KEY ISSUES CONCERNING WASTE PROCESSING DESIGN

GEORGE M. SAVAGE and LUIS F. DIAZ
Cal Recovery Systems, Inc.
Richmond, California

ABSTRACT

The paper reviews the state of the art of processing equipment for resource recovery processing and certain peripheral issues involved in process design. The peripheral issues include the use of waste characterization data during the early stages of process design, properties and characteristics of recovered materials and energy forms (e.g., RDF), health and safety precautions, and potential environmental consequences of front-end processing of waste prior to its combustion in thermal conversion facilities.

INTRODUCTION

The past decade and a half of solid waste management practice has witnessed a marked proliferation of systems, each of which was firmly believed by its staunch protagonists as being not only the solution to the solid waste management problem, but also as serving in part to alleviate a perceived energy shortage. The proliferation was characterized by a correspondingly pronounced flux of casualties that accompanied the scale-up of the systems from laboratory through pilot to field scale. The casualties usually stemmed not only from technical shortcomings of many systems, but also from the staggering economics associated with them and their application.

Around the world, among the more successful (persistent) systems have been direct combustion and composting. Among the less successful have been biogasification and thermal gasification; and among the least successful, saccharification of the cellulosic fraction for alcohol production. Secondary fiber recovery may perhaps be ranked with direct combustion and composting. An interesting point about most of these systems is that when resurrected and refurbished in the past decade and a half, they were offered as novel systems; whereas in reality they can be traced, albeit in more simplified form, to the 1950's and early 1960's (e.g., composting, thermal gasification, biogasification, steam and electrical generation).

With the exception of massburn and one or two other systems, all of the systems are designed to deal with processed municipal waste. Each rely upon a feedstock prepared by processing raw MSW such that it acquires properties and characteristics that are compatible with the operation of the subsequent conversion system. Appropriately, this processing has taken on the designation "pretreatment," and its function is to prepare and beneficiate the raw waste for treatment and conversion by the system of choice. Because chronologically and spatially the system of choice comes after pretreatment, it is termed "back-end system." In short, with the aforesaid exceptions, all resource recovery technologies generally involve a pretreatment system, alternatively a front-end system working in tandem with a back-end system.

Characteristically, most pretreatment systems have features common to all; and as a rule, their feedstocks can be used by more than one type of back-end system with minor alterations. An example of commonality of features is the fact that the most widely used pretreatment systems are mechanical in nature and involve little or no chemical or biological reaction. The multiple suitability of prepared MSW feedstock is exemplified by the feedstock commonly prepared for direct combustion—it can be used for thermal or biological gasification, or for composting.

PRETREATMENT UNIT OPERATIONS

The major subject matter of the present paper is the mechanical pretreatment of urban wastes. The three basic functions of such a mechanical pretreatment are particle size adjustment, classification, and separation (segregation). Particle size adjustment is accomplished by size reduction. Classification is done by way of screening and by exposure to air flow in an especially designed unit (air classification). Separation is done by way of physical phenomena (e.g., magnetic separator) and partly by air classification. The four unit processes generally involved in mechanical separation are size reduction, air classification, magnetic separation, and screening. The sequence of the arrangement of the processes is based chiefly upon the quality and nature of the waste being treated and upon the availability, location, and specifications of markets for recovered materials and forms of energy.

An excellent example of mechanical pretreatment is the production of a product destined for use in thermal gasification and direct combustion. The product generally is termed "refuse derived fuel" (RDF), and comes in one of two forms, namely, fluff RDF or densified RDF (d-RDF). Among the important properties and characteristics of RDF (and of most feedstocks) are particle size distribution, composition, ash content, moisture content, organic content, and heating value.

Size Reduction

Initially used almost exclusively as a first step in the conversion of municipal solid wastes into a feedstock for composting, size reduction (shredding, grinding, milling) has now become a relatively widely applied process in solid waste management practice. Now, size reduction is generally regarded as being an integral part of large solid waste mechanical processing systems. Its importance with respect to mechanical separation arises in part from it generally being first in the series of unit processes involved in the separation process. Because size reduction is first, the type and degree of size reduction exerts a direct influence upon the performance of the equipment used in subsequent handling and separation.

As one would expect, aspects that exert an effect on the functioning of equipment positioned downstream and which influence cost are the more important of those of size reduction. The size distribution of the shredded material delineates the effect on downstream processes. Cost is that of machine wear and the energy consumed in the operation of the machine.

Usually, size reduction results in a size distribution of the shredded refuse that is one to two orders of magnitude less than that of the feed. Composition of the waste, feed rate, moisture content of the feed, and type (design) of machine are among the more important factors that determine particle size distribution.

A characteristic of the size reduction of urban waste that leads the promotion of the separation process is the tendency of specific materials to concentrate within certain size ranges in the overall size distribution. This tendency can be used to advantage in processing the shredded product in other unit operations such that certain materials can be separated from other materials.

Energy consumption is a principal consideration in designing size reduction equipment, because it is a major item in the cost of operating the equipment. Experiments and field tests conducted by the authors and others have made possible the accumulation of data that serves as a basis upon which relationships can be developed for predicting specific energy as a function of characteristic product size. The data indicate that the specific energy requirement for producing shredded waste having a nominal particle size (screen size corresponding to 90% cumulative passing) of 10 cm is on the order of 6 kW·h/t; whereas if the desired size is 1 cm, the energy requirement is on the order of 50 kW·h/t. The influence of product size on the energy requirement for size reduction, based upon field testing, is illustrated in Fig. 1.

Wear of the rotating cutting elements in refuse size reduction equipment, e.g., the hammers in a hammermill, also contributes substantially to the cost of the size reduction process. Wear is primarily a function of the composition of the waste feedstock, the degree of size reduction required, and the hardness of the surface of the cutting elements. The relationship is illustrated in Fig. 2.

