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Treatment of Municipal Solid Wastes by Steam Classification for Recycling and Biomass Utilization

Scientific Note

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ABSTRACT

A patented method of steam classification (the Holloway Process) and a prototype process unit have been investigated. The process treats municipal solid wastes (MSW) with steam and pressure to yield sterilized recyclable metals, glass, and plastics and a cellulosic pulp. After processing, the components of the mixture are separated into three sizes by vibratory screening. The recyclable materials must be subsequently separated from the screened fractions. Process conditions have been optimized to maximize the yield of a sterile cellulosic fraction that has a variety of possible end uses, such as compost, combustion fuel, and feedstock for conversion to fuels and chemicals.

Index Entries: Municipal solid wastes; recycling; resource recovery; biomass conversion.

INTRODUCTION

Steam classification (the Holloway Process) provides an alternative to sanitary landfilling and refuse derived fuel or mass burn facilities for the disposal of MSW. The process allows considerable versatility to achieve any or all of several potential benefits from the treatment of MSW. When residential and most commercial wastes are treated, the volume of the waste is initially reduced by about 60%. The processed

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waste mixture is sterile and can be classified by size using a vibratory screen. After size classification, recyclable ferrous and nonferrous metals, plastics, and a mixed color cullet of glass can be recovered. Both natural resources and energy are conserved by recycling these components. By recycling of these materials, the volume of waste is further reduced by 5–10% and the revenues offset part of the processing costs.

The remaining components of the sterile waste mixture are composed mostly of cellulosic and food wastes. The noncellulosics remaining, which represent about 10% of the dry weight, are a mixture of fabric, plastics, and small pieces of metals and glass. The cellulosic fraction that comprises 50–60% (dry wt) of the original waste is in the form of a damp sterile pulp (65–70% moisture). This material can be used directly as a composting material. The cellulosic pulp (18,600 kJ/kg, dry wt) can be partially dried and may be used as combustion fuel. Combustion energy would be used to produce both process steam and electricity by cogeneration. The process would be more than self-sufficient for energy production alone, and excess cellulosic materials would be either composted, combusted to produce steam and/or electricity for sale, or consumed in conversion processes to more valuable fuels and chemicals. The cellulosic pulp, which is about 50% cellulose, may also be used directly as a feedstock for either enzymatic or chemical conversion to fermentable sugar and fermented to a variety of end product fuels and chemicals. The unreacted solids from conversion and fermentation can be separated, partially dried, and used as combustion fuel. The liquid effluents from conversion and fermentation can be treated in an anaerobic digester producing biogas which would also be used as a combustion fuel.

We have investigated steam classification using a prototype unit, and we have established the optimum operating conditions for the steam treatment and size classification of the products of the process. We have also proposed possible alternatives for utilization of the sterile cellulosic product.

METHODS

The Prototype Unit

The overall dimensions of the prototype unit are 1.5 m in diameter and 3.8 m in length with dished ends. The vessel is inclined at about 15° toward the lower exit door. The MSW entry port located top center is 0.5 m in diameter, and the lower exit door has a 0.25 × 0.4 m rectangular opening. The vessel contents are agitated by means of a 5.6 kJ/s electric motor driven bull gear attached to a central shaft that extends the length of the vessel. A basket, slightly less in diameter than the vessel interior is attached by connecting rods to the central shaft for agitation. The basket occupies only the lower end of the vessel interior because of the centrally located entry port. Although the basket occupies only the lower half of the vessel interior, the basket is connected to four baffles that extend the full length of the straight-walled interior, thus providing a means of agitation in the upper half of the vessel interior. Curved and angular paddle-type scrapers are attached to the lowest end of the basket to clean materials away from the dished end and exit port. Flat paddles, about 8 cm tall and 1 m long are attached to the interior surface of the basket at about a 30° angle relative to the length of the vessel. These paddles provide a means of linear conveyance of the contents of the basket. The direction of rotation of the basket determines the movement of materials away from the lower end of the inclined vessel during the filling, heatup, and cooking cycles. By reversal of the rotation, the materials are conveyed toward the exit port at the lower end of the vessel, thus providing a means for removal of the vessel contents. Saturated steam at 414 kPa is injected directly into the vessel interior by means of 5.1 cm piping via any or all of three locations. Pressure is vented via a 5.1 cm valve located on top of the vessel. The entry and exit ports are gasket sealed and the central agitator shaft is sealed with packing materials at each end. The unit has been pressure tested to 689 kPa, but is equipped with a 517 kPa pressure relief valve.

