Air Classification of Solid Wastes

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Performance of Experimental Units and Potential Applications for Solid Waste Reclamation

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Foreword

The objective of this laboratory-scale study by the Stanford Research Institute was to determine the technical feasibility of using air classification to process or treat selected types of nonhomogeneous, dry solid wastes. Design requirements for processing solid wastes with a full-scale commercial unit are estimated and the required supplemental equipment (shredders, screens, dryers) are identified. Limitations and advantages of the method are listed.

The air classification method was shown to be applicable to salvage of paper, recovery of nonferrous metal from shredded automobile body waste, and processing of compost.

This method was shown to be technically feasible for processing wastepaper. Furthermore, by analogy from calculations on a model compost-processing operation, it is thought that the method should also be economically feasible. Limitations for wastepaper processing are not inherent in the method itself but result rather from the size of the unit and the character of the shredded feed material.

Nonferrous trash from automobile body processing can be separated without special feed preparation other than screening of oversize materials. The method permits separation of materials with only slightly differing densities whose other properties, such as size, are identical.

Theoretically, in the processing of shredded automobile body materials, air classification can improve cleanliness and reduce nonferrous contamination of the steel scrap, reduce quantities (and cost) of wastes requiring landfill disposal, and increase the capacity of nonferrous-recovery processing facilities.

It was concluded from bench-scale experiments with the laboratory unit that air classification is technically feasible for processing semifibrous solid waste materials such as compost. Compost can be cleaned of glass and other contaminants that reduce its marketability. Yields of more than 50 percent combined bulk and horticultural-grade material can be produced. Recovery and reuse of glass could stimulate a greater use of nonreturnable glass bottles by the beverage industry.

As a unit operation, the advantages of air classification include the following: dry processing capability; sharp, clean separation capability; high-capacity throughout; low power requirement; low operating manpower requirement; dust-free operation.

We should like to acknowledge the work of the project officer, Dr. Boyd T. Riley, Jr., in coordinating this study.

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Air Classification of Solid Wastes

Since the enactment of the Solid Waste Disposal Act (PL 89-272) on October 20, 1965, the spotlight of publicity has been thrown on the Nation's solid waste management problem. Under the Act, research and development programs have been initiated to investigate, study, and develop new and improved methods of solid waste management.

Those already in the field know that populations whose living habits are undergoing the changes that accompany increased affluence are generating increased quantities of waste; that air pollution legislation that outlaws open burning has brought about rapid increases in the quantities of solid waste; and that massive programs of urban renewal, central-city freeway construction, and replacement of older buildings with modern structures have increased demolition wastes.

Also to be considered, along with the quantitative and qualitative changes in the material being collected, are the changes in collection and salvage methods being brought about by continually increasing labor costs. Combined collections have largely replaced segregated collections and have thereby reduced collection costs. On-site compaction of commercial wastes containing large quantities of paper and cardboard is a rapidly growing extension of this trend. In only a few specialized cases is it now economical to salvage rags, newspapers, and corrugated cardboard boxes by handpicking them from combined collections of municipal solid wastes.

There is a growing realization of the desirability of reducing the quantity of wastes requiring disposal by reclaiming a portion of the flow for reuse. There is also, however, the realization that only processes that are mechanized and that operate continuously can be seriously considered. Acceptable processes require a minimum input of labor per ton of refuse to separate material into those portions that are reusable and those that must be discarded. Air classification appears to be one such process, judged from work done before this study with Scientific Separators* air classification unit in handling agricultural materials and simulated domestic and demolition wastes.

OBJECTIVE AND SCOPE

The objective of the first phase of research reported herein was to make a preliminary determination of the technical feasibility of using air classification to process selected types of nonhomogeneous, dry solid wastes. A small laboratory-size Scientific Separators air classifier was available. The feed mechanism and throat size of the classifier accepted wastes shredded to a particle size of 1 to 1-1/2 in. A blower provided air velocities adequate for separation from refuse of materials with the densities of wood, glass, or steel. A number of solid wastes were prepared and processed under different operating conditions. Methods of waste preparation and processing were sought that could be used by refuse contractors or industrial firms to recover a stream of salvaged material having commercial value.

First-phase results indicated the desirability of further experiments to investigate techniques for paper stock recovery from combined collections of municipal and commercial wastes. For this purpose a larger air classification unit was built and operated in the second phase of the program to do the following: (1) determine the degree of separation possible in a zigzag air classification column capable of processing paper-containing refuse material 4 to 6 in. in size and (2) evaluate the influence of various commercially available shredding methods on the degree of separation obtainable. The study was limited to technical aspects of air classification. It did not include comparative evaluations of other separation processes, process economics, market studies, or the economics of reclaimed products that might be salvaged by processing the waste streams.

This final report of the research investigation is intended to acquaint interested engineers with characteristics of the air classification device and to suggest potential applications for separating mixed solid wastes. It also contains speculations on the role that this equipment might have in the management of solid waste.

METHOD OF APPROACH

The wastes to be processed in the first-phase work were selected by the Institute's research team in accordance with criteria established by the office's project officer. Wastes selected for experimentation were expected to be successfully air classified. Moreover, selection was made after interviews with representatives of agencies who had extensive solid waste experience. During these interviews, opinions were solicited on the kinds of separations that would be desirable from the standpoint of commercial exploitation. An experimental program was then developed that established the objectives and outlined tentative classification procedures for each of the wastes

*Mention of commercial products does not imply endorsement by the U.S. Government.

selected. The experiments performed illustrated both the limitations and the advantages of the air classification separating process.

For the second phase, five samples of municipal solid waste were obtained and shredded in different types of commercial shredding equipment. Two of these shredded samples were preponderantly of the largest particle size (4- to 6-in. maximum dimension) that could be processed in the pilot unit, and three samples were generally of considerably smaller particle size. All the shredded material was air classified. Only limited experimentation was possible for paper recovery in these initial, larger scale classifier runs; classifications made were intended primarily to establish qualitatively the type of separations that could be effected on a commercial scale and to indicate characteristics of the shredded material that would be desirable in specifying the performance of shredders for reclamation, by air classification, of paper and other secondary raw materials in municipal solid waste.

In most cases, the only way to characterize the wastes and the separated products was to describe them visually. For the most part this proved adequate; it was supplemented where possible by determinations of bulk density for separated fractions and moisture content* and bulk density of the material as received. Photographs were taken of a number of the samples and of the separated streams. With vehicular scrap samples, i.e., the nonferrous metal and trash stream after magnetic separation of shredded automobile body material, visual evaluation of the effectiveness of the separation was not possible. Hence, separations were made over a range of throat velocities, and the separated materials were analyzed for density, oil and moisture content, percentages of combustible organic and magnetic material, and composition as indicated by spectrographic assay. For certain of the recovered paper samples, analyses made by the St. Regis Paper Company's Technical Center are reported.

The performance of Scientific Separators laboratory- and pilot-scale air classification units were evaluated by SRI in terms of the technical feasibility of making the various separations, together with their advantages and limitations. With appropriate scale-up factors, the laboratory results are reported in terms of full-scale process power requirements, limitation on density, optimum size reduction, and problems that can be anticipated with various types of granular and fibrous materials. To illustrate the possible role of air classification in processing solid wastes, results obtained are presented in the form of preliminary process flow sheets showing the shredding, drying, screening, air classification, and other unit operations required for reclamation processing of solid waste materials.

INFORMATION SOURCES

In addition to Boyd T. Riley, Jr., Chief, Waste Handling and Processing Branch, Solid Waste Management Office, U. S. Environmental Protection Agency, who was designated project officer for this research, 21 government agencies and other organizations were contacted.† These were the regional representatives: Region IX, Solid Waste Management Office; Los Angeles County Sanitation Districts; Los Angeles Bureau of Sanitation; the municipal refuse retorting project, being conducted for the Solid Waste Management Office by the San Diego Utilities Department and San Diego State University; the California solid waste management project, being conducted for the Solid Waste Management Office by the Bureau of Vector Control, California State Department of Public Health, Berkeley, California; the California integrated systems study in solid waste management, being conducted for the Solid Waste Management Office by the California Department of Public Health, Fresno, California; Sanitary Engineering Research Center, University of California, Richmond Field Station, Richmond, California; Utilities Division, Department of Public Works, Sacramento County, Sacramento, California; Governmental Refuse Collection and Disposal Association, Pasadena, California; Office of the Los Angeles County Engineer, Los Angeles, California; Departments of engineering, University of California, Los Angeles, and the University of Southern California; Chemical Engineering Systems Research, Division of Wood Fiber Products, Forest Products Laboratory, USDA, Madison, Wisconsin; Aerojet-General Corporation and Ralph Stone Engineers (engaged in contract research and proprietary developments related to solid wastes); National Metals Company; Clean Steel, Inc.; Pan American Resources; Universal By-Products, Inc.; St. Regis Paper Company, Technical Center; United Paper Stock Co.; U.S. Gypsum Company; Metropolitan Waste Conversion Corp.; Lone Star Organics, Inc.

ACKNOWLEDGMENTS

The Institute team wishes to express its appreciation to the Clean Steel Division of National Metals, Lone Star Organics, Universal By-Products Company, Eidel International Corporation, Alpha Beta -Acme Markets, and the PHS TVA Johnson City, Tennessee, composting project for cooperation in providing and for shredding solid waste samples. These samples were in addition to the samples of municipal waste provided by the Cincinnati labora-

*Moisture contents in this report are based on the dry weight of the sample.

†Individuals interviewed are listed in Appendix A.

tory of the BSWM.* The fact that all samples submitted had already received primary shredding simplified laboratory operations considerably.

Useful industry information and an understanding of wastepaper salvage operations were provided by Richard T. Stevens, president of Universal By-Products, and by Mr. Stevens' father, Robert W. Stevens, an independent paper mill consultant. Information on the utilization of secondary fibers in paper manufacture was provided by Harry Armstrong, works manager, and A. Chaves of U.S. Gypsum Company, by A.C. Veverka of St. Regis Paper Company, and by Charles Pabigan of United Paper Stock Company. The Institute team is also grateful to Donald A. Hoffman, research coordinator of the San Diego Utilities Department, and his staff for pyrolysis runs on samples of automobile body material.

*BSWM (Bureau of Solid Waste Management) is the former designation of the Federal solid waste management program

Summary and Conclusion

Preliminary research on air classification, as investigated with laboratory- and pilot-scale zigzag air classification units, has indicated the feasibility of using this method of separation to process a number of types of solid waste mixtures. Satisfactory separations require the following:

Suitable feed preparation. An air classification unit alone does not usually constitute a complete solid-waste-processing system. Operations such as shredding, drying, and screening must often be combined with the air classifier to achieve optimum separation.

Particles with maximum dimensions no greater than three-quarters the least dimension of the column throat.

Particles that flow in a granular fashion when fluidized by air. For fibrous materials, this precludes a shredding method that achieves particle size reduction but produces detrimental aerodynamic characteristics and an undesirable agglomeration of the components of the refuse.

The need for feed preparation was revealed by work with all three general types of waste processed experimentally. These wastes were municipal refuse; aged stockpile compost; and nonferrous trash from automobile body processing.

With municipal refuse, shredding was essential before air classification. Shredding is not practiced at the present time, except to a limited extent in recovery of usable corrugated and high-grade mixed papers from commercial and industrial collections. Shredding is, however, practiced for municipal wastes being composted and for developmental transfer/baling, retorting, incineration, and landfill operations. Thus, it would not represent an additional processing step in these methods of refuse handling.

Compost that has been aged in outdoor stockpiles requires additional light shredding to break up lumps before it can be air classified to remove impurities, even though it has already been shredded in normal processing. Needed feed preparation for air classification of compost also includes drying and screening, because of the presence of large amounts of fine materials that behave aerodynamically the same as low-bulk-density cellulosic components. Similar reprocessing also may be needed for municipal refuse.

Nonferrous trash from automobile body processing could be separated effectively without special feed preparation in an air classifier designed to handle quantities available from typical automobile body-fragmentizing operations. In certain applications, it probably would be desirable to remove oversize material by screening to reduce the required size and power requirements of the air classification device. In the experiments performed as part of this research, screening of the automobile body trash was necessary because of the small throat size of the laboratory column.

Limitations observed in the operation of the laboratory zigzag classification unit on municipal refuse are those related to the size of the unit and the characteristics of the materials fed—resulting from the shredding methods used to produce an acceptably small particle size—rather than from limitations of air classification itself as a method of separation. First, these limitations could be one, as was demonstrated by successful operation of the pilot-scale air classification unit. Thus, separating usable wastepaper from municipal refuse appears to be technically feasible in an integrated system employing air classification. A schematic flow diagram of an air classification process is shown (Figure 1) and an alternate system is described on p. 48. The high capacities, low equipment cost, and low power requirements of such a system, as illustrated by calculations for a compost-processing operation, should make salvage of municipal refuse by air classification economically feasible as well. Large markets exist for secondary fiber of acceptable quality. Consequently, a significant contribution can be made to conservation of the nation's forest resources by increased recycle of air-classified wastepaper.