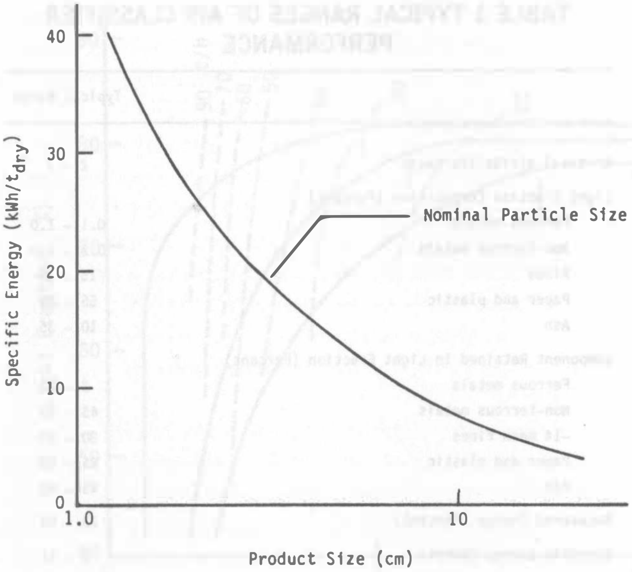

FIG. 1 SPECIFIC ENERGY REQUIREMENTS FOR SIZE REDUCTION OF MUNICIPAL SOLID WASTE

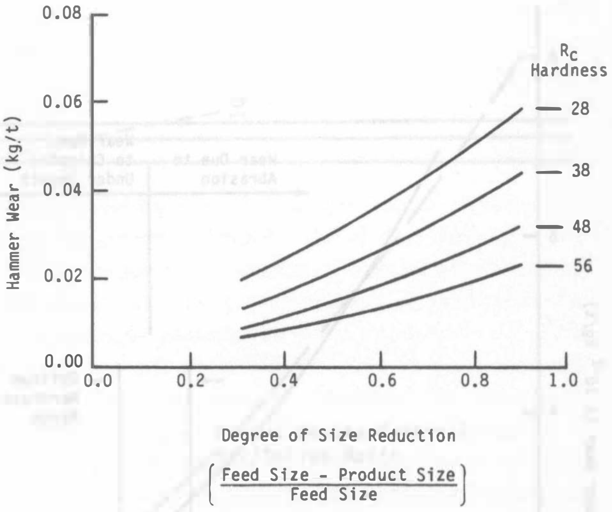

FIG. 2 HAMMER WEAR AS A CONSEQUENCE OF SHREDDING SOLID WASTE

Substantial savings in the rate of wear are possible if the correct hardfacing materials are chosen for use. The results of experimentation with hardfacing materials at several refuse processing facilities are shown in Fig. 3. The abrasive nature of shredded refuse has an important bearing on the extent of hammer wear. Early in the development of refuse size reduction, hammers were designed for impact, i.e., parent hammer material and hardfacing were in the range of 15 Rockwell C. Many refuse size reduction units still use hammers with hardnesses in this low range and suffer the corresponding penalty in terms of substantial rates of hammer wear.

Using rotational speed as the basis, size reduction equipment (shredders) used in the industry can be classified into the two categories "low rpm" and "high rpm." Shear shredders are an example of the former category, while hammermills are examples of the latter. The primary mechanisms of size reduction in the low rpm machines are tearing and shearing; whereas tearing and impact constitute the major mechanisms in high-rpm machines. Currently, the maximum capacity of commercially available shredders is about 100 t/h.

Unfortunately, shredder explosions no longer are rare occurrences in size reduction operations. Although the causes may be many, the explosions themselves are to a great extent preventable through the institution of proper system design. Most of the shredder explosions have been traced to the ignition of volatile organic chemicals that had been released and dispersed within the shredder cavity as a result of the disruptive impact of the rotating cutting elements of the machine upon the container in which the chemicals had been confined. Among the means of reducing the risk, incidence, and severity of explosions are: *(a)* through the institution of educational and visual observation programs to bring about a reduction in the amount of combustible and explosive materials entering the processing equipment; *(b)* installation of properly designed explosion suppression and venting systems; and *(c)* provision of adequate ventilation of the shredder cavity. The last named means is important, because research indicates that volatile organic gases in the shredder cavity of horizontal hammermills tend to concentrate in discrete zones [1, 2].

Air Classification

Air classification may be loosely defined as a process, in which a mixture of particles of a variety of materials and sizes is suspended in a gaseous stream such that the particles are segregated on the basis of their aerodynamic characteristics. In some urban waste processing facilities, the air classifier is positioned after the size reduction equipment; and in others, after the screening equipment. Air classifiers are designed such that the refuse stream is separated into a light fraction ("lights") that contains an abundance of combustible material, and a heavy fraction ("heavies") that is mostly inorganic in nature.

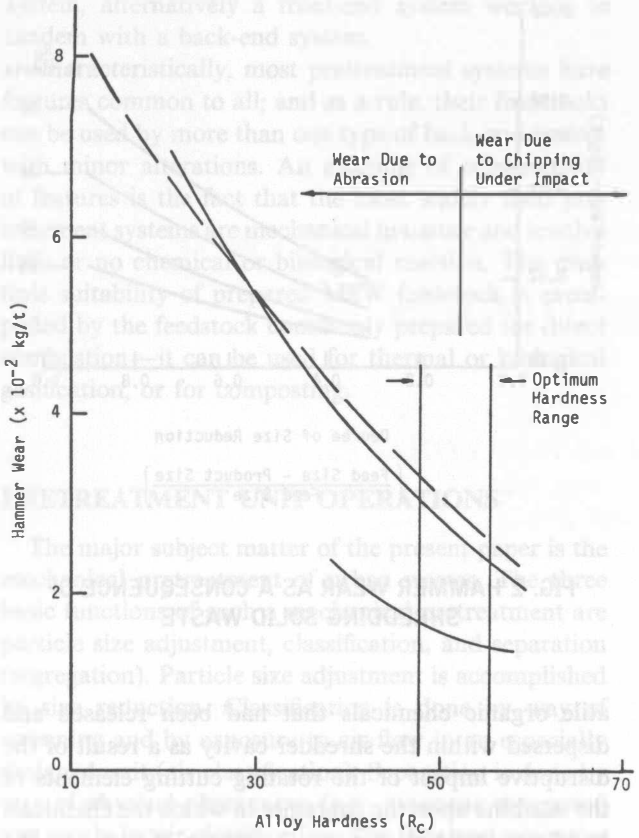

FIG. 3 RELATIONSHIP BETWEEN HAMMER WEAR AND PROPERTIES OF HARDFACING ALLOYS FOR THREE DIFFERENT SITES

Several factors determine the course of separation in an air classifier. Among the more important are: *(a)* size-distribution, shape, density and moisture content of the individual particles; *(b)* direction of the flow, velocity, and density of the gas; and *(c)* the size, shape, and interior surface of the air classifier. Air classifier performance depends largely on feed rate, uniformity of feed, air-to-solids ratio, and column loading.

