5.1 cm (0.5–2 in) fraction is essentially void of any recyclable materials worth the recovery effort. The less than 1.3 cm (0.5 in) fraction is composed essentially of combustible cellulosics with less than 1% plastic and only 6–8% ash [4].

### Physical and Chemical Properties of RDF Fuel

Properties of importance when cofiring RDF with coal are [2]:

Ash Content
Particle Size
Proximate and Ultimate Analysis
Higher Heating Value
Moisture Content
Bulk Density
Heavy Metals Content
Chlorine Content
Ash Fusion Temperatures
Ash Chemical Analysis

Because of the preliminary nature of the investigation into the possibilities as a boiler fuel, only a limited number of these have been investigated.

Table III provides a sieve analysis of the product screened below 1.3 cm (0.5 in). The product was screened when wet, but drying had occurred before the sieve analysis was made. Shrinkage during drying permitted the entire fraction to pass a 0.95 mm (3/8 in) screen. This result indicates the possibility that drying before screening would increase the recovery of the fuel fraction.

The bulk density of the UAH-RDF is about 265 kg/m$^3$ (16.5 lb/ft$^3$) at 15% moisture content and 9.09 lb/ft$^3$ dry. Particle size is less than 1.3 cm (1/2 in). Visually it resembles finely shredded bark without the stringy material. For comparison typical fluff RDF-3 is 64 kg/m$^3$ (4 lb/ft$^3$) with a particle size less than 5 cm (2 in).

Property data are limited, but Alabama Power Company (APC) and the University have analyzed four samples of UAH-RDF produced by the prototype processor. All samples were produced from MSW taken from local apartment complexes in Huntsville, Alabama and therefore are somewhat representative of a residential source with little or no curbside recycling effort. A summary of the dry basis ultimate analysis (% weight basis) of the four samples is provided in Table IV. For comparison, Table V provides the ultimate analysis of a specification, medium ash RDF-3 and some selected coals [2].

The high ash content in Sample 1 is the result of conveying the material to the processor using a screw conveyer. This method of transport fractures and grinds the glass into particles too small to classify with the equipment available in the current facility. The screw conveyer was replaced with a belt conveyer to reduces the glass fracture. The decrease in ash from Sample 1 illustrates the effect system design has upon the product. The prototype system is a small pilot scale with little opportunity to consider a wide range of design options for transport and classifying. As the transporting, classifying, drying and other unit operations are optimized and selected, further gains in resource recovery and fuel quality can be anticipated. One option that should be considered as another means of reducing ash is to trommel the raw garbage to remove glass bottles before introduction to the processor.

**TABLE III SIEVE ANALYSIS OF UAH RDF**

| Screen Size Number | Sieve Opening (mm) | Total Sample Percent Finer |
|---|---|---|
| 3/8" | 9.51 | 100.0 |
| #4 | 4.76 | 84.5 |
| #8 | 2.38 | 59.7 |
| #16 | 1.19 | 26.4 |
| #30 | 0.59 | 6.7 |
| #60 | 0.25 | 1.6 |
| #100 | 0.15 | 1.0 |
| #200 | 0.075 | 0.5 |

**TABLE IV ULTIMATE ANALYSIS OF UAH RDF**

| Ultimate Analysis, % by Wt | Sample 1[a] | Sample 2[b] | Sample 3[c] | Sample 4[d] |
|---|---|---|---|---|
| C | 37.65 | 45.82 | 39.07 | --- |
| $H_2$ | 4.73 | 5.69 | 5.20 | --- |
| $N_2$ | 1.02 | 0.97 | 0.73 | 0.81 |
| $O_2$ | 28.35 | 31.98 | 33.85 | --- |
| S | 0.13 | 0.21 | 0.19 | 0.16 |
| Cl | 0.16 | 0.20 | 0.16 | 0.11 |
| Ash | 27.96 | 16.13 | 20.81 | 14.10 |
| HHV | 14,825 | 16,823 | 15,626 kJ/kg | 16,628 |
| | (6375) | (7234) | (6719 Btu/lb) | (150 Btu/lb) |

[a] Alabama Power Company, Sample No. 930312-0059
[b] Alabama Power Company, Sample No. 930312-0060
[c] Alabama Power Company, Sample No. 930917-0045
[d] UAH