Separation of heavy materials from dry, shredded municipal and commercial refuse can be accomplished easily. It is possible to insert an air classfication column into a vertical run of pneumatic conveyor piping handling the output of a refuse shredder and to remove metal, glass, rocks, rubber, and wood from the shredded refuse. The cost is estimated to be less than 10¢ per ton more than shredding alone, including the cost of pneumatic conveying. Such a separation should be highly desirable in refuse composting, refuse retorting, and for certain experimental types of refuse incineration. It is being considered for commercial operation in the recovery of noncombustibles and the salvage of paper from municipal refuse.

Conceptually, air classification can provide a number of benefits in the processing of shredded automobile body material. Included are the following: (1) improved cleanliness and reduced nonferrous contamination of the steel scrap, (2) reduced quan-

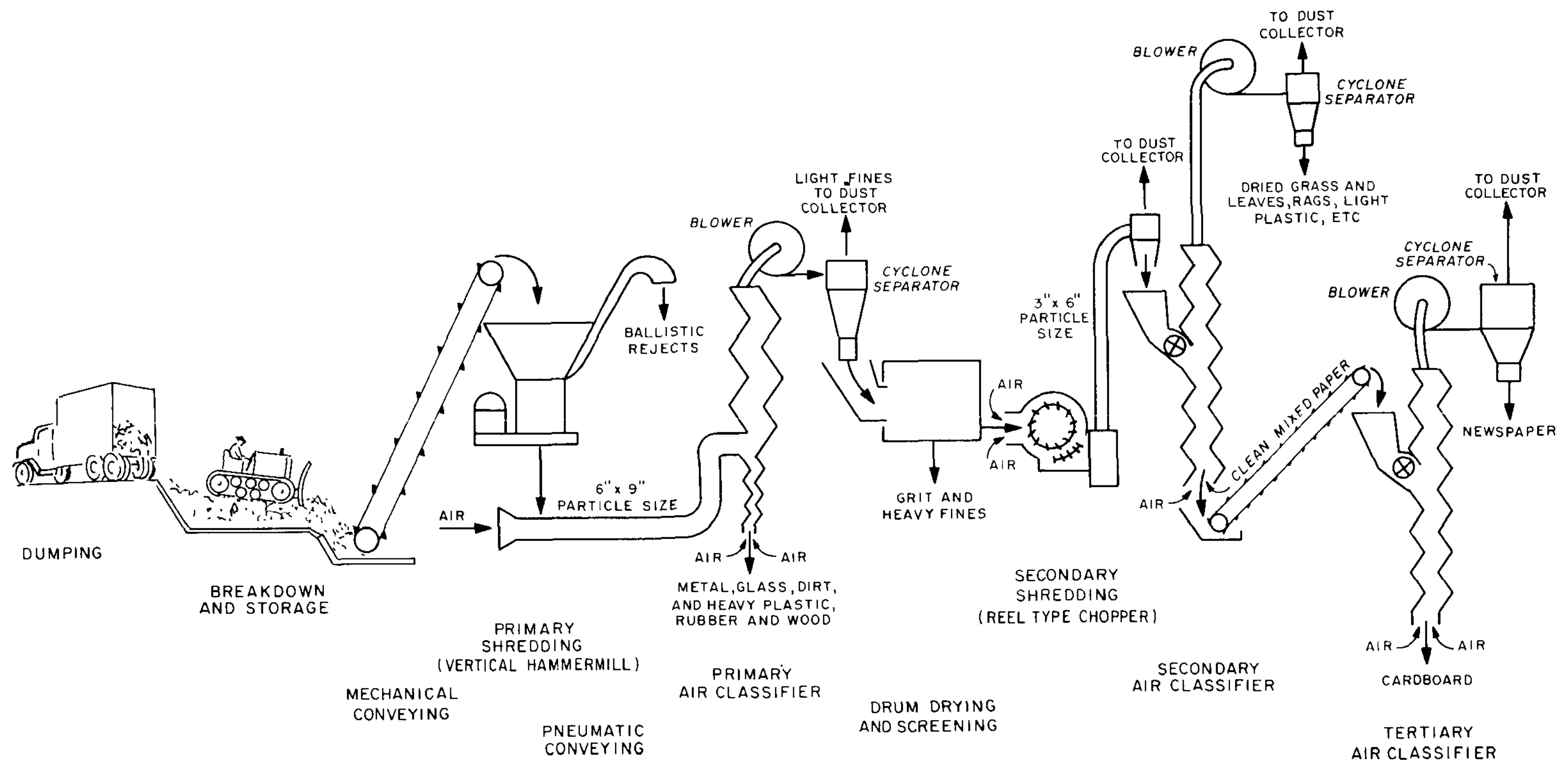

Figure 1. Schematic flow diagram of air classification process for wastepaper recovery from municipal refuse. (Secondary and tertiary air classification columns are sufficiently similar that a single column might be used in a time-phased operation by storing the clean mixed paper product and running in the secondary column when no refuse is being received.)

tities (and cost) of waste requiring landfill disposal, and (3) increased capacity of nonferrous recovery processing facilities.*

Compost can be cleaned of glass and other contaminants that reduce its marketability. Yields of more than 50 percent combined bulk and horticultural-grade material can be produced by an air classification process developed by laboratory column operation. In a 30-ton-per-hour plant, the cost is estimated to be 30¢ per ton of material processed (24-hr operation), including amortization.

Other findings of importance include the following:

The laboratory- and pilot-scale air classifiers are useful tools for empirical design.

For a particular type of refuse and a particular reclamation objective, final system design requires that separations be optimized by a more extensive series of experiments than was performed herein.

Empirical determination of design criteria for full-scale air classification systems and the development of economic recovery processes, especially for municipal refuse, require a pilot-plant research facility that might best be combined with a demonstration facility in which municipal solid waste is being shredded routinely for purposes other than salvage.

The characteristics of material shredded by commercially available shredders are compatible with sorting by air classification. For predicting the characteristics of individual components of municipal solid waste after shredding—as related to rotating speed, feed rate, and other variables of shredder operation—a cooperative test program with shredder manufacturers would be desirable.

Commercial interest might be stimulated by the construction of a demonstration plant for salvage of paper or other secondary raw materials from refuse.

Nonferrous metal recovery from automobile body trash should be particularly attractive commercially.

Recovery and reuse of glass could stimulate a greater use of nonreturnable glass bottles by the beverage industry.

As a unit operation, the advantages of air classification include the following: dry processing capability; sharp, clean separation capability; high-capacity throughput; low power requirement; low operating manpower requirement; dust-free operation.

Air classification is subject to certain limitations, the most significant of which are the following:

Feeder and column throat size impose particle-size limitations for low-capacity systems.

Multiple-column or repetitive operation is required for more than two-component separations.

Oversize, semifibrous materials require shredding before classification.

*These processing possibilities are illustrated in the body of this report by process flow block diagrams.

Laboratory-scale Unit Experiments

Selection of Solid Wastes for Experimental Program

Criteria for Selection. In the selection of solid wastes for the experimental program, the Institute team was aided by a number of State and local governmental agencies, by representatives of firms engaged in solid waste collection and disposal, and by solid waste program contractors and grantees engaged in research and demonstration activities. A series of personal interviews was employed, supplemented by telephone contact as needed. During the interviews, experimental equipment to be used in the separation process was described and the objectives of the program were outlined. Each person interviewed was requested to suggest a number of types of solid wastes that might be classified experimentally and to indicate the separations that would be of greatest potential value. In all cases, the criteria for selection of materials were the following:

Wastes that by their nature or quantity are creating a problem at present or may be expected to become a problem

Wastes that could be separated by air classification into more easily disposable or reclaimable fractions

Combined wastes whose composition varies at different times but from which a uniform fraction might be separated

Wastes possessing reclamation potential–currently not realizable because of high processing costs of existing methods and equipment–that might be feasibly realized by air classification

Outside Agencies' Consensus. Names of individuals with whom discussions were held are given in the chronological interview record included in Appendix A. In conducting these discussions, an attempt was made to obtain suggestions on various types of wastes to be processed. Because of the large volume of wastes from municipal domestic and municipal commercial sources, the majority of interviews centered on these types of refuse. Industrial wastes were also considered important because of the opportunities for by-product recovery or other forms of reclamation. Wastes from the processing of agricultural materials and municipal demolition wastes were also discussed, as well as a number of specialized opportunities, such as cleaning of aged compost from plants processing municipal refuse, nonferrous metal recovery from the trash stream after magnetic separation of crushed automobile bodies, cleanup of the char product from refuse - retorting operations, and reclamation of usable pigment from paint sludge. In each case, an opinion was requested about the recovered component that would have greatest value and the use or uses that could be foreseen if recovery could be effected. Information was also sought on the type of contaminants that might be permitted in the reclaimed product as an indication of the selectivity of classification that would be required.

Interview responses suggested 10 types of solid waste from 15 sources for air classification (Table 1). Items 1, 2, and 3, important as types of wastes from which usable grades of reclaimed paper might be obtained, are listed in order of probable ease of classification. Relatively clean collections of waste paper from office buildings and large commercial establishments, mainly department stores, are not included, because such collections are now marketed as mixed paper.

The preferred grade of mixed paper for secondary fiber repulping is a material that is shredded before it is baled. To protect shredding equipment, the salvage operator removes heavier metal from collected material before shredding and thereby reduces the amount of unpulpable trash requiring removal from a user's pulping equipment and possible damage to this equipment.

Where collection routes can be so arranged that only *municipal domestic refuse from apartments* predominates, it was the consensus of respondents that a fairly good grade of wastepaper might be reclaimed, because the refuse would normally not contain garbage or garden trimmings. Virtually all the newer apartments are equipped with garbage grinders, and landscaping is done by gardeners who are required to dispose of their own clippings. Municipal domestic refuse in which collections from single-family residences predominate might contain a salvable wastepaper component, but it was expected that this would be of a lower quality than that from either shopping centers or apartments because of a greater number of contaminants. Refuse that was segregated before collection was, of course, not considered for air classification.

A substantial amount of corrugated carton material is collected from markets. It has been the practice of paper dealers to collect this material without charge when it is segregated. Recent developments in the use of on-site compaction equipment have reduced the cost of collecting this material, and this saving permits the collector to pay a small amount for it and to supply his customer with the compaction equipment.

TABLE 1

SOLID WASTES SUGGESTED IN INTERVIEW RESPONSES FOR AIR CLASSIFICATION

Item number	Type of solid waste	Source	Air classification product	Possible reuse
1	Municipal, commercial	Small commercial establishments not segregating for paper salvage	Wastepaper	Paper or board manufacture
2	Municipal, domestic	Apartments only	Wastepaper	Paper or board manufacture
3	Municipal, domestic	Single-family residences only	Wastepaper	Paper or board manufacture
4	Municipal, domestic	Combined collection, unsegregated routes	Beneficiated retort feed stock, by exclusion of glass and metals	Retort feed
			Beneficiated feed stock for composting process, by exclusion of material either not converted or converted slowly	Composting: alone, with sewage sludge, or with animal manures Paper salvage
			Beneficiated feed stock for fermentation, principally cellulosic material	Fermentation for synthetic proteins, alcohol, or other carbohydrate derivatives
5	Municipal demolition waste	Wood frame houses	Broken concrete	Aggregate for new concrete
			Wood waste	Charcoal, paper pulp, or particle board
6	Aged compost	Composting plants	Grades of compost; salvage material–glass, metal, etc.; uncomposted waste	Higher value material bagged for horticultural use; coarse material for planting freeway slopes (mulch)
7	Retort char	Retorting of domestic waste	Clean char, without glass or metal contamination	Water or sewage treatment; low-ash fuel; carbon black for rubber compounding: activated carbon
		Retorting of industrial wastes (Pan-American Resources)	Clean char, without glass or metal contaminants	
8	Industrial wood waste	Debris from small cabinet shops	Wood waste separated into hardwood and softwood fractions	Charcoal, paper, pulp, or particle board
9	Automobile body reclamation	Nonferrous metal and trash stream after magnetic separation	Metallics only	Feed to various systems of nonferrous separation
			Glass or rubber	Secondary raw material

(Continued next page)

TABLE 1 (Concluded)

SOLID WASTES SUGGESTED IN INTERVIEW RESPONSES FOR AIR CLASSIFICATION

Item number	Type of solid waste	Source	Air classification product	Possible reuse
			Separation of metallics (cheaper than flotation or sweating)	Secondary raw material
10	Airplane fuselage reclamation	Shredder output	Metals other than aluminum	Reclaimed metal
11	Miscellaneous industrial wastes	Ford assembly plant at Milpitas	Miscellaneous salvage	Reclaimed metal, paint pigment, charcoal
12	Agricultural processing	Nutshells	Broken nutmeats; clean shells	Activated charcoal
13	Agricultural processing	Raisin processing; trash	Good raisins in trash stream	Raisins
14	Agricultural processing	Cotton ginning trash	Cotton lint	Reclaimed cotton lint
15	Agricultural processing	Oilseed processing trash	Oilseed meat	Oil and meal

There are at least five possible uses for products separated from municipal domestic refuse (Table 1). Since paper now accounts for more than 50 percent of domestic collections on a dry-weight basis, paper salvage for reuse of its cellulose content would be preferable to any method of utilization that would require degradation of the cellulose. Reuse in paper or board manufacture would accomplish this resource conservation objective. If refuse is converted to charcoal, with or without recovery of gaseous products and pyroligneous acids, it is desirable to remove glass and metals from the retort feed. This reduces process heat requirements and the ash content of the char. For composting and fermentation, all nonbiodegradable materials must be removed, the most difficult of which are plastic wrapping materials and styrofoam packing.