Three general types of air classifiers are available at present, namely, the "horizontal," the "vertical," and the "inclined." As of this writing, the largest air classifiers available in the U.S. have a capacity on the order of 70 t/h. The energy consumed by air classifiers ranges from 1 to 11 kW·h/t of throughput. These figures do not take into account the energy consumed by the dust control equipment. The performance of air classifiers varies substantially depending upon the type of air classifier, characteristics of the feedstock, and the operating conditions. Ranges of performance for a number of parameters are given in Table 1.

TABLE 1 TYPICAL RANGES OF AIR CLASSIFIER PERFORMANCE

	Typical Range
Critical Air/Solids Ratio	2 - 7
Light Fraction Composition (Percent)	
Ferrous metals	0.1 - 1.0
Non-ferrous metals	0.2 - 1.0
Fines	15 - 30
Paper and plastic	55 - 80
Ash	10 - 35
Component Retained in Light Fraction (Percent)	
Ferrous metals	2 - 20
Non-ferrous metals	45 - 65
-14 mesh fines	80 - 99
Paper and plastic	85 - 99
Ash	45 - 85
Recovered Energy (Percent)	73 - 99
Specific Energy (kWh/t)	1 - 11
Column Loading (t/h)/m2	5 - 40

As of this writing, the popularity of air classification has declined substantially due primarily to the excessive degree of wear experienced in the pneumatic lines transporting the light fraction and to a perceived lack of system capacity. It should be pointed out that the issue of wear can be addressed by applying the basic principles that were discussed previously for hammer wear. With respect to the perceived lack of system capacity, in the 1970's air classifiers were designed using pneumatic transport theory. The theory is based on relatively homogeneous materials of relatively uniform size. Neither of the criteria apply to shredded MSW. Consequently, the air/solids (A/S) ratios of 2:1 to 3:1 that are appropriate for pneumatically handling homogeneous materials failed to achieve adequate mixing, separation, and transport of shredded MSW in air classifiers. Thus, units designed to accommodate 50 t/h could only handle one-quarter to one-half the flow since shredded MSW requires an A/S ratio of five or better to prevent choking (i.e., settling of virtually the entire feed stream in the air classifier column).

The influence of the air/solids ratio on the percentage of material flying with the light fraction is shown in Figs. 4 and 5, for light fraction and for selected refuse components, respectively. For steady-state operation, i.e., the point where the split to the light fraction remains independent of the air/solids ratio, the air flow set point must be such that the A/S ratio is beyond the critical A/S value. (The latter is defined as the A/S ratio wherein the constant light fraction split falls off by 1%.) For a given throughput