Process Operations

With the steam inlet valves closed and the lower exit door sealed, MSW is weighed, and water is added to the empty vessel via the top entry port at about 0.5 kg water/kg of MSW. The agitator is turned on to direct the flow of materials up and away from the lower end of the vessel. The MSW is conveyed from ground level to a working platform located on top of the unit at the entry port by means of an inclined belt conveyor. The MSW is then manually placed into the vessel via the entry port. Although the unit can process both larger and smaller quantities of MSW and water, for routine testing we have determined that about 272 kg of MSW (as is basis) and 136 kg of water provides a representative sample that can be processed in a convenient time period of about 3 h from start to finish. The MSW and added water are agitated to insure even distribution and absorption of the moisture throughout the wettable materials. This wetting and agitation brings about some volume reduction in the MSW and promotes even heat distribution when steam is introduced. The prototype unit can process about 1800 kg MSW/24 h. The entry port is closed and sealed. Saturated steam at 414 kPa is injected into the vessel via one or more of the steam inlet valves. The steam is injected with continuous agitation (6–8 rpm) until the internal pressure reaches 414 kPa, and steam injection and mixing are continued for 1 h after reaching 414 kPa. The combined effects of mixing, absorbed moisture, heat, and pressure brings about a pulping of the cellulosic materials similar to paper product recycling in pulp mills. This process thus disrupts the structural integrity of the cellulosic materials and produces a paper pulp. The vessel is depressurized via the steam vent. The lower exit door is opened, and the contents are conveyed by reversal of the rotation of the agitator onto a vibratory screen separator. The materials are separated on the vibrating screens into 5.1 cm or larger, 1.3–5.1 cm, and less than 1.3 cm fractions that are transferred to separate storage containers. The end products thus separated are weighed for quantitation of the test run. Additional manual sorting of the fractions provides the quantitation of individual components in each of the sized fractions, such as metals, glass, plastic, etc. Figure 1 shows a process flow diagram and the results of such treatment and separation.

RESULTS

It seemed appropriate to develop the process on the basis of wastes containing the most diverse composition to optimize the conditions for processing and separation. Therefore, the data that follow were obtained from processing residential MSW. Table 1 shows a typical composition for residential MSW.

The composition of the MSW was found to have little effect on the performance of the system. As mentioned previously, the sample size (272 kg) appears to be adequate to provide a rather uniform composition. It appears that as long as the paper products, food wastes, and moisture are present in amounts similar to the combined total in Table 1 of about 75%, the end results are very similar. The results of nine repetitive tests under nearly identical conditions are shown in Table 2. The results show the consistency of the data, which most likely arises from the uniformity of the MSW used in each test run.

The amount of water added to the MSW has a significant effect on the performance of the process. The inherent moisture in the MSW would also have an impact on the total moisture present in the final

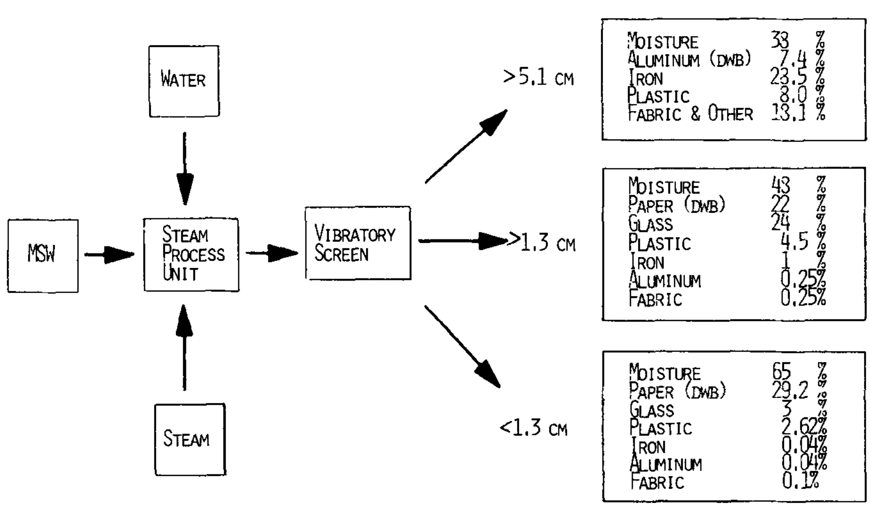

Fig. 1. Steam classification process flow.