Composting of domestic refuse collections, as it has been practiced to date, usually includes handpicking to preclean the digester feed prior to shredding, primarily to protect the shredding equipment but also to recover wastepaper. Besides being economically marginal as a salvage operation, handpicking leaves a great amount of glass and other materials in the feed to the composting digester; these elements reduce the quality and salability of the compost product. It would be highly desirable to remove all materials that could be salvaged or could not be composted from the digester feed as easily as tin cans are now removed by magnetic separation. It would also be desirable to clean existing stockpiles of compost to improve salability of the product. The removal of glass, metal, and material that either is uncomposted or cannot be composted appears possible by air classification.

Among the industrial possibilities, greatest promise appears to exist in the recovery of nonferrous metals from automobile body-shredding operations. Processing of agricultural materials—while desirable because of the magnitude of solid waste problems involved—appears to offer specialized economic opportunities.

Materials Selected and Test Program. The 15 different solid wastes listed (Table 1) were suggested by interview respondents as meeting the established selection criteria. Although it was originally intended to air classify only five samples of waste, it was considered feasible—owing to the probable similarity of a number of the samples of municipal domestic waste that were suggested and the similarity of products to be recovered—to process six separate samples. The six samples selected as having the greatest probability for successful air classification were the following:

Sample 1. Single-family domestic waste, Los Angeles, California. This sample was to be representative of single-family residences in the higher-than-average income area of San Fernando Valley, as collected in the dry weather of late fall.

Sample 2. Single-family domestic waste, Houston, Texas. This sample was to represent the material delivered by municipal collection trucks to the composing plant of Lone Star Organics.

Sample 3. Domestic waste from multi-family dwellings, Los Angeles, California. This sample was to be taken in essentially the same area and at the same time as sample 1 and was to be from a collection route where apartments predominate.

Sample 4. Commercial waste, Los Angeles, California. This sample was to be taken from selected San Fernando Valley collection routes along with shopping centers and small commercial establishments predominate.

Sample 5. Industrial waste sample from automobile body reclamation plant in the Los Angeles harbor area. This sample was to be representative of the trash stream containing nonferrous metal and other materials remaining after magnetic separation of shredded steel scrap from an automobile body-crushing operation.

Sample 6. Aged Compost. This sample was to be representative of material from outdoor stockpiles that has been aged 6 months or more. The source of this material was the domestic-refuse-composting plant of Lone Star Organics, Houston, Texas. The aged compost contained glass, metal, and other impurities that made it unsuitable for horticultural use without further cleaning.

For samples 1 and 2, single-family domestic wastes, the test program consisted of separation runs on each of the samples to determine the feasibility of the following operations:

Salvage of wastepaper for use in paper or board manufacture

Removal of noncompost material

Removal of metal, glass, and plastic for salvage

Removal of materials to improve the wastes for destructive distillation (retorting)

Removal of materials to improve the wastes for fermentation of cellulosic constituents

The test program for samples 3 and 4 was limited to the recovery of a grade of wastepaper stock known as No. 1 mixed paper. The objective of classification was to produce a higher quality of mixed paper—from the standpoint of cleanliness and contamination by metal, glass, and other noncellulosic products—than the scrap paper that is normally supplied by salvage contractors to secondary fiber processors. Both samples were expected to yield a salvage wastepaper of higher quality than would be obtainable from processing of single-family residential refuse.

The components of sample 5, the nonferrous trash stream from automobile body reclamation, were not readily identifiable by visual means. The test program included, therefore, analysis of the composition of various fractions of this waste material after initial screening into four size ranges. The larger size fractions could not be air classified. Air classifications were made of a minus 3/8-in. and a 3/8- to 1-in. screen fractions. Each fraction was separated by air classification into seven subfractions, with corresponding superficial air column velocities from 500 to 3,000 ft/min. The subfractions could not be described adequately by appearance; therefore, a series of physical and chemical tests was made for more complete characterization. These tests were to determine density, oil and moisture content, percentages of combustible organic and magnetic material, and chemical composition as indicated by spectrographic assays.

The test program for the compost material of sample 6 required shredding and screening followed by air classification of relatively close-graded middlings and coarser material. This procedure provided the following: (1) a lightweight fraction consisting mainly of plastic (nonbiodegradable); (2) a heavy, oversize fraction requiring regrinding for return to the compost digester; (3) a clean, granular material suitable for sale; and (4) two waste streams for landfill disposal.

More nearly complete test program descriptions, together with diagrams and photographs, are given in conjunction with later discussions of laboratory air classifier performance. In the detailed test program employed for air classification of each of the selected types of waste, data were sought on the following:

- Characteristics of the material fed
  - Density (overall and by size fractions)
  - Moisture content
  - Particle size gradations
  - Visual identification of separated fractions
  - Analytical identification of separated fractions
- Processing required for air classification
  - Drying
  - Shredding
  - Screening (removal of oversize material or separation into fractions for air classification)
- Operating parameters for air classification
  - Throat velocity
  - Feed rate

Sources of Sample Material. Samples 1, 3, and 4 (San Fernando Valley solid waste material) were provided through the cooperation of Universal By-Products, Sun Valley, California. Mr. Richard P. Stevens, president, is a member of the California State Department of Public Health's 1968 Solid Waste Advisory Committee. His firm represents an integrated operation comprising collection, disposal, by-products salvage and processing, and equipment sales. This firm is extremely interested in improved methods for mechanical salvage of wastepaper from refuse streams and the salvage of nonferrous materials from automobile body reclamation operations. Since their mixed paper is now shredded prior to baling, it was relatively simple for them to provide the Institute with shredded samples. These were in the 3- to 6-in. size range that could be reduced further by the Institute's laboratory shredding equipment. With this firm it was possible to make a careful selection of sample material. To obtain samples that were representative of a typical collection route at a given season of the year, an Institute technician accompanied the collection truck. He selected a 4-cu-yd sample (for primary shredding) from the contents of the truck at the time of discharge at the landfill. From the shredded material, a 100-gal sample was selected for subsequent laboratory processing.

Samples 2 and 6 were provided in three 50-gal steel drums by Lone Star Organics, Houston, Texas. Sample 2 consisted of two drums, one that had undergone primary shredding to a 3- to 6- in. size in a Williams 475-GA mill and the other that had been shredded to a nominal 1-in. size by a Williams 80-GA mill. The material had undergone secondary shredding and required drying prior to laboratory storage. Compost sample 6 was taken directly from the outdoor stockpile of aged material and also required drying.

Approximately 150 lb of the nonferrous automobile body trash, sample 5, was selected by Institute representatives from the outdoor stockpile of Clean Steel, Inc. The sample was dry, and care was exercised to obtain a sample that was visually representative of the material in the stockpile, which contained several hundred cu yd of waste.

In addition to these six samples, four additional domestic and commercial refuse samples were supplied from the U.S. Public Health Service's solid waste program laboratory in Cincinnati, Ohio. For each type of refuse, one preground sample that had been passed through a Williams Model 30-S hammermill, without a screen, and one final-grind sample that had been shredded with a 1-in., round-hole screen were supplied. Each of these samples was 1 to 2 cu ft in size and weighed between 15 and 25 lb. The domestic waste samples were very wet and required air drying before they could be stored at the laboratory.

The Laboratory-Scale Air Classification Unit

Background. Classification is used preponderantly in the treatment of raw material. By definition, it is an operation in which a mass of granular particles of mixed sizes and different specific gravities is allowed or caused to settle through a fluid that may be either in motion or substantially at rest. Sizing or screening is defined as the separation of various sizes of particles into two or more portions by means of a screening surface acting as a multiple "go" and "no go" gauge such that the final portions consist of particles of more nearly uniform size than those in the original mixture. Although the definitions of classification and sizing describe operations that apply best to free-flowing granular materials, these operations can obviously be applied to any particulate material. Properly applied, therefore, both operations (screening and classification) should have value for separating various types of solid wastes.

Air classification, air sizing, and dust collection all deal with different facets of the relative motions between components of mixtures of solids and gases (in this case, air). The theory and principles that apply are covered in a number of references[1-4] and will be presented here only in generalities sufficient for an understanding of the operation of the laboratory unit. In the range of particle sizes and densities that we are concerned with in the air classification of solid wastes, the considerations of settling velocity, buoyancy, and interparticle collisions are not important. The primary theoretical consideration in air classification is that of terminal velocity—the constant velocity reached by a particle falling from rest in a body of gas at rest when the gravitational pull is equal to the resistance offered by the gas.

Expressions have been developed for terminal velocity under turbulent, streamline, and transitional conditions. These expressions generally apply to spherically shaped particles and involve the particle's diameter, its specific gravity, and the density and viscosity of the gas. Constants in these equations must be determined experimentally and can, therefore, be determined for irregular fragments as well as spherical particles. In all cases, the terminal velocity increases with increasing particle density and particle size. Particle shape exerts a great deal of influence on this velocity, particularly for lightweight fibrous materials. When the flow is confined, electrostatic forces on smaller sizes of these materials can become as important as gravitational forces. The air velocity required to float a particle when the current as a whole is vertically upward is usually different from the velocity with which the particle settles in still air, and both are different from the velocity necessary to transport the particle, as for pneumatic conveying, when a major component of the current direction is horizontal. Although related to terminal velocities and floating velocities, fluidizing velocities for the zigzag air classifier, as reported herein, are not directly comparable, because of the acceleration effects caused by impact of the particle with the column's walls and because of the special conditions of turbulence produced by the tortuous airflow.

Zigzag air classification has been pioneered by the Institute for processing dry mixtures containing material that can be fluidized and transported in an airstream. Particles of these mixtures are fractionated according to density, size, and aerodynamic properties. Thus, zigzag air classification is somewhat analogous to distillation of hydrocarbon liquids in a petroleum refinery's fractionating column. The zigzag principle permits separation of materials with only slightly differing densities whose other properties, such as size, are identical and has proved in almost all cases examined to be more efficient than any other air classification system.

Frequently, the air classifier is used with chopping, grinding, and screening processes to obtain particles of nearly uniform characteristics for improved process efficiency. Capacity, both in terms of throughput rate and maximum particle size, can be increased by increasing the dimensions of the column's throat. The range of density can be increased by increasing the maximum throat velocity. Thus, the air classifier is a flexible separating tool.

As a tool for the empirical design of full-scale separating systems, the Scientific Separators laboratory-size air classifier as evaluated by SRI has been used for separating products such as the following:

Roasted coffee beans (coffee has been graded to separate dense, high-quality coffee from improperly roasted or cull beans).

Seed and grain cleaning (successful work in this area has led to the design of commercial equipment that is now being marketed).

Dehydrated alfalfa (dried leaf has been removed for pelletizing before the stems are sold for cattle feed).

Oil seed meal (the protein level of rendered meal can be increased by selective removal of the oil seed hulls).

Fish protein concentrate (experiments have indicated that a combined process, including air classification, may be the most efficient as well as the least expensive method for controlling fluoride concentrations by the selective removal of bone).

Data on typical performance of the laboratory unit on materials processed in previous experimental work at the Institute indicates that increasing throat velocities and increasing horsepower are required with increases in the bulk density of material classified (Table 2).

TABLE 2

TYPICAL FLUIDIZING VELOCITIES AND HORSEPOWER REQUIREMENTS FOR AIR CLASSIFICATION ON MATERIALS PROCESSED IN PREVIOUS EXPERIMENTAL WORK AT SRI

Material	Bulk density (lb/cu ft)	Superficial velocity (ft/min)	Estimated range of horsepower requirements per ton/hour capacity
Dehydrated alfalfa	5*	800-900	0.45-0.67
Garlic†	20-30	1,450-1,700	0.75-1.1
Almonds‡	40	1,750-2,000	0.80-1.3
Raisins	40-45	2,150*	1.0-1.5
Peanuts	45-50	2,550*	1.1-1.8
Pinto beans	45-50	2,600*	1.1-1.8

*Approximate.
†Root crowns being separated from cloves.
‡Splits and hulls being separated from whole meats.