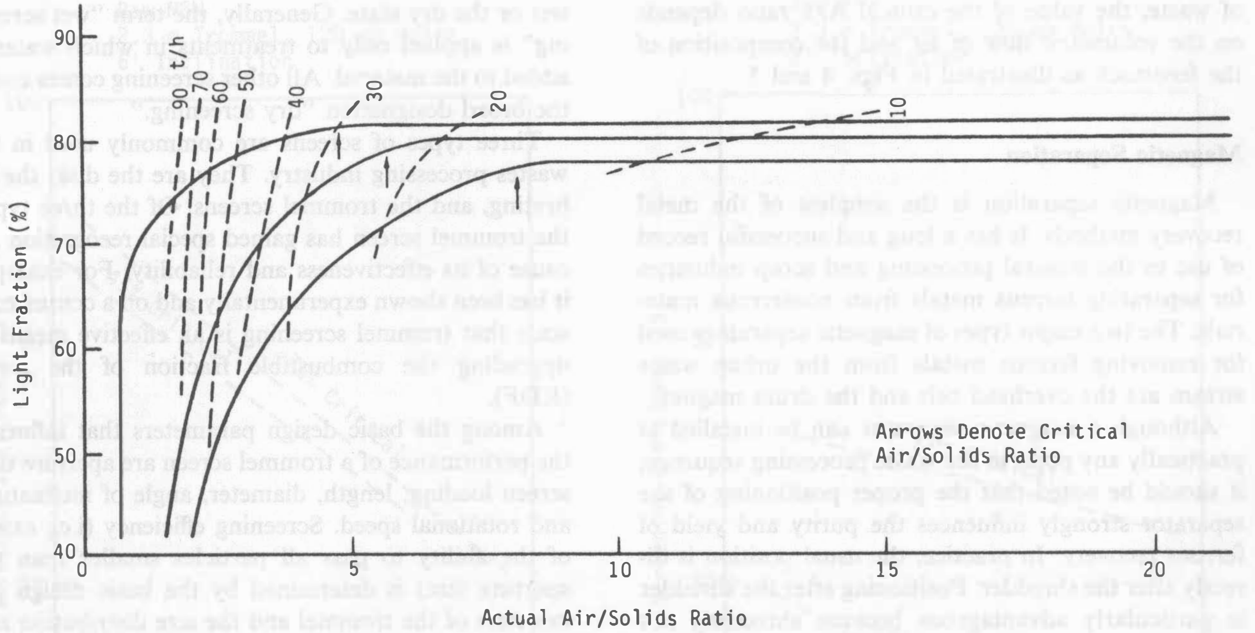

FIG. 4 INFLUENCE OF AIR/SOLIDS RATIO UPON LIGHT FRACTION SPLIT FOR DIFFERENT AIR FLOW SETTINGS

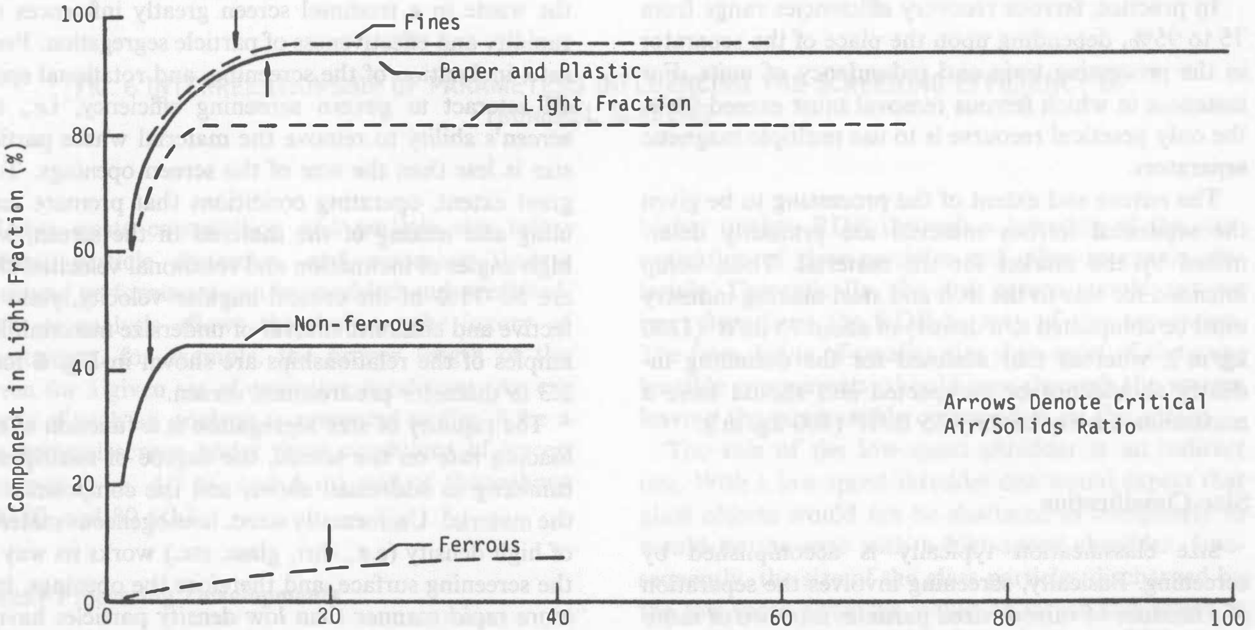

FIG. 5 EFFECT OF AIR/SOLIDS RATIO IN COMPONENT SPLIT

of waste, the value of the critical A/S ratio depends on the volumetric flow of air and the composition of the feedstock as illustrated in Figs. 4 and 5.

Magnetic Separation

Magnetic separation is the simplest of the metal recovery methods. It has a long and successful record of use in the mineral processing and scrap industries for separating ferrous metals from nonferrous materials. The two major types of magnetic separators used for removing ferrous metals from the urban waste stream are the overhead belt and the drum magnet.

Although a magnetic separator can be installed at practically any point in the waste processing sequence, it should be noted that the proper positioning of the separator strongly influences the purity and yield of ferrous recovery. In practice, the usual position is directly after the shredder. Positioning after the shredder is particularly advantageous because shredding not only reduces the refuse particles to sizes that can be managed by the magnetic separator, it also removes objectionable substances (e.g., labels and coatings) from ferrous objects. Removal of the objectionable materials is a requisite for meeting the specifications usually insisted upon by a buyer.

In some operations, the "heavies" separated by the air classifier are exposed to magnetic separation.

In practice, ferrous recovery efficiencies range from 75 to 95%, depending upon the place of the separator in the processing train and redundancy of units. For instances in which ferrous removal must exceed 95%, the only practical recourse is to use multiple magnetic separators.

The nature and extent of the processing to be given the separated ferrous material are primarily determined by the market for the material. Thus, scrap intended for sale to the iron and steel making industry must be compacted to a density of about 75 lb/ft^3 (1200 kg/m^3); whereas that destined for the detinning industry should not be compacted and should have a maximum density of only 25 lb/ft^3 (400 kg/m^3).

Size Classification

Size classification typically is accomplished by screening. Basically, screening involves the separation of a mixture of various sized particles into two or more fractions on the basis of differences between the respective sizes of the particles. It follows that each of the separated fractions will be more uniform in terms of particle size than was the case with the original mixture. Particles can be screened while in either the wet or the dry state. Generally, the term "wet screening" is applied only to treatments in which water is added to the material. All other screening comes under the broad designation "dry screening."

Three types of screens are commonly used in the wastes processing industry. They are the disk, the vibrating, and the trommel screens. Of the three types, the trommel screen has gained special recognition because of its effectiveness and reliability. For example, it has been shown experimentally and on a commercial scale that trommel screening is an effective means of upgrading the combustible fraction of the waste (RDF).

Among the basic design parameters that influence the performance of a trommel screen are aperture size, screen loading, length, diameter, angle of inclination, and rotational speed. Screening efficiency (i.e., extent of the ability to pass all particles smaller than the aperture size) is determined by the basic design parameters of the trommel and the size distribution and properties of the feedstock. The screen may be positioned either before the shredding step (pre-trommel) or after it (post-trommel). Overall trommel screening efficiencies typically range from 75 to 95%.

With respect to trommel screens, research has been conducted on their governing principles and performance, both in the pre-trommel mode and the post-trommel mode. The degree of mixing and tumbling of the waste in a trommel screen greatly influences the rapidity and effectiveness of particle segregation. Feedrate, inclination of the screening, and rotational speed all interact to govern screening efficiency, i.e., the screen's ability to remove the material whose particle size is less than the size of the screen openings. To a great extent, operating conditions that promote tumbling and mixing of the material in the screen, e.g., high angles of inclination and rotational velocities that are 50–75% of the critical angular velocity, yield effective and efficient removal of undersize material. Examples of the relationships are shown in Fig. 6 for a 2.3 m diameter pre-trommel screen.

The rapidity of size segregation is a function of the loading rate on the screen, the degree of mixing and tumbling as addressed above, and the composition of the material. Uniformally sized, homogeneous material of high density (e.g., dirt, glass, etc.) works its way to the screening surface, and therefore the openings, in a more rapid manner than low density particles having large area-to-volume ratios (e.g., plastic, aluminum, and paper). The slow removal of paper and aluminum as opposed to the denser materials (e.g., glass and organic other) is illustrated in Fig. 7 for a pre-trommel screening process.