Table 1
A 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

MSW–water mixture in the vessel prior to steam injection. However, the amount of inherent moisture in the MSW appears to be fairly constant in these tests, since the effects of added water appear to be consistent with repetitive test runs having identical water to MSW ratios. Figure 2 shows the distribution of the processed components as a function of added moisture. As the added moisture increases from zero to about 0.33 kg water/kg MSW the quantities of materials being retained on both the 5.1 and 1.3 cm screens decrease while the quantity of less than 1.3 cm material increases. The relative amounts of each fraction remain nearly constant up to about 0.6 kg water/kg MSW. Larger proportions of added water produce endproducts that are too wet for separation on the vibratory screen separator. As the composition of MSW changes, such as increased plastics and less paper in future years, the ratio of added water will have to be reduced to maintain the final cellulosic product moisture content within the optimum range for separation (60–70% moisture).

The time after reaching the 414 kPa steam pressure in the unit has also been found to have an effect on the process performance. As shown in Fig. 3, there is a significant increase in the less than 1.3 cm fraction with corresponding decreases in the other two fractions. Cooking times longer than 1 h have little effect upon performance, since the maximum levels of separation are achieved in 1 h for all three fractions.

The steam pressure achieved in the process unit has a significant effect on the performance of the process, as shown in Fig. 4. As the steam

Table 2
Results of Nine Tests Under Nearly Identical Conditions

Input	Weight, kg	Volume, m^3
MSW	274 ± 0.5	2.4 ± 0.1
Water	165 ± 0.0	0.16 ± 0.0
Output, cm		
>5.1	30 ± 5.5	0.22 ± 0.02
1.3–5.1	118 ± 15	0.2 ± 0.05
<1.3	381 ± 17	0.6 ± 0.04