Physical and Operating Characteristics of Laboratory-Scale Air Classification Unit. The Scientific Separators zigzag air classification unit available at the Southern California Laboratories of Stanford Research Institute is a 12-stage, zigzag column (fed at the eighth stage from the bottom), through which air is drawn by a high-capacity induction blower. This blower draws air first through the column and then through a conventional cyclone separator that removes material passing upward through the column. Heavy material that cannot be transported in the airstream at any set velocity moves countercurrently to the stream and is discharged from the bottom of the column. The separation achieved by the process can be observed through the transparent side walls of the column. The general arrangement of the unit and a flow diagram are shown (Figure 2).

The 1-hp induction blower can provide superficial velocities of as much as 3,000 ft per min for fluidizing material in the 2- by 6-in. throat of the classifier. The flow is controlled by means of a sliding gate valve, and pressure drop is measured by means of a manometer. Originally, this manometer operated across an orifice in the air outlet of the cyclone separator, but it was found that the direct measurement of the pressure drop across the classifier and the cyclone could be calibrated in terms of throat velocity.

The laboratory-scale unit is operated for batch processing only. Although the rotary airlock feeder permits continuous feeding, separated overhead material dropping out of the cyclone separator must be withdrawn intermittently. A feeder attachment is available for insertion between the rotary feed valve and the column that allows fibrous agglomerates to be broken up and propelled into the column mechanically. A feed hopper with a screw-type conveyor is also available. A tight cover on this hopper prevents leakage of air into the column at the feed point, this leakage being undesirable because it disturbs the uniformity of the column's flow pattern.

When the column is operated to separate a mixture of two uniform granular materials of different aerodynamic characteristics, it is a simple matter to adjust

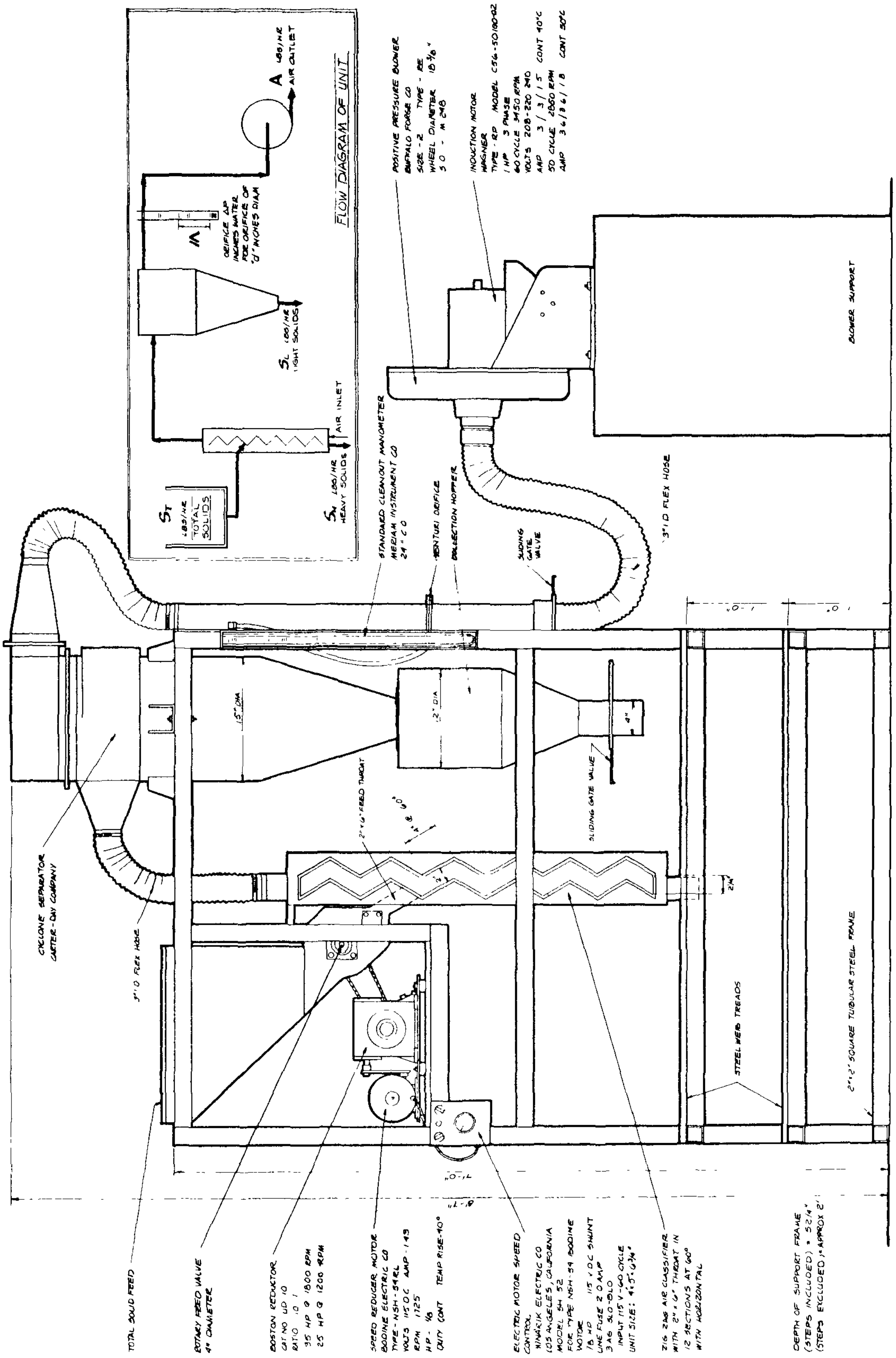

Figure 2. Scientific Separators zigzag air classifier evaluated by SRI.

the airflow—as the mixture is fed at a uniform rate into the column—so that conditions of feed rate and airflow are achieved that permit free flow of solid material both up and down the column. Under these conditions, both the heavy and light materials are separated and reentrained at each step in the column.

A relatively high-speed airstream exists in the center of the column and along the column's faces exposed to the upward flow. Active vortices are created in the pockets of the column and on the faces along which the heavier material is falling. The falling material and the upward flowing air that is transporting the lighter material provide a combined centrifugal and entrainment action (Figure 3). Flow patterns were further confirmed by observing smoke patterns with airflow only. These were made at velocities of approximately 500, 750, and 1,100 ft/min. At the lower velocity, flow in the central core appeared to be laminar, with vortices at the edges that project into the stream. At the 750 ft/min throat velocity, the space occupied by the corner vortices becomes smaller and the central stream becomes wider. At velocities higher than 1,000 ft/min, corner vortices could not be observed; the entire cross section appeared to be full of turbulent smoke.

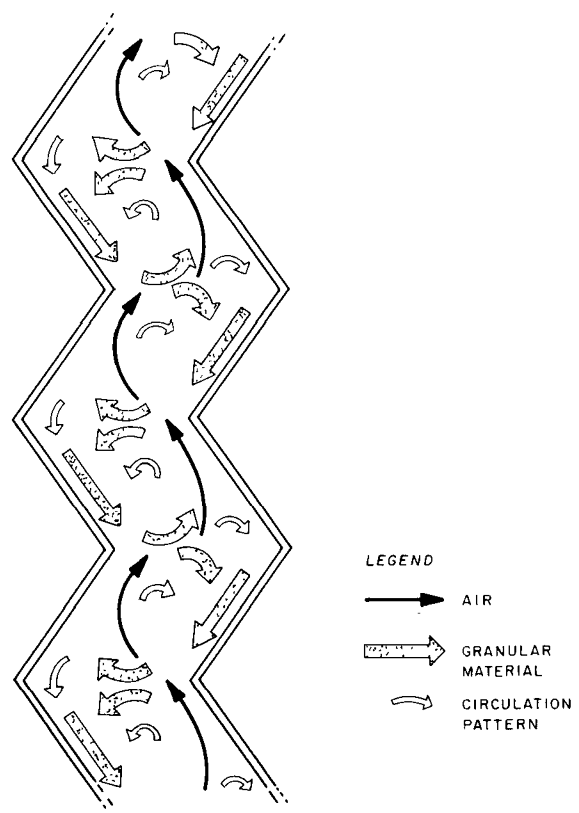

Figure 3. Flow pattern of granular material in the Scientific Separators zigzag air classifier evaluated by SRI.

Before the experimental work on solid wastes reported herein, a series of experiments were made on solid waste material that included combined domestic refuse, demolition waste, and a sample of the automotive shredding trash stream. These preliminary experiments indicated that air classification could prove to be a useful unit operation in the continuous processing of a number of types of solid wastes. High-capacity separation on materials of different densities appeared to make the unit particularly applicable to the removal of concrete, metal, and similar contaminants from demolition wastes so that the wood fraction could be used for the production of paper pulp, fiberboard, or charcoal briquettes. Air classification appeared to be equally useful as a pretreatment for combined domestic wastes that were to be fed to a retort for the production of char oil or briquetted fuel or were to be processed to recover coarse cellulose for fiberboard, roofing, or similar products. The primary difficulty encountered in these preliminary experiments was caused by the feeder mechanism of the classifier. The screw-type feeder used in the preliminary experiments was built primarily for granular materials, and it was believed that the difficulty could be easily remedied by minor redesign.

Modification of Laboratory-Scale Unit to Facilitate Testing of Selected Wastes. For granular materials such as beans and seeds, the hopper with a screw conveyor in the bottom proved to be an excellent device for introducing the material to be classified at a uniform rate. Varying the speed of the screw proved to be an effective way of controlling the feed rate to the classifier. Initial experiments with solid wastes demonstrated, however, that the screw conveyor would be inappropriate for heterogeneous material because of the ease with which the feeder could become jammed. In addition, this type of feeder did not provide a positive seal against entry of air, and it was necessary to have a tight feed-hopper cover for proper operation of the column.

These problems were largely remedied for this project by fabricating a new hopper that incorporated a four-blade, rotary airlock feeder with rubber blades. This feeder provided both sealing and metering functions. The maximum particle size of solid material was limited to 1-in. spheres by the feeder mechanism. As an accessory for the rotary feeder, a small electrically driven shaft with prongs extending radially from it was installed in the feed slot between the rotary feeder and the feed plate of the classifier column. The shaft projections mated with similar stationary projections on the bottom of the feed slot and provided a means of separating agglomerated fluffy material and projecting it into the airstream. This so-called "kicker" limited the particle size to no more than about 3/8-in. diameter. With the stationary teeth removed, particles up to 1/2-in. or slightly more in diameter could be handled. Thus, both the column throat and the feeder mechanism constituted limitations on the size and shape of particles that could be fed to the column. With most solid wastes, therefore, a need existed for shredding before air classification.

The question immediately arose whether or not additional shredding should be employed to prepare an already shredded material for air classification in the laboratory column, since this would change the aerodynamic properties of the material. This applied particularly to the automobile body trash stream. Rather than reshred, it was believed that a classifier column should be designed with a throat large enough to process the material in the already existing size range if air classification processing were to be used commercially for this material. Since the throat size of the column is related to the capacity of the column as well as to the size of the particle, the design of a full-scale column would also take into account the rate at which it was desired to process the material. Further, considering commercial scale-up, there is a relationship between column size and initial and operating cost and the cost of shredding or crushing the material for processing by air classification. These relationships are suggested by Figure 4, which indicates that there is an optimum size to minimize the combined cost of shredding and air classification.

Another consideration related to particle size must also be taken into account in deciding what degree of size reduction is to be employed for laboratory air classification experiments. The alternative to complete shredding is to remove oversize material by screening, an operation that is practical if the oversize constituents are of such a nature that their classification characteristics can be determined readily by judgment.

In addition to the new feed hopper with its rotary valve and "kicker" attachment, three additional modifications of facilities were required. New 1- and 1-1/2 in. screens had to be fabricated for the laboratory screening equipment. It was necessary to relocate the laboratory shredder and air classification column to a roofed, outdoor dock to provide a working area sufficiently large for both pieces of equipment and for storage of the material being processed. It was necessary also to fabricate a new bar grate for the 5-hp McCormick No. 4E hammermill used for laboratory shredding. The 1-in. and smaller round-hole screens previously used with this shredder produced an overshredded product (almost dry pulp) when fed a waste with large paper content. Although not wholly satisfactory, the shredder output with the 1-1/2-in. bar grate represented a significant improvement.

Performance of the Laboratory-Scale Unit on Selected Wastes

Operating Procedure. When samples of the selected wastes arrived at the laboratory, the densities and moisture contents were determined. If the samples had more than approximately 20 percent moisture content, they were air dried so that they could be stored without decomposition. The wastes were also inspected to determine visually the nature of the major constituents and the degree of contamination. Even though all samples received were in the range of 3- to 6-in. particle size, or less, they could not be fed directly to the small laboratory-scale air classification unit. Either shredding or removal of the oversize fractions by screening was necessary before the material could be processed.