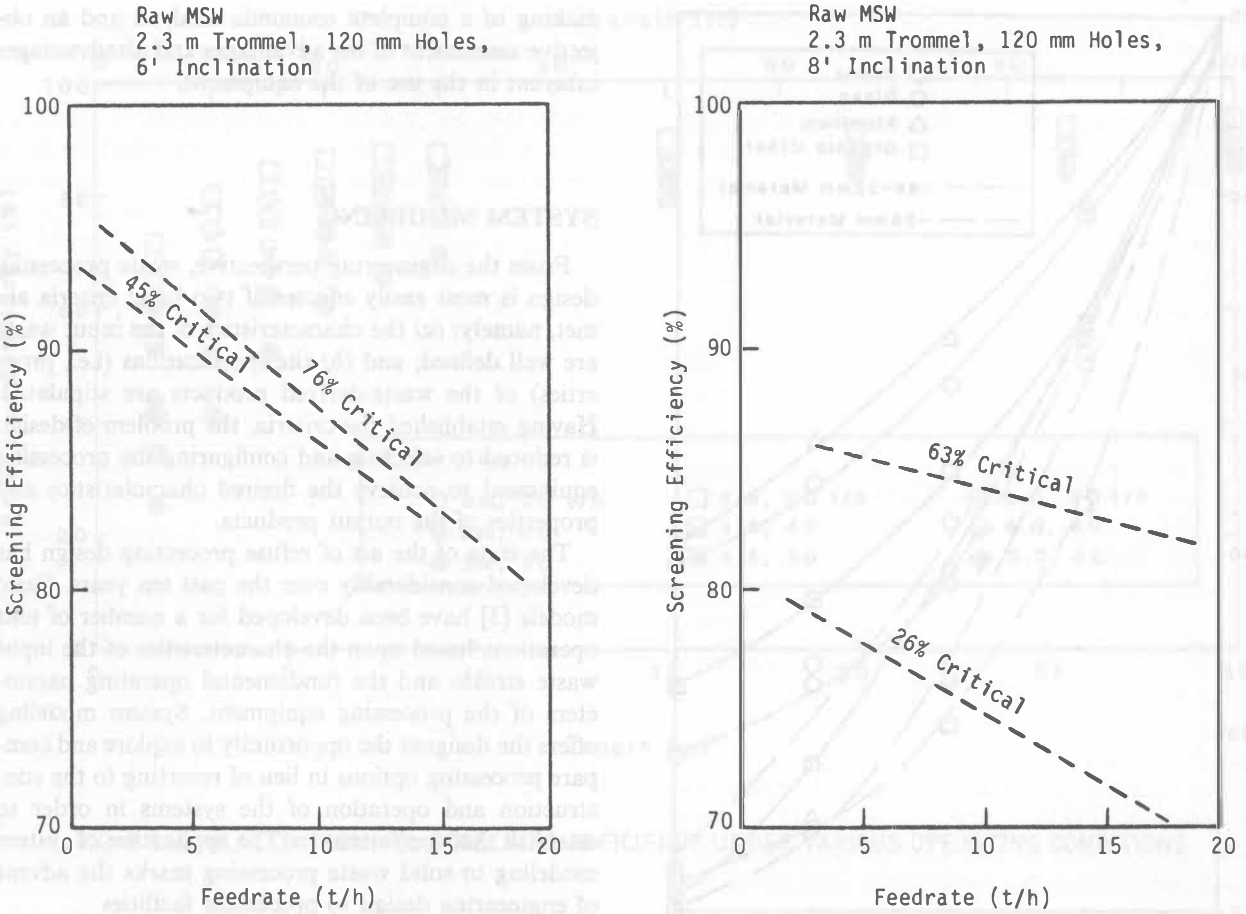

FIG. 6 INTERRELATIONSHIP OF PARAMETERS INFLUENCING THE SCREENING EFFICIENCY OF TROMMEL SCREENS

Using waste composition and particle size information, particle dynamics, and screening theory, screening performance can be modeled and predicted. Such an analysis allows the designer the luxury of ascertaining, for example, the proper length of the screen for a given set of operating conditions. An example of such an analysis is presented in Fig. 8 for a pre-trommel screen under three conditions of screen diameter (3 m, 4.5 m, and 6 m) and of throughput (20, 60, and 80 t/h).

Recent Processing Developments

One of the recent developments of note in the waste processing industry has been the attention given disk screens and low-speed (< 200 rpm) size reduction equipment. The attention is generated by the supposed ability of the two types of equipment to produce a higher quality RDF through a lowering of the concentration of glass particles and other inorganic materials. Theoretically, the disk screen should remove inert fines from the RDF by way of size separation. The fines, being of smaller size than most of the combustible components, should pass through the screen, leaving the combustible components on the screen.

The role of the low-speed shredder is an indirect one. With a low-speed shredder one would expect that glass objects would not be shattered as completely as would be the case with a high-speed shredder. Consequently, the size of the glass particles discharged by the low-speed shredder would be larger and easier to screen out than would be those from the high-speed shredder. (Other purported advantages associated with low-speed shredding are a lessening of the incidence of explosions and a reduction in the number of fines embedded in the individual paper particles.)