**TABLE V ULTIMATE ANALYSIS OF RDF AND SELECTED COALS [2]**

| Ultimate Analysis % by Wt. | Type C RDF | Illinois Bituminous | Eastern Bituminous |
|---|---|---|---|
| C | 43.4 | 65.3 | 71.1 |
| $H_2$ | 6.7 | 4.2 | 4.5 |
| $N_2$ | 0.7 | 1.0 | 1.3 |
| $O_2$ | 32.9 | 6.6 | 5.0 |
| S | 0.3 | 4.5 | 0.9 |
| Cl | 0.4 | 0.1 | 0 |
| Ash | 15.8 | 18.2 | 17.2 |
| HHV | 17,907 | 22,691 | 29,801 kJ/kg |
| | (7700) | (11,477) | (12,505 Btu/lb) |

Sulfur and chlorine are important constituents in RDF that must be dealt with in the design of the preparation facility, control of stack emissions, and operation of the boiler. When combusted, these elements form acid compounds that can corrode surfaces exposed to hot gases and lead to metal wastage. Chlorine enters largely through plastics and bleached paper products contained in the MSW. Chlorine content of the UAH-RDF is less than one half that of RDF prepared by the standard shredding process, which is most likely a result of the more effective plastics removal. Reference 6 indicates that high temperature corrosion is not indicated "at chloride levels of 0.1 to

0.2 percent normally encountered in coal firing," and using this is a criteria, the UAH-RDF will be non-corrosive or marginally corrosive at worst. In addition, Reference 7 notes that about 58% of the chlorine in typical RDF is present as sodium chloride which is not likely to enter into the corrosion chemistry when the RDF is burned. Because the UAH-RDF is more effective in removing plastics, the percentage of chlorine in salts is potentially higher, thus, having a lower corrosion potential than indicated by the chlorine content alone.

Reference 8 provides the ultimate analysis of a wide range of biofuels. The chlorine content of paper from selected sources are as follows:

| | |
|---|---|
| Commercial Office Paper | 0.048% |
| Residential Recycled Paper | 0.047% |

Thus, while the UAH process produces significantly lower chlorine content than RDF-3 by improved plastics removal, comparison with chlorine content of paper indicates that there may be some potential left for improvement of the plastics removal process through optimized classification techniques, although food and yard wastes will also contribute significant quantities of sodium and potassium chloride by their presence in MSW.

As expected, sulfur content of MSW is low compared to coal and therefore is a principal reason for cofiring MSW produces combustion products which serve as a diluent to $SO_2$ produced from burning high sulfur coal.

While sulfur, sodium, potassium, lead and zinc are contributors to corrosion, chlorine is the most serious [9]. The following conclusions were reached on a study of cofiring with coal:

- Conversion of chlorides to sulfates in ash deposits by the action of $SO_2$ releases hydrochloric acid at the metal surfaces.
- Chloride corrosion can be made negligible by increasing the available sulfur in the fuel to 2% by weight of refuse.
- Cofiring of MSW with high sulfur coal for up to a 60/40 blend (weight basis) will not increase the initial corrosion rate beyond coal alone.

Thus, there are two benefits to cofiring high sulfur coal with RDF. The first is that decreased high sulfur coal input means less sulfur oxide emissions and correspondingly less acid gas ($H_2SO_4$) emission. The second is that chloride corrosion is reduced significantly.

The ash analysis of samples 1 and 2 are provided in Table VI. High levels of alkali metals (potassium and sodium) create serious fouling of convection surfaces and slagging of grates and some fluid beds in combustion boilers. One of the effects of alkali metals is to depress the melting point of the ash. For example, silicon dioxide melts at 1700C (3100°F) but with a 32% $K_2O$ and 68% $SiO_2$ the melting point is 769C (1420°F). $Na_2O$ produces a similar effect whereas magnesia (MgO) produces a reverse effect by increases the melting point [10].