Shredding was usually done dry because wet material was subject to a greater degree of overshredding. On relatively moist samples, however, a drying effect amounting to as much as a 5 percent change in moisture content was produced by the shredding operation. Shredding of materials having a large paper content at moisture levels approaching 100 percent produced a definite pulping effect. Shredding at a large moisture content, or even addition of moisture during the shredding operation, is claimed to be desirable to reduce the explosion hazard in commercial operations. Following shredding, a preliminary air classification run was generally made on the sample at its air-dried moisture content.

Experiments were made with some materials to determine whether or not an improvement in the ease of separating plastic wrapping materials and newspaper fractions could be brought about by moistening the sample slightly before air classification. This appeared to be of some benefit, especially where electrostatic effects inhibited separation. In commercial practice, however, accurate control of the moisture content of material to be air classified would complicate the operation to a prohibitive extent.

Screening before air classification often improved the separating effectiveness of the air classifier by limiting the range of sizes in the classifier feed. It also appeared, in this series of experiments, to remove effectively leaf fragments and other low-density fines that adhered to paper and cardboard. Three types of laboratory screens were available as follows: (1) a shaker screen, which can continuously separate as many as four different sized gradations; (2) a standard Ro-tap unit used with Tyler testing sieves; and (3) a laundry tumbler-type drier in which the basket could be operated as a rotating screen. Screened fractions were air classified to determine the combination of separations and removals that appeared to produce the best results. In most cases, this could be determined visually. In some cases, however, notably the automobile body trash stream, the constituents were not readily identifiable, and analytical procedures had to be used to identify the concentrations being produced by air classification.

In all cases a method was sought that would involve minimum processing only. The order of sequential operations was approximately as follows:

Air classification of air-dried sample

Air classification at controlled moisture content

Shredding plus air classification

Screening plus air classification

Shredding plus screening followed by air classification

From the initial series of experiments, a detailed test program was developed for each waste sample. The samples were then run according to the detailed procedure and results evaluated. If improvement in separating efficiency or concentration of recoverable fractions appeared desirable or achievable, the detailed test procedure was modified and the series of experiments rerun. Results reported for the individual wastes may thus be the outcome of a number of minor improvements of the initial test program, the fundamental objective remaining the same and only the procedures being modified.

No standard methods of determining the physical characteristics of solid waste could be found. For moisture content, the determinations made for this study followed procedures described in ASTM D143, Tests of Small Clear Timber Specimens, Sections 122 through 125. Bulk density tests for building materials, such as those described in ASTM C519-63T for fibrous, loose-fill building insulation, appeared to be most adaptable to density determinations for solid wastes. If the waste were to be reduced first to a uniform moisture content, a great deal of information might be obtained about its physical nature by conducting a three-step density measurement. Ideally, these density determinations would be made (1) after the waste had been loosely packed into a container, according to some standard method of procedure; (2) after compression to 10 psi (conventional packer forces amount to 7 to 15 psi); and (3) after rebound. Unfortunately, time did not permit development of this density procedure to the point where it could be reliably employed. Uncontrolled, loose-fill density determinations made for the material as received were used instead and are the bulk densities reported herein.

The determination of moisture and volatile oil content for the automobile body trash samples followed procedures described in ASTM D1800-63, Moisture and Creosote Preservative in Wood. These determinations were made on the screened and air-classified fractions of this material. Moisture contents were also spot checked by drying samples in an oven.

Performance of the Laboratory-Scale Unit on Selected Wastes. Detailed procedures for operating the air classification unit, together with other neces-

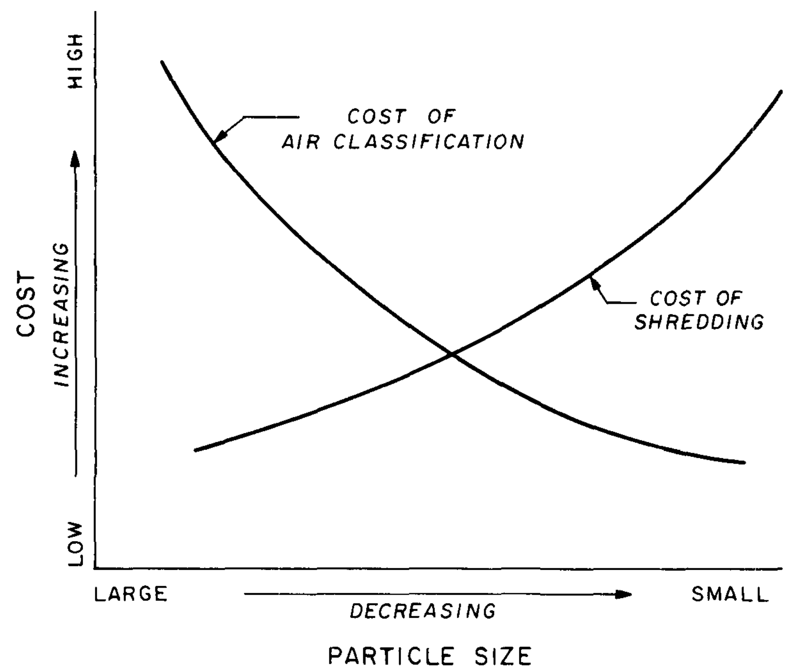

Figure 4. Hypothetical cost relationships for shredding and air classification.

sary unit operations of a pilot-plant system for the laboratory processing of each solid waste sample, were determined by the approach outlined in the previous paragraph. Operating procedures and the performance of the laboratory unit are reported in this section for the three general classifications of solid wastes that were processed in this experimental program. The characteristics of the wastes, the procedures for their processing, and results are now reported.

Compost from Municipal Refuse. The compost material, aged approximately 6 months in the outdoor stockpile of the Lone Star Organics waste disposal plant at Houston, Texas, was received in a single 55-gal steel drum. The net weight of the sample was 233 lb and its calculated bulk density was 32.7 lb/cu ft (833 lb/cu yd). On the assumption that the barrel had been filled before shipment, the sample had compacted to 87 percent of its original volume during the 10-day railway express shipment from Houston to Los Angeles.

At the Houston plant*all waste material processed is collected from residential routes. After manual selection and sorting, followed by magnetic separation to remove tin cans, the waste is shredded, mixed with sewage sludge to a moisture content of 60 to 70 percent (dry basis) and continuously digested while being aerated and mechanically agited. After 6 days' residence time, during which aeration is regulated so that the temperature increases from 135 F to a final temperature of approximately 170 F, the material is discharged to an outdoor stockpile for completion of the composting action.

When received, the compost sample was too wet for storage (moisture content estimated at 80 to 100 percent) and had to be air dried. Before being air dried, a small portion of the sample was air classified at velocities of 1,100 and 1,600 ft/min. Although the sample ran well, the separations were unsatisfactory as determined by visual observation. After being air dried to approximately 20 percent moisture content (dry basis), the sample was shredded through a 1-in., round-hole screen to break up lumps in the dried material. Dedusting at a superficial velocity of 600 ft/min effectively removed fines, fibrous material, and plastic wrap. There materials were present, however, in only very small amounts. Some feeder trouble and a small amount of column clogging were encountered. Separation into two fractions at 800 ft/min, followed by screening to remove fines, did not produce a substantially improved product. A shredded sample was then screened before air classification to remove glass, dirt, and the like from the compost. Classfication of material remaining on No. 8 screen at 400, 500, and 1,100 ft/min produced separations that appeared to have little commercial value.

On the basis of these preliminary experiments, a test program was developed. This program is diagrammed (Figure 5), and photographs of the original shredded compost material and the fractions into which it was separated by a combination of screening and air classification are presented.

Figure 5 indicates that approximately 20 percent by weight of the stockpile material can be recovered as horticultural-grade compost. The air-classified bottoms of the coarser screened material might be ground, and this product would conceivably have a market as bulk compost for use in landscaping of freeway slopes and other such areas. The diagram also indicates the possibility of the materials being returned to the compost digester, if it contains a considerable amount of uncomposted material that would benefit by additional digestion. When this material is combined with the horticultural material, 55 to 60 percent recovery of the stockpile is obtained. Approximately 35 to 40 percent would require ultimate disposal as landfill, and approximately 5 percent could be burned to obtain heat for drying, if required.

A small amount of work was done with the screened fines, and it appears that air classification of this fraction followed by tabling of the overhead might recover as much as half of the stabilized organic fines. Air classification alone does not produce a satisfactory product, because of its contamination by fine glass. The presence of glass would also create slag problems if this fraction were to be burned.

Automobile Body Trash. It was considered desirable from the standpoint of scale-up of laboratory results to commercial operation to remove oversize material from the automobile body trash sample by screening and to experiment with air classification of those portions of the sample that could be processed in the laboratory without further shredding. (The hammermill shredding operation that produces the trash stream being reported on in this section has been described by Ralph Stone and Company.[5]) Essentially, this stream consists of all material that cannot be removed magnetically from the output of a 5,000-hp, 600-rpm hammermill that is fed junked automobile bodies from which easily salvageable copper items (such as radiators) tires, and in some cases engines and transmissions, have been removed.

This material was divided into four fractions as

*For descriptions of this plant, see Prescott, J. H. Composting plant converts refuse into organic soil conditioner. *Chemical Engineering*, p. 232-234, Nov. 6, 1967 and *American City*, Compost works in Houston. Oct. 1967.

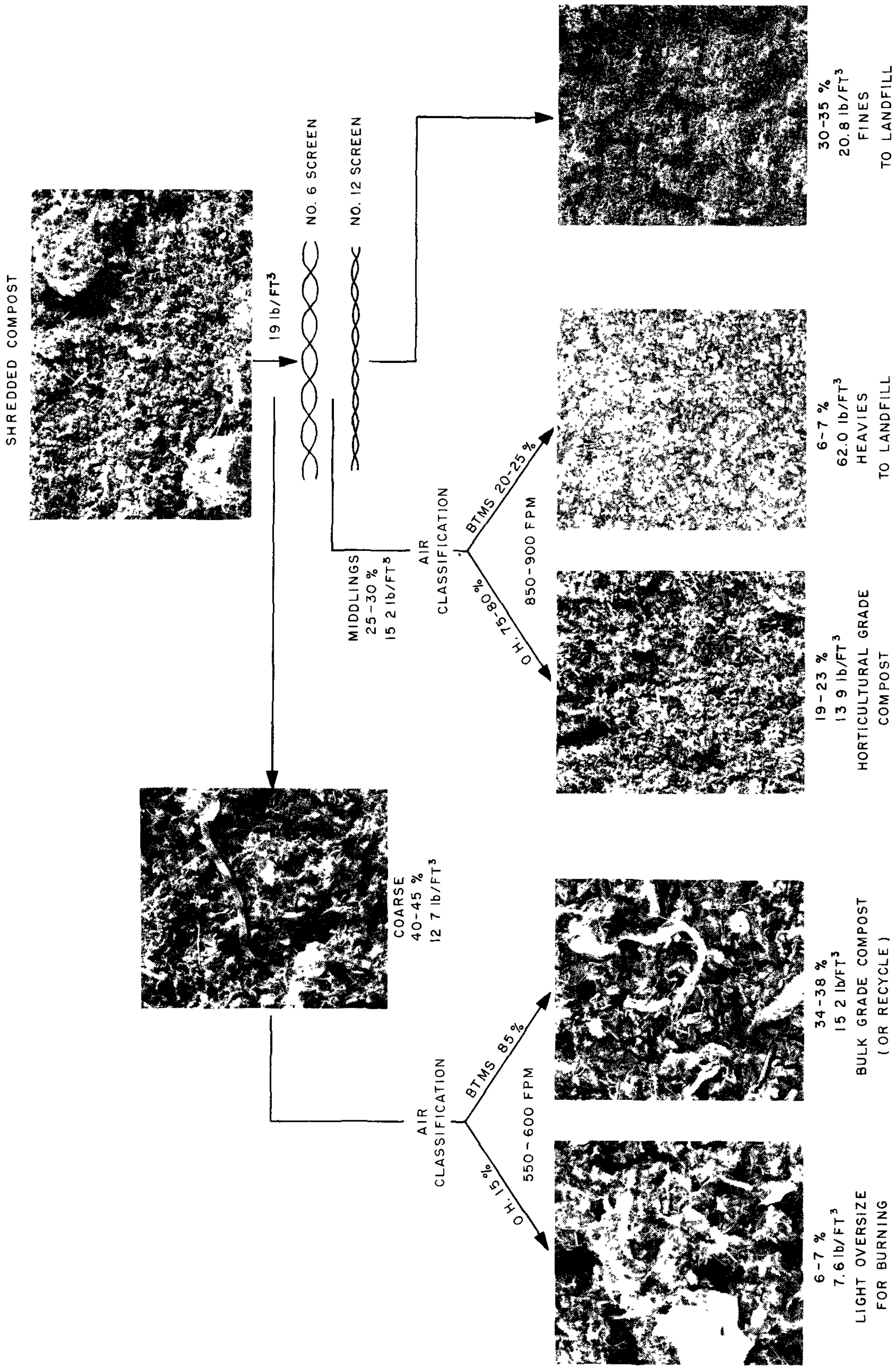

Figure 5. Compost-processing diagram and photographs of the original shredded compost and the fractions into which it was separated by screening and air classification. (Percentages are by weight.)

follows: fraction 1 consisted of material retained on a 1-1/2-in. screen; fraction 2, of material passing a 1-1/2-in. screen but retained on a 1-in. screen; fraction 3, of material passing a 1-in. screen but retained on a 3/8-in. screen; and fraction 4, of material passing the 3/8-in. screen. Fractions 1 and 2 could not be fed to the laboratory classifier. A description must suffice to characterize these materials. Fractions 3 and 4 were characterized by air classification.