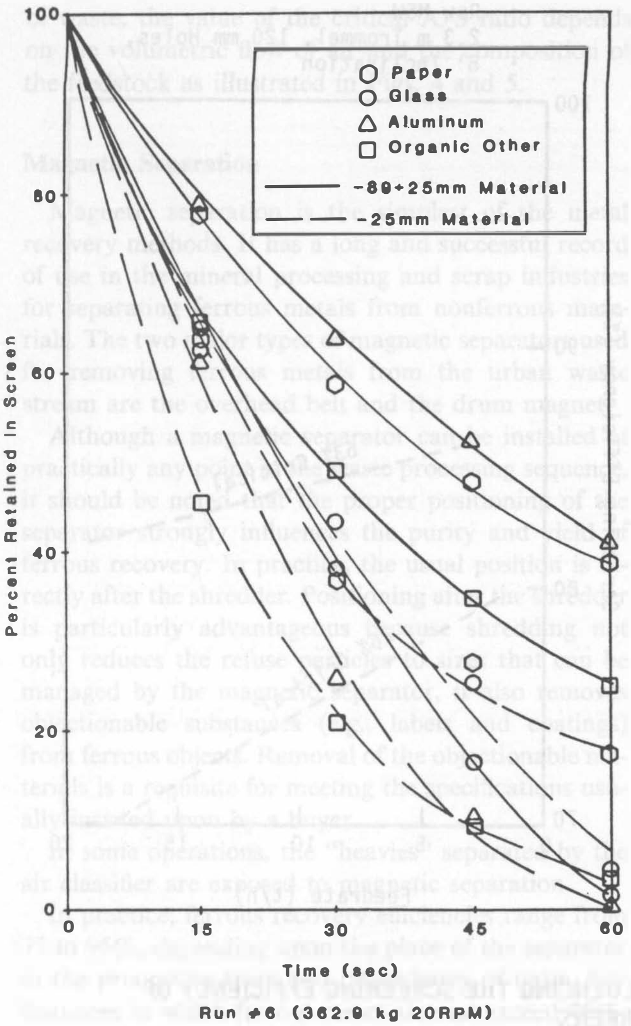

FIG. 7 VARIATIONS IN SCREENING EFFICIENCY AMONG SOLID WASTE COMPONENTS FOR A PRE-TROMMEL SCREEN OPERATING AT ZERO DEGREES INCLINATION

Before arriving at any firm conclusions regarding putative advantages attending the use of disk screens and low-speed (shear) shredding, one must be aware that the claims made by the proponents of the equipment have not as yet been backed by scientifically conducted comprehensive field test studies. To be truly comprehensive and conclusive, the tests should be designed such that equipment performance can be evaluated and presented in terms of parameters that allow an equitable comparison between similar pieces of equipment. Moreover, the studies should extend to the making of a complete economic analysis and an objective assessment of the advantages and disadvantages inherent in the use of the equipment.

SYSTEM MODELING

From the engineering perspective, waste processing design is most easily effected if two basic criteria are met, namely: *(a)* the characteristics of the input waste are well defined; and *(b)* the specifications (i.e., properties) of the waste-derived products are stipulated. Having established the criteria, the problem of design is reduced to selecting and configuring the processing equipment to achieve the desired characteristics and properties of the output products.

The state of the art of refuse processing design has developed considerably over the past ten years. Basic models [3] have been developed for a number of unit operations based upon the characteristics of the input waste stream and the fundamental operating parameters of the processing equipment. System modeling offers the designer the opportunity to explore and compare processing options in lieu of resorting to the construction and operation of the systems in order to establish their performance. The application of system modeling to solid waste processing marks the advent of engineering design to processing facilities.

As a means of illustrating the utility of system design as applied to refuse processing as well as the present state of the art, several examples are presented herein. All of the examples have as their basis a reference raw (i.e., unprocessed) solid waste composition and presume the production of a refuse derived fuel (RDF). The reference waste composition is given in Table 2. Several processing options (i.e., system configurations) are explored in terms of the properties of the recovered RDF. In addition the effect of changes in the composition of the waste is examined for a typical RDF processing configuration. The latter comparison serves to illustrate the potential impacts of changes in waste composition over a period of time as well as the potential influence of recycling on the properties of waste entering a processing facility and on the recovered RDF product. The properties of the MSW and of the recovered RDF are calculated from the component composition of the material (e.g., glass, newsprint, etc.) and a component property database as described in Ref. [4].

The first example illustrates the influence of mechanical processing of waste on the properties of the recovered RDF fraction. The properties considered in

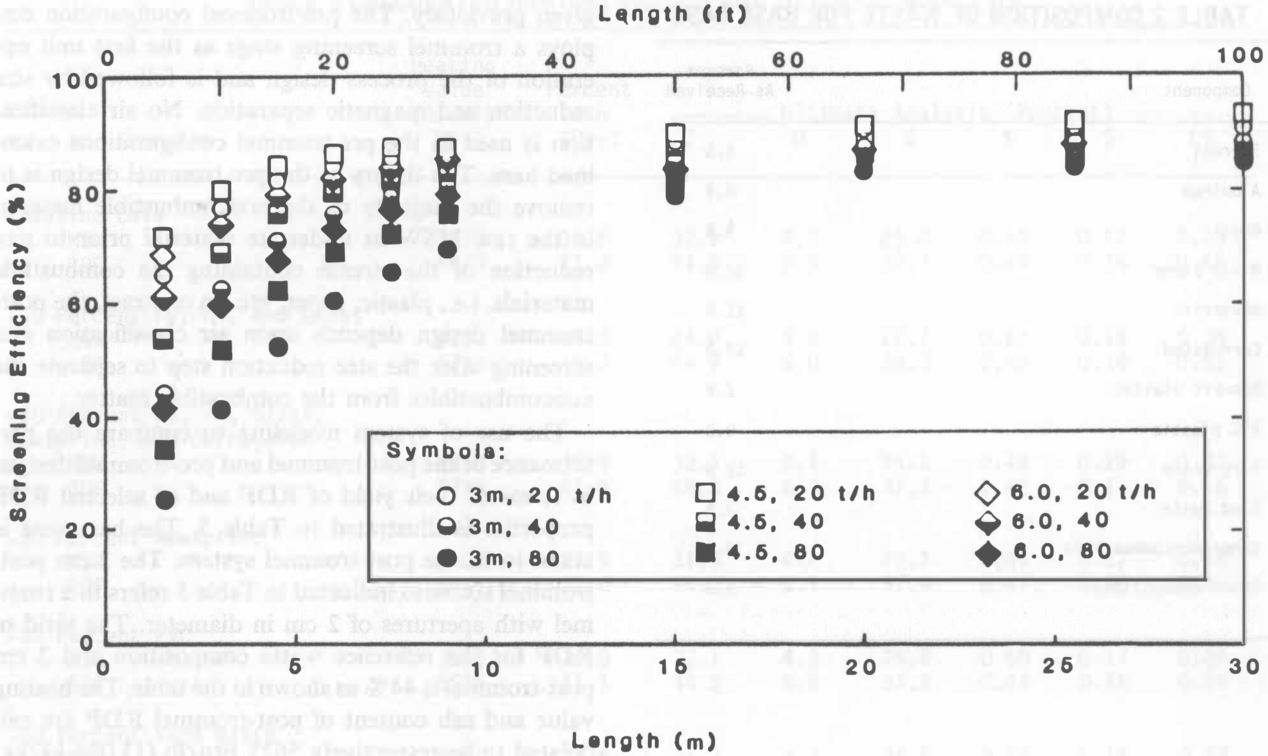

FIG. 8 CALCULATED TROMMEL SCREENING EFFICIENCY UNDER VARIOUS OPERATING CONDITIONS

the example are heating value, ash content, and ultimate analyses. The RDF processing configuration consists of size reduction of the raw waste to a nominal size (i.e., 90% cumulative passing) of approximately 5 cm, followed by air classification, trommel screening of the air classified light fraction, and removal of magnetic metal from the RDF stream. This processing configuration is termed the post-trommel scenario. Later it will be contrasted with several pre-trommel scenarios, i.e., the trommel placed before the size reduction step.