**TABLE VI ASH ANALYSIS OF TWO RDF SAMPLES**

| | Sample 1 | Sample 2 | |
|---|---|---|---|
| Aluminum Oxide ($Al_2O_3$) | 8.07 | 8.21 | % by Wt. |
| Antimony Oxide ($Sb_2O_5$) | 5. | 16. | mg/kg |
| Barium Oxide (BaO) | 443. | 395. | mg/kg |
| Beryllium Oxide (BeO) | 67. | 41. | mg/kg |
| Cadmium Oxide (CdO) | 9. | 12. | mg/kg |
| Calcium Oxide (CaO) | 10.37 | 10.56 | % by Wt. |
| Chromium Oxide (CrO) | 262. | 259. | mg/kg |
| Cobalt Oxide ($Co_2O_3$) | 49. | 82. | mg/kg |
| Copper Oxide (CuO) | 159. | 271. | mg/kg |
| Iron Oxide ($Fe_2O_3$) | 22.45 | 13.20 | % by Wt. |
| Lead Oxide ($PbO_2$) | 803. | 859. | mg/kg |
| Magnesium Oxide (MgO) | 1.13 | 1.48 | % by Wt. |
| Manganese Oxide ($MnO_2$) | 2361. | 1747. | mg/kg |
| Molybdenum Oxide ($MO_2O_5$) | 77. | 91. | mg/kg |
| Nickel Oxide (NiO) | 102. | 134. | mg/kg |
| Potassium Oxide ($K_2O$) | 1.60 | 2.72 | % by Wt. |
| Silica Oxide ($SiO_2$) | 44.66 | 55.92 | % by Wt. |
| Sodium Oxide ($Na_2O$) | 3.70 | 8.67 | % by Wt. |
| Titanium Oxide ($TiO_2$) | 1.32 | 2.10 | % by Wt. |
| Vanadium Oxide ($V_2O_5$) | 117. | 111. | mg/kg |
| Zinc Oxide (ZnO) | 796. | 3391. | mg/kg |
| Sum of Ignited Basis Oxides | 93.53 | 103.09 | % by Wt. |

A criteria has been developed to roughly classify the slagging potential of coals based upon the alkali ($K_2O$ + $Na_2O$) content known in pounds per million Btu calculated as [10]:

$$\text{Pounds of alkali/MMBtu}$$

$$= 10^6 \text{ Btu/HHV } \% \text{ Ash} \times \% \text{ Alkali}$$

A range of 0 to 0.93 × $10^6$ kJ/kg (0 to 0.4 lb/MMBtu) is considered a fairly low slagging risk while 0.03 × $10^6$ to 1.86 × $10^6$ kJ/kg (0.4 to 0.8 lb/MMBtu) will probably slag with increasing uncertainty as 0.8 lb/MMBtu is approached. Above 1.86 × $10^6$ kJ/kg (0.8 MMBtu/lb) the fuel is virtually certain to slag and foul [10]. The above equation applied to Sample 2 provides a content of 0.75 lb/MMBtu thereby indicating a high probability of fouling. Reductions in ash content will lower this quantity, however, the ash content of paper (7 to 9%) indicates the lower limit of ash content that can be achieved.

Table VII provides the ash fusion temperatures for the three samples. These temperatures serve as an indicator of clinkering and slagging tendencies. The temperature differential between initial deformation and fluid temperatures gives an insight into the type of formation to expect on the furnace tube surfaces. This difference is 7.2%, well above the 1.7 percent reported for various RDF fuels reported in Reference 9. The higher temperature differential indicates the ash-tube bond is less adhesive and therefore responds better to sootblowing [6]. However, the fluid temperature of UAH-RDF is about 180C (100°F) lower

## TABLE VII ASH ANALYSIS OF TWO RDF SAMPLES

| | Sample 1 | Sample 2 | |
|---|---|---|---|
| Aluminum Oxide ($Al_2O_3$) | 8.07 | 8.21 | % by Wt. |
| Antimony Oxide ($Sb_2O_5$) | 5. | 16. | mg/kg |
| Barium Oxide (BaO) | 443. | 395. | mg/kg |
| Beryllium Oxide (BeO) | 67. | 41. | mg/kg |
| Cadmium Oxide (CdO) | 9. | 12. | mg/kg |
| Calcium Oxide (CaO) | 10.37 | 10.56 | % by Wt. |
| Chromium Oxide (CrO) | 262. | 259. | mg/kg |
| Cobalt Oxide ($Co_2O_3$) | 49. | 82. | mg/kg |
| Copper Oxide (CuO) | 159. | 271. | mg/kg |
| Iron Oxide ($Fe_2O_3$) | 22.45 | 13.20 | % by Wt. |
| Lead Oxide ($PbO_2$) | 803. | 859. | mg/kg |
| Magnesium Oxide (MgO) | 1.13 | 1.48 | % by Wt. |
| Manganese Oxide ($MnO_2$) | 2361. | 1747. | mg/kg |
| Molybdenum Oxide ($MO_2O_5$) | 77. | 91. | mg/kg |
| Nickel Oxide (NiO) | 102. | 134. | mg/kg |
| Potassium Oxide ($K_2O$) | 1.60 | 2.72 | % by Wt. |
| Silica Oxide ($SiO_2$) | 44.66 | 55.92 | % by Wt. |
| Sodium Oxide ($Na_2O$) | 3.70 | 8.67 | % by Wt. |
| Titanium Oxide ($TiO_2$) | 1.32 | 2.10 | % by Wt. |
| Vanadium Oxide ($V_2O_5$) | 117. | 111. | mg/kg |
| Zinc Oxide (ZnO) | 796. | 3391. | mg/kg |
| Sum of Ignited Basis Oxides | 93.53 | 103.09 | % by Wt. |