Fraction 1–more than 1-1/2 in. in size. This sample appeared to be equally divided between organic material (rubber, cardboard, cloth, and paper) and inorganic material (metal and dirt). There was a surprising amount of fine dirt, rust, and glass fragments that were carried through with the coarse fractions by being entrapped in shreds of fiber, cardboard, and cloth. Rubber moldings, hose, and extruded seals predominated; many chunks were 6 to 8 in. long or longer and 3/4- to 1-1/2-in. maximum transverse dimension. Rubber- and asphalt-impregnated cardboard sheet material were also present in significant quantity, along with other combustible sheet material and fabrics of various sorts such as seat cover materials. The metal material, which appeared to be about one-fourth to one-third of the sample by volume and probably more than 50 percent by weight, consisted of chrome-plated pot metal (zinc) and aluminum trim, a large crumpled piece of 1/16-in.-thick sheet zinc about 18-in. long by 6-in. wide, and some copper and iron parts. Identifiable objects were door handles, an ignition coil, the armature from a starter or generator, and a small electric motor. There were also several small electrical components and a portion of the heavy glass from a head lamp. There was little wood or wire.

Fraction 2–maximum size between 1 and 1-1/2 in. This sample was predominantly organic, metals and glass accounting for only about 10 to 15 percent of the total volume. There were many 2- to 3-in. lengths of rubber molding and a number of plastic parts. The greatest amount of material consisted, however, of roughly equidimensional pieces of shredded sheet cardboard, sheet rubber, upholstery padding, floor matting, and fabric. The metal fragments were primarily diecast zinc, many from chrome-plated trim parts. Hydraulic brake wheel cylinder plungers were recognized. There was little wire or wood and very little iron. Fines were present but in somewhat lesser quantity than in fraction 1. There were several chunks of broken safety glass held together by the safety laminate.

Fraction 3–3/8 to 1 in. in size. This sample was air classified to determine its composition. Most of the material was oil soaked and dirt impregnated and was fibrous; the fraction was homogeneous. Metal fragments were not easily recognizable although insulated wire could be identified. Small splinters of wood were also present.

Fraction 4–smaller than 3/8 in. in size. This fraction was air classified. It was oily and fibrous, appearing to be about an equal mixture of fiber and dirt. Except for its oil-soaked appearance, it resembled the material found in the dustbag of a household vacuum cleaner.

The relative sizes of the samples, by weight and by volume, and their densities are listed (Table 3).

Fractions 3 and 4 were each fed to the air classification column and separated into seven subfractions at column differentials (fluidizing velocities) that were arbitrarily selected to give reasonably sized subfractions for analysis. The original fractions were first classified at a column differential of 0.2 in. of water column differential. The overhead fraction was collected and the bottoms fraction passed through the column again at a column differential of 0.5 in. of water. This overhead fraction was collected and the bottoms fraction passed through the column again at 1 in. of water column differential. This procedure was repeated until separations had been made and overhead fractions obtained from column differentials of 0.2, 0.5, 1, 2, 4, and 8 in. of water column differential, representing superficial velocities in the column throat of 400, 600, 800, 1,100, 1,600 and 2,500 ft/min, respectively. The 8-in. bottoms sample was also collected. Compositions and analyses of these subfractions are given (Tables 4 through 7).

Visual examination revealed little about the original fractions or about the subfractions separated by air classification; photographs were taken of automobile body trash fractions selected as typical and are reproduced in Figures 6 and 7.

Because of its semigranular nature and the relatively high proportion of dense material, the automobile body trash samples fed well and could be classified at high rates with no difficulty.

Results obtained by pyrolizing fractions 3 and 4 at approximately 1,500 F in an electrically heated batch retort are given in Appendix B, which contains the report of the San Diego Utilities Department. The conclusions drawn from this report are as follows:

1. Both fractions have large contents of inert material such as metal, dirt, and glass, separated inerts plus ash in the char exceeding 50 percent of the original sample.

2. In the coarse fraction, the calorific values of the chars are almost four times those of the fines, because of the large ash content of the char in the fine material. The total heating value is about 2,100 Btu/lb for the coarse fraction and 1,400 Btu/lb for the fine fraction. Approximately 55 percent of the heat produced comes from the gas in the fines and

TABLE 3

FRACTIONS RESULTING FROM SCREENING RESIDUE
AFTER MAGNETIC SEPARATION FROM AUTOMOBILE BODY SHREDDING

Fraction number	Screen size particle retained or	Weight (lb)	Volume (cu ft)	Percentage of total sample By weight	Percentage of total sample By volume	Bulk density (lb/cu ft)
1	1-1/2-in. square hole	37.5	1.07	25.2	24.5	35.0
2	1-in. mesh, 16-gauge, square hole	17.0	0.72	11.4	16.5	23.6
3	10-mm round hole	30.0	1.15	20.2	26.4	26.0
4		64.0	1.42	43.2	32.6	45.0
Total sample		148.5	4.36	100.0	100.0	34.0 (avg)

TABLE 4

SUBFRACTIONS RESULTING FROM AIR CLASSIFICATION.
SCREEN FRACTION 3 (COARSE)–AUTOMOBILE BODY TRASH

Designation	Superficial velocity (ft/min)	Weight (g)	Percentage of total sample By weight	Percentage of total sample By volume	Dry density* (G/cc)	Dry density* (lb/cu ft)
3,8-in. BTM†	2,500	506.1	37.9	9.2	1.09	68.0
3,8-in. OH‡	2,500	275.2	20.6	13.3	0.41	25.6
1, 4-in. OH	1,600	199.5	15.0	14.7	0.27	16.8
3, 2-in. OH	1,100	144.2	10.8	19.1	0.15	9.4
3, 1-in. OH	800	122.6	9.2	34.6	0.07	4.4
3, 0.5-in. OH	600	81.4	6.1	7.7	0.21	13.1
3, 0.2-in. OH	400	5.7	0.4	1.4	0.08	5.0
Total sample		1,334.7**	100.0	100.0		

*Volume of all samples weighed for density determination was 50 cc.
†Screen fraction 3, 8-in. manometer reading, bottoms (BTM) subfraction.
‡Screen fraction, 3, 8-in. manometer reading, overhead (OH) subfraction.
**46.2 g of wire removed before weighing.

TABLE 5

SUBFRACTIONS RESULTING FROM AIR CLASSIFICATION.
SCREEN FRACTION 4 (FINE)–AUTOMOBILE BODY TRASH

Designation	Superficial velocity (ft/min)	Weight (g)	Percentage of total sample By weight	Percentage of total sample By volume	Dry density* (G/cc)	Dry density* (lb/cu ft)
4, 8-in. BTM†	2,500	283.7	17.5	6.1	1.54	96.0
4, 8-in. OH‡	2,500	376.6	23.3	12.7	0.98	61.2
4, 4-in. OH	1,600	532.5	32.9	40.8	0.43	26.8
4, 2-in. OH	1,100	154.7	9.6	15.9	0.32	20.0
4, 1-in. OH	800	80.1	5.1	9.1	0.29	18.1
4, 0.5-in. OH	600	120.9	7.5	9.5	0.42	26.2
4, 0.2-in. OH	400	64.8	4.1	5.9	0.36	22.5
Total sample		1,613.3	100.0	100.0		

*Volume of all samples weighed for density determination was 50 cc.
†Screen fraction 4, 8-in. manometer reading, bottoms (BTM) subfraction.
‡Screen fraction 4, 8-in. manometer reading, overhead (OH) subfraction.

only 30 percent from the gas in the coarse material.

Spectrographic assays were performed on fractions 3 and 4, and the results are listed (Table 8). Results of similar assays on the air-classified subfractions are also presented (Tables 9 and 10).

Spectrographic analyses are usually made on ores, the material being vaporized in a carbon arc. It is first necessary, therefore, to reduce a sample to ash, and this was done. The ash from the entire fine material sample that was analyzed represented 68 percent of the original screen fraction, while that from the coarse material represented 59.5 percent of the original screen fraction. For the subfractions, the percentage ash ranged from 40 to 85.

The relative abundance of the various basic elements is disclosed from a spectrographic analysis. However, the elemental combinations and the mineral forms in which the metallic elements occur probably

TABLE 6

PHYSICAL CHARACTERISTICS OF SUBFRACTION RESULTING FROM AIR CLASSIFICATION. SCREEN FRACTION 3 (COARSE)–AUTOMOBILE BODY TRASH

Designation	Superficial velocity (ft/min)	Percentage moisture*	Percentage extractable oil*	Percentage magnetic material	Percentage combustible material†	
					Run 1	Run 2
3, 8-in. BTM‡	2,500	0.9	12.7	33.2	21.0	19.7
3, 8-in. OH**	2,500	2.4	28.4	9.5	46.1	53.3
3, 4-in. OH	1,600	4.1	35.8	3.0	61.5	61.0
3, 2-in. OH	1,100	–	–	2.5	67.0	60.5
3, 1-in. OH	800	6.3	14.6	2.0	61.0	55.0
3, 0.5-in. OH	600	4.7	13.4	1.0	44.0	54.4
Total sample		3.3	24.2	- -	41.4	- -

*Following procedure described in ASTMD-1860.

†Following procedure described in ASTM D271-58, 600 C oven. Run 1, 20-g samples from initial experimental classification; Run 2, approximately 500-g samples (57 to 585 g) from production separation.

‡Screen fraction 3, 8-in. manometer reading, bottoms (BTM) subfraction.

**Screen fraction 3, 8-in. manometer reading, overhead (OH) subfraction.

TABLE 7

PHYSICAL CHARACTERISTICS OF SUBFRACTION RESULTING FROM AIR CLASSIFICATION. SCREEN FRACTION 4 (FINE)–AUTOMOBILE BODY TRASH

Designation	Superficial velocity (ft/min)	Percentage moisture*	Percentage extractable oil*	Percentage magnetic material	Percentage combustible material†	
					Run 1	Run 2
4, 8-in. BTM‡	2,500	0.5	15.1	36.5	3.0	- -
4, 8-in. OH**	2,500	0.6	13.7	24.5	18.9	14.8
4, 4-in. OH	1,600	1.4	9.7	25.5	24.5	19.1
4, 2-in. OH	1,100	1.7	10.0	14.0	27.6	27.1
4, 1-in. OH	800	1.5	10.2	16.0	24.5	30.6
4, 0.5-in. OH	600	2.5	1.1	15.5	24.0	30.0
4, 0.2-in. OH	400	2.9	- -	7.5	25.5	30.9
Total sample		1.5	10.3	17.5	25.5	- -

*Following procedures described in ASTM D-1860.

†Following procedures described in ASTMD 271-58, 600 oven. Run 1, 20 g samples from initial experimental classification; Run 2, approximately 500 g samples (123 to 405 g) from production separation.

‡Screen fraction 4, 8-in. manometer reading, bottoms (BTM) subfraction.