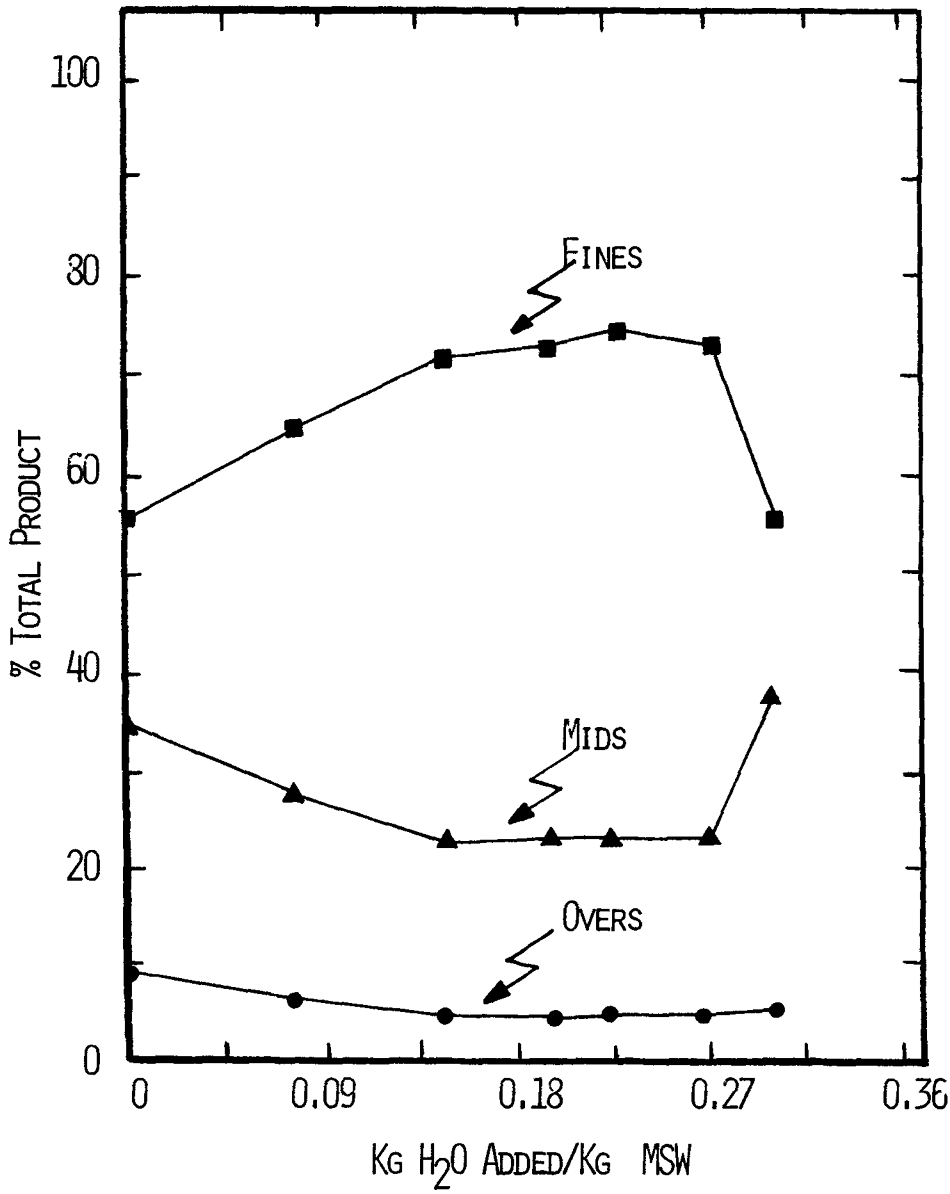

Fig. 2. Effects of added moisture on separation.

pressure increases from 103–276 kPa there is a decrease in the quantities of materials retained both by the 5.1 and 1.3 cm screens and a corresponding increase in the quantity of less than 1.3 cm material. From 276–414 kPa the quantity of less than 1.3 cm material increases slightly with pressure, and the other two fractions decrease slightly. Thus, the vibratory screening process operates most efficiently providing the largest percentage of less than 1.3 cm material when the steam treatment is performed at about 414 kPa steam pressure. The increased yield in fines is due to increased pulping of the cellulosics remaining in the 5.1–1.3 cm