In the baseline case, the refuse is of the reference composition (i.e., that described in Table 2) and processed with the post-trommel configuration. The calculated properties of the raw MSW and the recovered RDF are shown in the first two rows of data of Table 3. The increase in the heating value and the decrease in the ash content as a consequence of processing are evident from the data. The effect of changes in the composition of the raw MSW feedstock are shown subsequently to the baseline case in Table 3 for several selected situations. In terms of the influence of the changes in composition investigated herein, the heating value and ash content of the RDF remain remarkably constant, a significant circumstance with respect to maintaining constant fuel properties over relatively substantial changes in waste composition. Other noteworthy observations evident from Table 3 are:

(a) In all cases, the calculated fuel nitrogen of RDF is lower than that for the parent MSW.

(b) In comparison with the baseline case, the calculated concentration of chlorine (Cl) in both raw MSW and RDF (a potential precursor of HCl formation from combustion of solid waste) is substantially less for the case where the concentration of polyvinyl chloride plastic (PVC) has been reduced by 50% (i.e., the −50% PVC case in Table 3).

(c) The concentration of sulfur (S) remains relatively unchanged in both the MSW and the recovered RDF (i.e., 0.16–0.19%) for all waste compositions considered here.

Many other comparisons and conclusions can be drawn from the data in Table 3. Further comparisons are left to the reader. Those described in the preceding paragraph are meant to illustrate the utility of system modeling with respect to refuse processing and some of the consequences of variations in the composition of the municipal solid waste stream.

TABLE 2 COMPOSITION OF WASTE FOR BASE CASE

Component	Percent As-Received
Ferrous	5.5
Aluminum	0.9
Glass	9.5
Mixed paper	22.6
Newsprint	11.8
Corrugated	12.2
Non-PVC plastic	2.9
PVC plastic	0.3
Yard waste	12.5
Food waste	2.5
Other noncombustible	9.5
Other combustible	9.8

The analyses presented above can be extended to the study of the fate of heavy metals in the MSW stream and the resultant RDF as a consequence of variations in the composition of the waste stream, e.g., that brought about as a consequence of recycling programs. A baseline case is constructed similar to that presented in Table 3. Subsequently the composition of the waste stream is varied, and the resultant heavy metal content of the MSW and recovered RDF is calculated. The results for various waste compositions and for heavy metals of environmental interest are shown in Table 4.

The baseline case in Table 4 illustrates the general effect of processing on the heavy metal content of RDF. A majority of the ferrous metals are removed by processing. Thus, the concentration of lead (Pb) and zinc (Zn) are seen to be less for RDF than for the parent MSW. Both metals are present in the "tin" cans prevalent in the waste stream. The influence of processing for each recycling scenario considered is shown below the baseline case. For the changes in the waste composition modeled here, the concentrations of the heavy metals in the MSW and RDF are quite similar to those of the baseline case.

System modeling can also be extended to the analysis of differing refuse processing trains. Two such processing trains of interest to the industry are the post-trommel and the pre-trommel configurations. A description of the post-trommel configuration has been given previously. The pre-trommel configuration employs a trommel screening stage as the first unit operation of the process design and is followed by size reduction and magnetic separation. No air classification is used in the pre-trommel configurations examined here. The theory of the pre-trommel design is to remove the majority of the noncombustible material in the raw MSW as undersize material prior to size reduction of the stream containing the combustible materials, i.e., plastic, paper, etc. In contrast, the post-trommel design depends upon air classification and screening after the size reduction step to separate the noncombustibles from the combustible matter.

The use of system modeling to compare the performance of the post-trommel and pre-trommel designs in terms of their yield of RDF and of selected RDF properties is illustrated in Table 5. The base case is taken to be the post-trommel system. The 2 cm post-trommel scenario indicated in Table 5 refers to a trommel with apertures of 2 cm in diameter. The yield of RDF for the reference waste composition and 2 cm post-trommel is 44% as shown in the table. The heating value and ash content of post-trommel RDF are calculated to be respectively 5625 Btu/lb (13,084 kJ/kg) on a wet weight basis and 11.8% on a dry weight basis.

Also shown in the table are calculated properties of the RDF that are important from the standpoint of slagging of the fuel on boiler sidewalls and of fouling of the convection surfaces, namely the Base/Acid Ratio, Slagging Index, and Fouling Index. For the aforementioned ratio and indices, the larger the value the greater is the tendency of the fuel to slag and foul the boiler. For the sake of simplicity suffice it to say that the fuel will likely be bothersome when fired if the values exceed the following:

Base/Acid Ratio	0.4
Slagging Index	2
Fouling Index	0.5

Lastly, shown in the righthand-most columns of Table 5 are the acid gas precursors most associated with RDF, i.e., sulfur (S) and chlorine (Cl).

Below the post-trommel scenario are shown the pre-trommel scenarios. Again, the size designations refer to the diameter of the apertures. Note that as the aperture size increases from 10 to 16 cm, the calculated yield of RDF (the screen oversize fraction) decreases from 58 to 30%, about a 50% decrease. Also, as the size of the aperture is increased, a disproportionate percentage of noncombustibles (which tend to be smaller in size than the combustible materials) is dropped out of the feed and consequently the ash content decreases.