**Screen Fraction 4, 8-in. manometer reading, overhead (OH) subfraction.

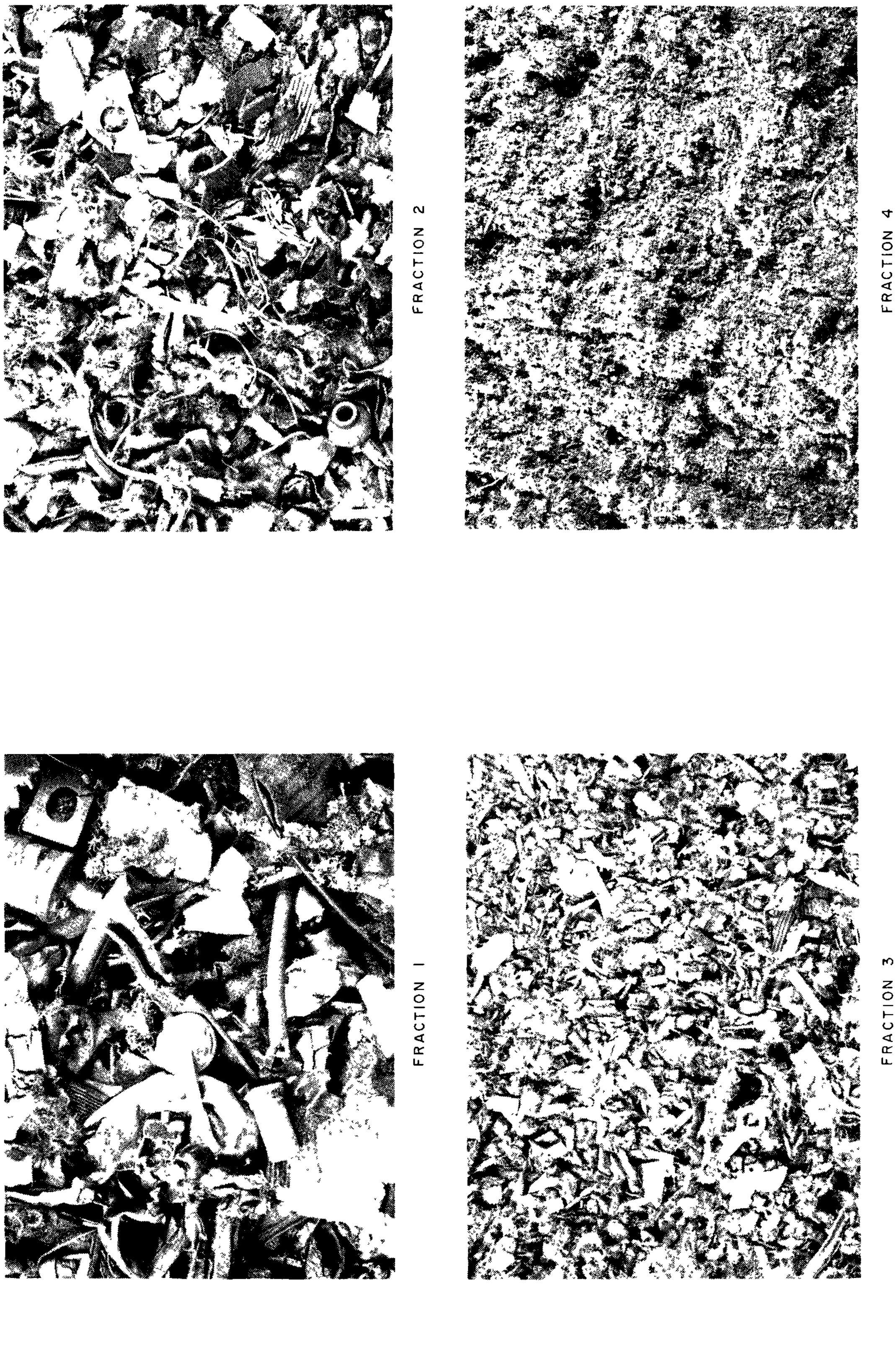

Figure 6. Automobile body trash-screened fractions.

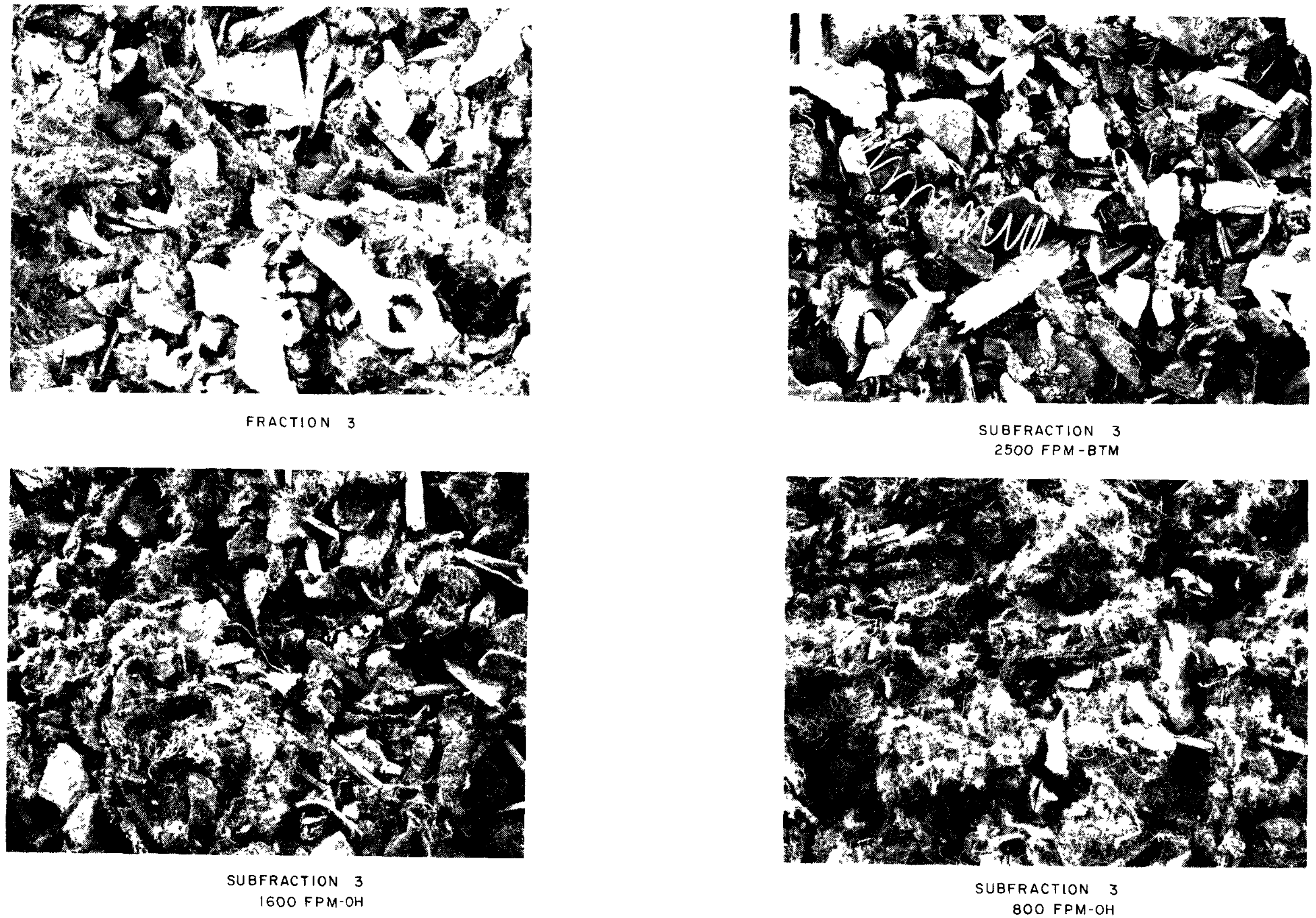

Figure 7. Automobile body trash–air-classified subfractions.

(Continued next page)

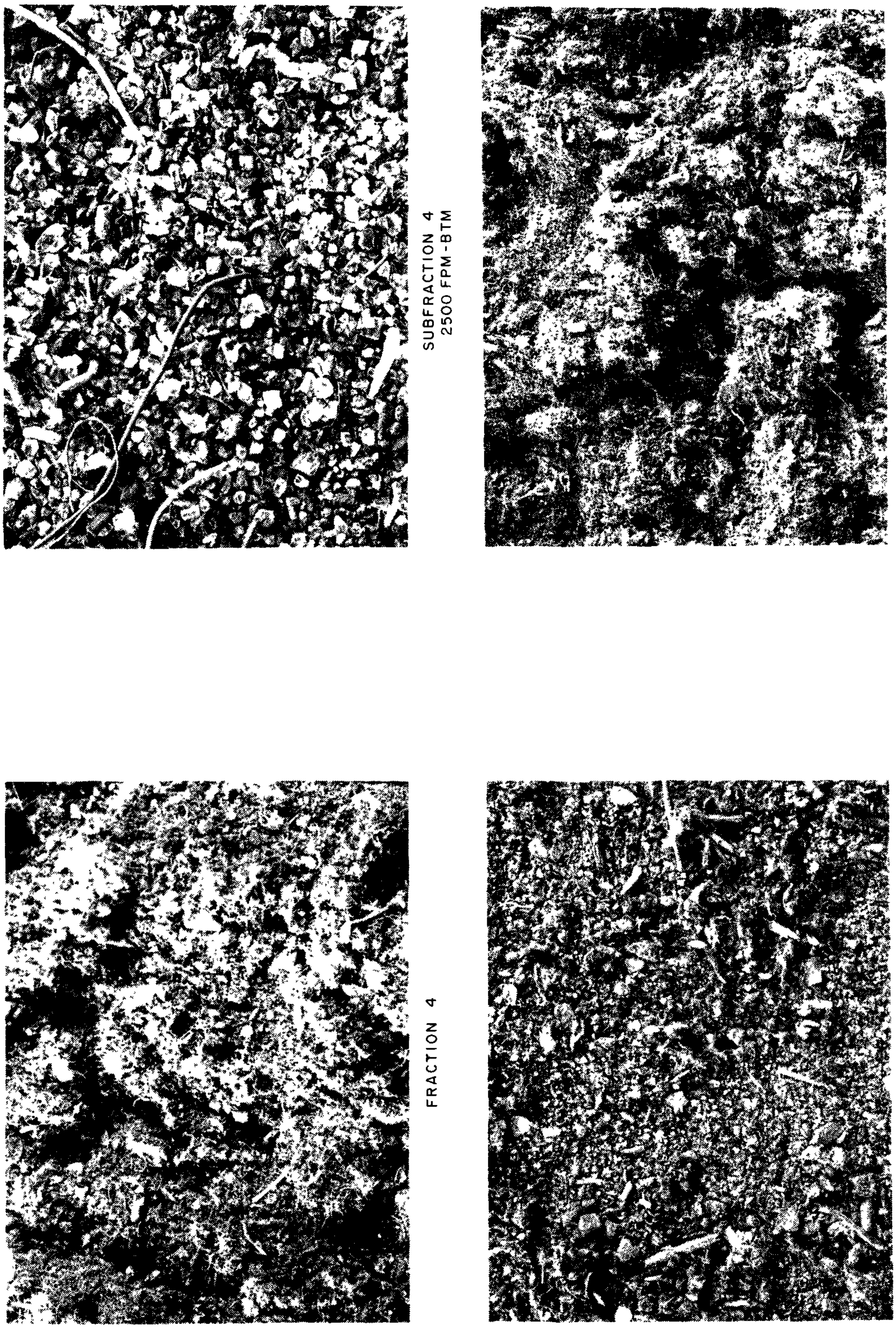

Figure 7. Automobile body trash–air-classified subfractions. (Concluded)

TABLE 8

SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF SCREENED FRACTIONS OF RESIDUE AFTER MAGNETIC SEPARATION FROM AUTOMOBILE BODY SHREDDING*

	Ash from fraction 3, coarse material† (% by weight)	Ash from fraction 4, fine material‡ (% by weight)
Silicon	10.9	16
Iron	32 (magnetic)	21
Copper	1.1	1.6
Calcium	2.1	3.8
Aluminum	5.5	5.1
Zinc	6.8	2.1
Magnesium	1.3	1.7
Chromium	0.046	0.095
Barium	0.14	0.16
Boron	0.02	0.016
Titanium	0.88	0.91
Lead	1.8	1.1
Tin	0.17	0.090
Manganese	0.051	0.077
Nickel	0.20	0.31
Molybdenum	0.0032	0.0097
Vanadium	0.007	0.0069
Sodium	Trace	Trace
Silver	0.0009	0.0042
Zirconium	0.011	0.019
Cobalt	0.0058	0.042
Strontium	0.011	0.015
Antimony	0.14	Nil
Potassium	Nil	Trace
Other elements	Nil	Nil

*Refuse material ashed at 600 C, per ASTM D271-58, to produce samples for spectrographic assay. Total will not equal 100%, because gases do not show. Quartz, for instance, is 28 parts silicon and 32 parts oxygen, which would show 46.7% silicon. For most ores, the total is less than 50%. Source: Materials Engineering Co. (MECO) analysis dated October 11, 1968.

†Ash was 59.5%, by weight, of original fraction. Course material designated MECO Sample 38699.

‡Ash was 68%, by weight, of original fraction. Fine material designated MECO Sample 38698.

bear little resemblance to the combinations and forms within a naturally occurring ore. The total sample appears to be fairly rich in aluminum, zinc, copper, and lead, with zinc concentrated in the coarse fraction. Such concentration could make it economical to process this material—especially so, when it is realized that quantities of from 50 to 200 tons per day can be obtained free at automobile body-processing plants in metropolitan areas.

From data on the air-classified subfractions (Tables 9 and 10), zinc was further concentrated in the heavy bottoms of the coarse screened material. More than 12 percent of the total zinc in material that was less than 1 in. in particle size was concentrated in this subfraction, and this concentration permitted recovery of as much as 13 lb of zinc per ton of the total nonmagnetic trash stream. Concentrations of other materials were indicated that may offer promise when the material is considered for processing as an ore. These materials include iron, chromium, copper, and possibly lead or titanium. Most of these metals or oxides appear to be concentrated in the heavy subfraction, either the overhead or bottoms, and this circumstance would make for a high-volume, low-cost separating operation.