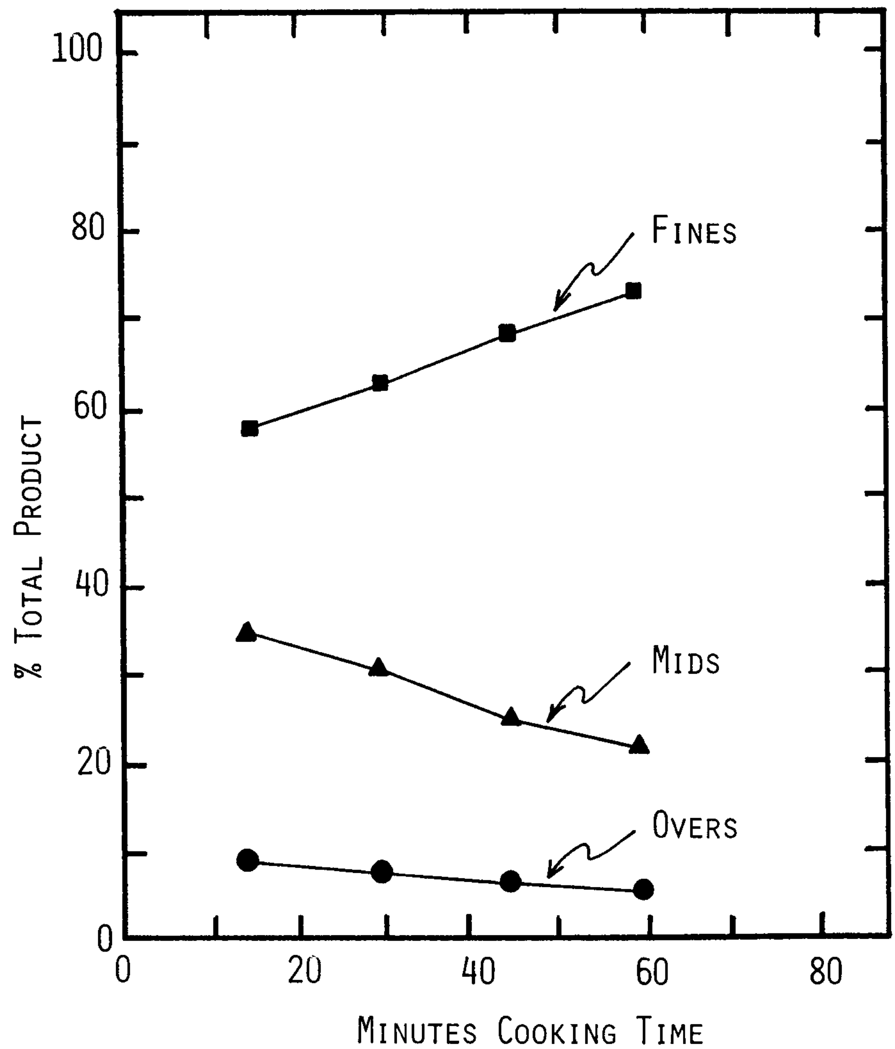

Fig. 3. Effects of cooking time on separation.

fraction into smaller fragments. The relative quantities of glass and plastics in the fines do not appear to change.

Under optimum conditions of moisture, steam pressure, and cooking time, the process initially consumes about 1 kg of saturated steam/kg MSW or about 0.6 kg of saturated steam/kg of MSW and water mixture. Of the 272 kg of steam utilized, about 33% is condensed into the final products as additional moisture, and the remaining 67% is vented during depressurization or evaporated during the separation process. The vented steam can be used in a heat recovery step to preheat the next batch process unit.

Upon completion of the depressurization, the vessel contents are usually separated by vibratory screening. Because of the process, the volume of the waste material has been significantly reduced (*see* Table 2).