TABLE 3 CALCULATED HEATING VALUES AND ULTIMATE ANALYSIS

Scenario	Heating Value (Btu/lb Wet)	Percent Ash (Dry)	Ultimate Analysis (Percent)					
			C	H	O	N	S	Cl
Baseline Case								
MSW	3970	36.6	32.1	4.3	25.8	0.58	0.17	0.33
RDF	5670	11.0	44.3	5.9	37.7	0.44	0.16	0.49
-30 Percent Fe, Al, and Glass								
MSW	4200	32.0	34.0	4.6	27.7	0.62	0.18	0.36
RDF	5740	9.7	44.9	6.0	38.3	0.45	0.16	0.51
-30 Percent Fe, Al, Glass, Newsprint, and Corrugated								
MSW	4070	35.0	33.3	4.4	26.1	0.70	0.19	0.37
RDF	5710	11.0	44.5	6.0	37.3	0.52	0.17	0.56
-30 Percent Newsprint								
MSW	3905	37.9	31.6	4.2	25.2	0.61	0.17	0.34
RDF	5635	11.6	44.0	5.9	37.4	0.47	0.16	0.52
-50 Percent PVC								
MSW	3950	36.8	32.1	4.3	25.8	0.59	0.17	0.24
RDF	5655	11.1	44.3	5.9	37.8	0.45	0.16	0.34
-50 Percent Yard Waste								
MSW	4055	37.6	31.7	4.2	25.5	0.50	0.16	0.33
RDF	5720	11.0	44.2	5.9	37.8	0.41	0.16	0.49
-50 Percent Food Waste								
MSW	3990	36.7	32.2	4.3	25.8	0.57	0.17	0.32
RDF	5680	11.0	44.3	5.9	37.8	0.44	0.16	0.48

The pre-trommeling configuration is shown to achieve the low ash content and high heating value of the post-trommel system design at sufficiently large screen openings. However, the yield of RDF is correspondingly lower. In order to maintain the low ash content and high heating value of the RDF and a yield similar to that indicated for the post-trommel design, processing of the pre-trommel undersize is necessary. Most likely the processing would include any or all of the following operations in order to recover the plastic and paper materials lost in the pre-trommel undersize:

- *(a)* air classification
- *(b)* screening
- *(c)* magnetic separation

The resulting concentrations of some of the heavy metal constituents of RDF produced from the post-trommel and pre-trommel options are compared in Table 6. The results shown in the table indicate that the calculated concentrations of some metals vary by as much as a factor of two or three, e.g., for antimony (Sb) and barium (Ba). For other metals there is relatively little change in concentrations as a consequence of the processing configuration, e.g., arsenic (As) and cadmium (Cd).

CONCLUDING REMARKS

The unit operations described and discussed in this paper may be arranged in a number of sequences, all of which would be conducive to the recovery of energy and useful materials. Because the optimum configuration will be primarily a function of the characteristics and properties of the refuse feedstock and the specifications of the recovered products, it is essential that a firm understanding and knowledge be had of the processes and equipment involved. Fortunately, there is a reasonable database available for characterizing the performance of refuse processing equipment and for modeling system operation. Although system modeling has not been applied extensively to refuse proc-

TABLE 4 CALCULATED HEAVY METAL CONTENT OF WASTE FRACTIONS FOR SELECTED RECYCLING SCENARIOS

Scenario	Heavy Metal Analysis (mg/kg) Sb	As	Ba	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Baseline Case										
MSW	53	4.9	2160	14.4	210	720	630	18	220	290
RDF	68	5.4	2620	14.0	200	170	500	23	40	160
-30 Percent Fe, Al, and Glass										
MSW	55	5.1	2220	15.0	200	570	600	18	160	270
RDF	65	5.2	2510	13.4	190	140	470	22	30	130
-30 Percent Fe, Al, Glass, Newsprint, and Corrugated										
MSW	62	4.8	2500	16.5	210	600	550	21	170	300
RDF	82	5.3	3200	16.2	210	160	440	28	30	160
-30 Percent Newsprint										
MSW	55	5.1	2250	15.0	210	750	590	18	230	300
RDF	74	5.9	2860	15.1	200	180	450	25	40	170
-50 Percent PVC										
MSW	52	4.8	2190	14.4	210	730	640	18	220	290
RDF	57	5.3	2680	14.0	200	170	500	23	40	160
-50 Percent Yard Waste										
MSW	55	5.1	2230	15.0	220	750	660	18	230	300
RDF	69	5.5	2670	14.1	210	170	500	23	40	160
-50 Percent Food Waste										
MSW	53	5.0	2170	14.2	210	700	630	18	220	270
RDF	68	5.4	2620	13.9	200	160	490	22	40	150

TABLE 5 CALCULATED PROPERTIES AND YIELD OF RDF PRODUCED FROM SELECTED PROCESSING OPTIONS

Scenario	RDF Yield (Percent Wet Basis)	RDF Properties Moisture Content (Percent)	Heating Value (Btu/lb Wet)	Ash Content (Percent Dry Basis)	Base/ Acid Ratio	Slagging Index	Fouling Index	S (Percent Wet Basis)	Cl
2 cm Post-trommel	44	21.3	5625	11.8	0.26	0.04	1.20	0.16	0.49
10 cm Pre-trommel	58	23.1	5099	20.2	0.29	0.06	1.60	0.21	0.38
13 cm Pre-trommel	42	22.8	5390	16.1	0.31	0.07	1.27	0.22	0.39
16 cm Pre-trommel	30	22.5	5701	11.3	0.38	0.09	1.69	0.24	0.39

TABLE 6 CALCULATED HEAVY METAL CONTENT OF RDF PRODUCED FROM SELECTED PROCESSING OPTIONS

Scenario	Sb	As	Ba	Cd	Cr	Cu	Pb	Hg	Ni	Zn
2 cm Post-trommel	69	5.5	2670	14.2	210	220	520	23	60	160
10 cm Pre-trommel	52	5.3	2050	15.3	190	230	590	17	40	240
13 cm Pre-trommel	40	5.1	1530	15.4	170	210	620	13	40	210
16 cm Pre-trommel	31	4.7	1140	14.0	150	180	610	10	30	180

essing design, its use will increase as system designers and vendors strive to develop efficient, and therefore economical systems. In addition, system modeling enables an evaluation of environmental impacts, an area wherein there are substantial differences between prepared fuel combustion technologies (i.e., RDF) and massburn systems, and an area which will draw more attention in the years to come.

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