## TABLE VIII ASH FUSION TEMPERATURE (REDUCING ENVIRONMENT)

| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Initial | 1010°C<br>(1850°F) | 1057°<br>(1935°F) | 1060°<br>(1940°F) |
| Softening | 1027°C<br>(1880°F) | 1071°C<br>(1960°F) | 1098°C<br>(2008°F) |
| Hemispherical | 1041°C<br>(1905°F) | 1078°C<br>(1973°F) | 1110°C<br>(2030°F) |
| Fluid | 1118°C<br>(2045°F) | 1141°C<br>(2085°F) | 1216°C<br>(2220°F) |

than that reported for several RDF samples for an oxidizing temperature [8].

Numerous other criteria exist for estimating slagging and corrosion potential [6], but a detailed assessment would not be fruitful until a wider variety of MSW samples are collected and processed.

## OPERATIONAL FACILITIES

The first prototype MSW process unit was put into operation in 1983 using a modified rendering vessel. This first prototype was found to be unsuitable for scale-up to a commercial size. However, use of this first prototype over a period of about six years yielded significant data that has led to the current process unit design concepts and improved operating conditions.

The current prototype was put into operation in 1989. This process unit is a concrete mixer modified as described earlier. The basic design concept of a rotating vessel with internal flighting for agitation of contents and for movement of the contents into or out of the vessel by the direction of rotation has proven to be easily scaled-up to small commercial size units that perform as well or better than the design prototype. Some additional design modifications are currently under way on the prototype to improve its loading and unloading characteristics.

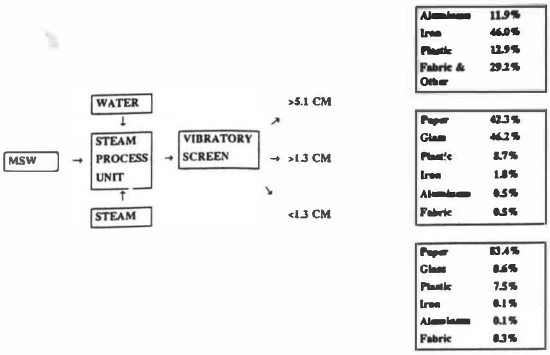

FIG. 2 VIBRATORY SCREEN CLASSIFICATION RESULTS (DRY BASIS)

One slightly larger demonstration unit has been built that is about 2.3 m (7.5 ft) in diameter and about 6.4 m (21 ft) in length. This unit is basically an extended version of a concrete mixer with one conical end having the single opening for loading and unloading by reversal of vessel rotation and the opposite end being a closed dome. This unit was designed to process 3.62 to 4.56 metric ton (4 to 5 tons) of MSW per batch. Based on a process cycle time of 2.5 to 3 hrs., a single unit of this size could process almost all of the MSW generated by a small residential community of 4000 to 5000 people (based on an average of about 2.5 kg (5.5 lb) MSW per person per day). This unit has so far been used only for demonstration purposes.

One small commercial unit has been built that is about 2.4 m (8 ft) in diameter and about 13 m (43 ft) in length. This unit was designed with both ends conical and with an opening in each end. The unit can be loaded at one end and unloaded at the opposite end. The unit is loaded with a hydraulic ram that provides additional compaction of the MSW to a capacity of 10.8 to 13.6 metric tons (12 to 15 tons), depending on the composition and moisture of the MSW. This unit has been operated over a period of about 6 months, processing an average of about 59 metric tons (65 tons) of residential and commercial MSW per day, 6 days per week, with two 9 hour shifts per day. The biomass fraction end-product was compost and therefore the facility design, other than the steam processor, is not directly relevant to RDF. Non-processibles and process residues were deposited in the on-site sanitary landfill.

## SUMMARY

In summary, the UAH-RDF process produces a product that has the following advantages relative to conventional fluff RDF-3:

- Easier to meter the flow of material because of small particle size.

- More uniform and consistent size, moisture content, bulk density and HHV value.
- Greater recovery of plastics/less chlorine.
- No wires or stringy material to interfere with operation.
- Less variation in volatilization rate due to more uniform particle size.
- Potentially higher % of RDF firing possible because of low moisture, lower chlorine, lower ash, uniform properties.
- Capability for indefinite storage

Because of the small particles [less than 1.3 cm (0.5 in)] and low particle density, the UAH-RDF has potential for suspension firing in pulverized coal utility boilers without the use of bottom grates. Full scale testing or testing in suitable simulators will be required to assess this capability.

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