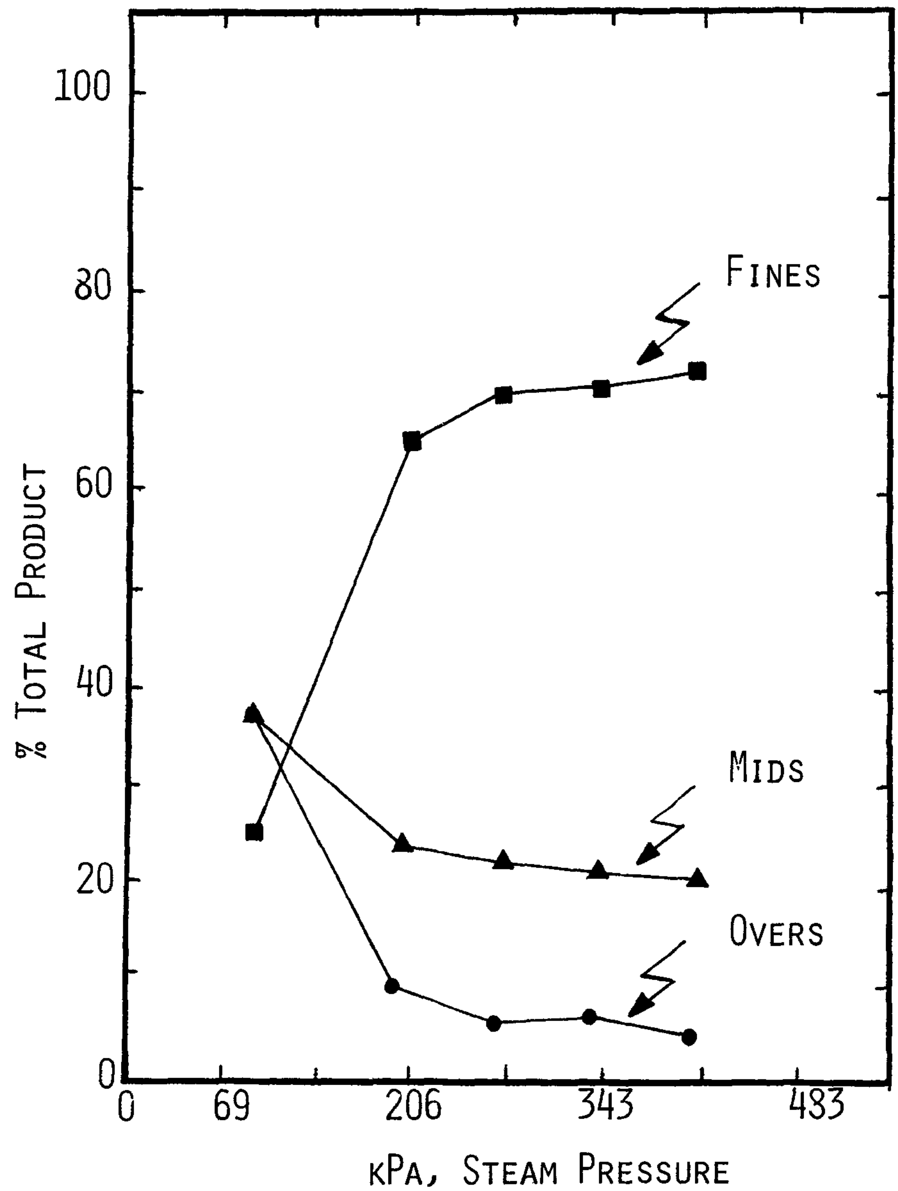

Fig. 4. Effects of steam pressure on separation.

The original density of MSW for processing is about 112 kg/m^3. The volume reduction in Table 2 is about 57%, although in this instance the fractions have already been separated. Since the metal containers and many other larger items retain their original shape for the most part, it is easy to envision that the less than 1.3 cm material could fill the air spaces inside and between these large items when measuring their combined volume. Therefore, if the component fractions were not separated by vibratory screening, the total volume reduction would likely be in the range of 60–70%.

For processing MSW using the Holloway Process, it is necessary to add water or other suitable aqueous solutions to the MSW as a wetting agent. In addition, there is the weight of steam condensate that ends up in the final product. For optimum process performance, it is necessary to add about 0.5 kg water/kg MSW, which is a 50% weight gain. Steam condensate from the cooking process accounts for an additional 33% weight gain. Therefore, the MSW typically exhibits an 83% net weight gain by this process. Referring to Table 1, we also find that the MSW possesses about 20% water from the start. Taking the composition of the MSW into account, we see that the paper products and food wastes are the major components that can absorb water. From a typical batch of 272 kg of MSW, about 55% or 150 kg is paper products and food wastes. By steam classification this material has the original moisture of 54 kg of water, the added water of 136 kg, and the steam condensate of 91 kg. Thus, the paper and food pulp should have a final moisture content of about 65%. Actual moisture analyses on processed materials in the less than 1.3 cm fraction verify the moisture content of about 65%.

Although the processed products are separated based on size by vibratory screening, the individual recyclable components, such as ferrous metals, aluminum, glass, and so on, must be separated by other means. By manually sorting the screened fractions, we have found that 80–90% of the recyclable metals are present in the 5.1 cm 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 fraction. Most of the additional ferrous metal was found in the 1.3–5.1 cm fraction, and very little was found in the less than 1.3 cm 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 fraction. Again, most of the additional nonferrous metal was found in the 1.3–5.1 cm fraction, and very little was found in the less than 1.3 cm fraction. Repeated sortings have shown that about 5% of the original MSW can be recovered as plastics. Some to the plastics have melted into agglomerates, whereas others are distorted and some remain unchanged because of the temperature of processing (150°C). About 60% of the plastics are in the 5.1 cm fraction. The remaining 40% of the plastics are found mostly in the 1.3–5.1 cm fraction with a small amount, possibly 0.5%, being present in the less than 1.3 cm fraction. Repeated sortings have shown that less than 1% of the original MSW is recovered as glass and ceramics in the 5.1 cm fraction. The majority, possibly 80% of the glass and ceramics, is present in the 1.3–5.1 cm fraction. The remainder of the glass is present in the less than 1.3 cm fraction. The cellulosic and food wastes are generally distributed 20% in the 1.3–5.1 cm fraction and 80% in the less than 1.3 cm fraction. Essentially all of the cellulosic pulp can be recovered from the 1.3–5.1 cm fraction upon reprocessing. Other than the recovery of the glass, the 1.3–5.1 cm fraction is essentially void of any recyclable materials worth the recovery effort. The less than 1.3 cm fraction is composed essentially of combustible cellulosics with less than 1% plastic and only 6–8% ash content. On a dry weight basis, this fraction possesses > 18,600 kJ/kg. The material is also potentially valuable for composting or conversion to fuels and chemicals.

Steam consumption is about 272 kg at 414 kPa per batch run. The total energy input is initially about 756,000 kJ. However, by using two process units the steam from the depressurization of one unit can be used to preheat the materials in the second unit. The quantity of steam and energy recovered in this manner is about 136 kg or 447,000 kJ (about 90%). Thus, the net steam consumption as condensate in the waste mixture is about 91 kg/batch or about 308,000 kJ. When the electrical consumption of about 11,000 kJ is included, the net energy requirement is about 319,000 kJ/272 kg batch or only about 1162 kJ/kg of MSW.

The process energy would be produced by using a portion of the cellulosic product as a combustion fuel to produce process steam and cogenerate electricity. The combustion emissions from this cellulosic product are expected to be much less of an environmental problem than mass burn or refuse-derived fuel because most of the metals and plastics are removed prior to combustion. The cellulosic material has a heating value of >18,600 kJ/kg on a dry basis, but the material is produced at 65% moisture content. Therefore, a portion of the fuel value will be required to evaporate the moisture. Since about 0.84 kg of water must be evaporated per kg of cellulosic material, the net heating value of the fuel is reduced to only about 6500 kJ/kg. Hot flue gases would be used to dry the fuel to about 35% moisture before entering the combustion chamber. Some supplemental fuel would be required to initiate the combustion process. Assuming that the combustion efficiency is about 70%, then additional fuel will also be required to overcome these losses. A total of about 457,000 kJ of fuel at 6500 kJ/kg net heating value or about 70 kg of fuel would be necessary to produce the process steam. Assuming a cogeneration efficiency of 40% and correction for moisture and combustion efficiency, an additional 6 kg of fuel is required for electricity. The thermal energy efficiency of this process compared to mass burn and refuse derived fuel facilities is lower, but the benefits of recycling, less combustion emissions, and alternate fuels may outweigh the lower thermal efficiency.

A 272 kg batch of MSW will yield 453–500 kg of this cellulosic fuel. Although about 90 kg is found in the 1.3–5.1 cm fraction, the remaining 360–400 kg comprises the less than 1.3 cm fraction. With a process energy fuel requirement of only about 77 kg, then a significant excess of cellulosic material is produced in this process, the fuel value of the excess cellulosic material is in excess of 2,100,000 kJ.

The ultimate fate of the excess cellulosic material is determined in part by the availability of various markets and the size of the process facility. If we assume a small plant, relative to other resource recovery plants, processing 90 metric tons/day of residential MSW, about 130 metric ton/d of the cellulosic material would be produced. Although composting is a possibility, it is unlikely that a market for such quantities could be sustained for very long. If a customer for steam is available, then about 9000 kg/h of steam at 2100 kPa could be produced. If a customer is available that can utilize densified refuse derived fuel, the material could be pelletized with a final moisture content of about 10% having a heating value of about 16,700 kJ/kg in quantities of 45–55 metric tons/d. If none of these above markets are available, a conversion plant using either enzymatic or acid hydrolysis could be included to convert the cellulose component to sugar for fermentation to a variety of possible fuels and chemicals. With an enzymatic process for example, about 45,000 kg of the sterilized material having 50% cellulose content and about 50% conversion efficiency would yield about 12,500 kg of fermentable glucose. Upon fermentation to ethanol, about 7600 L would be produced per day. The unreacted cellulosic residues would be recovered, partially dried, and used as combustion fuel for thermal and electrical energy for the enzyme production, hydrolysis, fermentation, and distillation processes. The liquid residue recovered from distillation would be concentrated and subjected to anaerobic digestion to produce additional combustion fuel (biogas).

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