Municipal refuse. Eight solid waste shredded samples of domestic and commercial solid wastes that were primarily wastepaper were obtained from the following locations:

Los Angeles, California (San Fernando Valley)
- Domestic waste from single-family residences
- Commercial wastes

Houston, Texas
- Domestic waste from single-family residences, coarse and fine grind

Cincinnati, Ohio
- Domestic waste, coarse and fine grind
- Commercial waste, coarse and fine grind

All samples were from combined collections. Sample sizes ranged from 15 to 100 lb; all samples provided an adequate quantity of waste for air classification experimentation. Information on these samples as they were received is summarized (Table 11).

We do not intend in this report to add to the confusion on solid waste terminology that is already extensive in statutes, literature, and in the vocabularies of professionals and laymen alike. Although we may use somewhat interchangeably terms such as garbage, rubbish, refuse, trash, and solid wastes, we accept the definition of solid wastes as used by the California State Department of Public Health in their recent publication on solid wastes management,[6] which defines solid waste as "all those materials that are solid or semisolid and that the possessor no longer considers of sufficient value to retain." Thus the term "solid wastes" is all inclusive and embraces all types of classifications, sources, and properties.

Expected ranges in percentage composition of mixed municipal refuse from U.S. cities are as follows (Table 12): paper, 37 to 60; metallics, 7 to 10; food, 12 to 18; other materials (leaves, wood, glass, plastic), 1 to 12. It is not, however, to be expected that any single sample of refuse would follow this composition exactly. The routing of collection vehicles as well as seasonal and economic factors will certainly influence the composition of any given refuse sample.

From visual inspection, it can be said that the Cincinnati refuse samples contained most of the components listed, and the composition fell within the ranges given (Table 12). The Houston refuse contained less newsprint and cardboard in the pri-

TABLE 9

SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF AIR-CLASSIFIED SUBFRACTIONS AFTER MAGNETIC SEPARATION FROM AUTOMOBILE BODY SHREDDING. SCREENED FRACTION 3 (COARSE)–AUTOMOBILE BODY TRASH*

	Percentage, by weight, from ash sample of subfraction					
	3, 8.0 BTM†	3, 8.0 OH‡	3, 4.0 OH	3,2.0 OH	3, 1.0 OH	3, 0.5 OH
Silicon	17	0.77	20	12	12	17
Iron	24	21	11	6.9	18	12
Copper	2.0	0.42	3.2	2.8	2 6	0.55
Calcium	4.2	0.26	5.0	2.8	2 2	2.8
Aluminum	4.9	1.5	4.1	2.4	3.1	4.5
Zinc	7.6	0.20	1.5	0.81	1.9	2.4
Magnesium	2.0	0.043	2.1	1.2	0.92	1.4
Chromium	0.026	3.2	0.052	0.027	0.037	0.059
Barium	0.34	Nil	0.58	0.48	0.23	0.31
Boron	0.0098	Nil	0.027	0.026	0.038	0.037
Titanium	0.17	0.057	0.87	0.42	0.51	0.91
Lead	4.0	0.028	0.81	1.1	0.38	1.2
Tin	0.096	0.041	0.13	0.20	0.19	0.072
Manganese	0.14	0.19	0.12	0.13	0.076	0.091
Nickel	0.25	0.075	0.11	0.072	0.076	0.094
Molybdenum	0.0073	0.012	0.0044	0.0055	0.0067	0.0078
Vanadium	Trace	0.0072	0.0025	0.0021	0.0027	0.0038
Sodium	Trace	Nil	Trace	Trace	Trace	Trace
Silver	0.00039	Nil	0.00029	0.00019	0.00026	0.00032
Zirconium	Nil	Nil	0.020	0.013	0.019	0.026
Cobalt	0.0084	Trace	0.013	0.0046	0.013	0.0084
Strontium	0.070	Trace	0.10	0.058	0.056	0.062
Antimony	0.21	Nil	Nil	Nil	Nil	Nil
Other elements	Nil	Nil	Nil	Nil	Nil	Nil
Total percentage ash by weight, at original sample	80.3	46.7	39.0	39.5	45.0	45.6

*MECO Samples 39384-39389. Refuse material ashed at 600 C, per ASTM D271-58, to produce samples for spectrographic assay. Total will not equal 100%, because gases do not show. Quartz, for instance, is 28 parts silicon and 32 parts oxygen, which would show 46.7% silicon. For most ores, the total is less than 50%.

†Screen fraction 3, 8-in. manometer reading, bottoms (BTM) subfraction.

‡Screen fraction 3, 8-in. manometer reading, overhead, (OH) subfraction.

mary shredded sample, because easily salvageable material of this type had already been handpicked from the sample. The Houston material (after secondary shredding) not only contained less newsprint and cardboard but also had no ferrous metal, since this had been removed by magnetic separation before the fine-shredding operation.

Because the Los Angeles samples were selected purposely to demonstrate differences of paper recovery potential, they showed a variation in both quantity and quality of paper content. In addition, the domestic waste sample was believed to contain less food wastes than the national average because of the more prevalent use of garbage grinders in the Los Angeles area. Apparently, because this sample was collected in the late fall from a relatively high-income suburban area, it was also characterized by a much higher than normal percentage of garden clippings and dried leaves. However, for the purpose of investigating the separating effectiveness of the air classification unit on mixed municipal refuse, the actual composition of the waste processed was not of paramount importance. It was important that material that would normally be expected to be present in the collected waste and that would constitute a contaminant of the intended air classification product be present in the samples classified to determine whether satisfactory removal could be effected. In this respect, the presence of a larger-than-normal quantity of yard wastes in the San Fernando Valley single-family domestic sample was of benefit because this type of contamination is especially detrimental to reuse of a salvaged, mixed-paper product. The same comment pertains to the unusually large amounts of sawdust and floor sweepings in the San Fernando Valley commercial sample.

TABLE 10

SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF AIR-CLASSIFIED SUBFRACTIONS OF RESIDUE AFTER MAGNETIC SEPARATION FROM AUTOMOBILE BODY SHREDDING. SCREENED FRACTION 4 (FINE)–AUTOMOBILE BODY TRASH*

	Percentage, by weight, from ash sample of subfraction						
	4, 8.0 BTM†	4, 8.0 OH‡	4, 4.0 OH	4, 2.0 OH	4, 1.0 OH	4, 0.5 OH	4, 0.2 OH
Silicon	21	12	20	24	19	17	20
Iron	11	46	9.1	16	11	13	14
Copper	0.60	0.63	0.029	0.037	0.032	0.047	0.071
Calcium	3.9	2.9	4.6	4.5	2.5	2.5	3.4
Alumium	4.3	1.9	4.5	5.2	4.5	4.7	5.7
Zinc	0.61	1.6	0.42	0.61	0.30	1.3	0.93
Magnesium	1.7	1.8	2.1	2.2	1.5	1.3	1.7
Chromium	0.10	0.048	0.14	0.065	0.047	0.033	0.039
Barium	0.16	0.17	0.30	0.43	0.44	0.37	0.43
Boron	0.010	0.0084	0.013	0.022	0.015	0.014	0.027
Titanium	0.42	0.22	0.58	1.1	1.2	0.81	0.59
Lead	1.7	0.83	0.64	0.96	0.65	0.83	0.91
Tin	0.037	0.037	0 030	0.035	0.053	0.035	0.044
Manganese	0.0081	0.17	0.086	0.086	0.083	0.12	0.17
Nickel	0.096	0.19	0.034	0.31	0.061	0.070	0.065
Molybdenum	0.0067	0.0080	0.0060	0.0065	0.0067	0.0067	0.0091
Vanadium	Trace	Trace	0.0013	0.0019	0.0017	0.0038	0.0036
Sodium	4.4	2.3	3.0	3.9	2.2	0.84	0.80
Silver	Trace	0.0027	Trace	Trace	Nil	0.0013	0.0011
Zirconium	0.016	Nil	0.016	0.020	0.025	0.021	0.026
Cobalt	0.018	0.0078	0.0045	0.011	0.0069	0.0072	0.0078
Strontium	0.066	0.058	0.11	0.14	0.080	0.12	0.090
Antimony	Trace	Nil	Nil	Nil	Nil	Nil	Nil
Other elements	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total percentage ash, by weight, of original sample	--	85.2	80.9	72.9	69.4	70.0	69.1

*MECO Samples 38384-39389. Refuse material ashed at 600 C, per ASTM D271-58, to produce samples for spectrographic assay. Total will not equal 100%, because gases do not show. Quartz, for instance, is 28 parts silicon and 32 parts oxygen, which would show 46.7% silicon. For most ores, the *total is less than 50%.*

†Screen fraction 4, 8-in. manometer reading, bottoms (BTM) subfraction.

‡Screen fraction 4, 8-in. manometer reading, overhead (OH) subfraction.

One factor related to refuse composition and the effectiveness with which components can be separated for salvage or reuse is the amount of time that elapses between refuse collection and the separation process. In a commercial application, refuse would probably be separated immediately after collection. In the Institute's laboratory experiments, this was not physically possible. In many cases, the samples had to be stored for a month or more while preliminary investigations were being carried out to determine the most advantageous detailed test program. The effect of storage, it is believed, is to make more difficult the separation of fine, gritty contaminants that may embed themselves in, or become cemented to, paper or cardboard surfaces.

Another characteristic of solid waste that is likely to be of interest in processing studies is its calorific value. Drying may become necessary for air classification of certain wastes. If so, a portion of the waste or a separated fraction most likely will be burned to provide the heat needed. For that reason, the heating values (2,500 to 8,500 Btu/lb) of various types of municipal refuse are listed (Table 13).

A general problem encountered by the Institute's research team with all paper-containing wastes was that of overshredding. Overshredding produces an effect similar to that for which a "Jordan" or a beater is used in the original paper-making process—that is, to cut and scuff the edges of each fiber so that it will cling strongly to another fiber. The small size of the overshredded particles reduces the air velocity required for fluidization (and thus the available separating force) and the fuzzy nature of the particles causes the paper and cardboard to agglomerate and thus form a floc that picks up and carries with it a great deal of the other light and fine material. It was found

TABLE 11

CHARACTERISTICS OF MUNICIPAL REFUSE SAMPLES AS RECEIVED FOR EXPERIMENTATION AT STANFORD RESEARCH INSTITUTE

Source and type of sample	Dry net weight of sample (lb)	Maximum particle dimension (in.)	Air-dried bulk density (Lb/cu ft)	Air-dried bulk density (Lb/cu yd)	Percentage moisture content as received	Remarks
San Fernando Valley, California						
Domestic waste, single family	94	12-14	7.0	189	35	More than 25% yard trimmings and dry leaves
Domestic waste, apartments	Segregated sample not obtainable					
Commercial waste	100	12-14	7.2	195	20	Considerable sawdust and other wood waste; high percentage corrugated material
Houston, Texas						
Domestic waste, single family						
Primary shredding	47	8	6.6	178	25	
Secondary shredding	70	Mostly 1 in. or less; 8-in. plastic strips (length)	10.9	294	59	Slightly over-shredded
Cincinnati, Ohio						
Domestic waste, single family						
Preground (Sample 79-H)	14	12	--	--	149	Very heterogeneous, but constituents recognizable.
Final grind (Sample 80-H)	16	1-1 1/2	--	--	163	Semipulped
Commercial waste						
Preground (Sample 78-H)	21	12-16	--	--	14	High percentage of corrugated material.
Final grind (Sample 81-H)	25	1 1/2-2	--	--	*	Overshredded

*Air dried, approximately 20%.

that a major improvement resulted as the particle sizes became larger; this was particularly the case when the edges were not ragged and torn but were sharply cut. Runs on mixed newspaper and corrugated cardboard that had been cut with a punch into 1-in. rounds revealed that sufficient differences existed in the fluidizing velocities to permit effective separation by air classification. In a column designed for volume processing, the column throat and allowable particle size would be much larger than in the laboratory equipment, and this circumstance would make very effective separation possible.

When fibrous agglomerates of paper and cardboard formed in the column (this also happened with wet compost material but to a lesser extent), the column immediately lost capacity, separation efficiency dropped owing to the overload condition, and column clogging usually resulted. An expedient for remedying this condition was to "pulse" the column as follows: At the point of clogging, if the air inflow to the column was alternately stopped and started by covering the air inlet at the bottom of the column, sufficient additional agitation could often be produced to break up the floc and to maintain effective column action. Done rapidly, this did not affect separation. Occasional purging at higher velocity was sometimes also necessary. The obvious solution to the problem of column clogging in larger scale operations

TABLE 12

EXPECTED RANGES IN COMPOSITION OF MIXED MUNICIPAL REFUSE*

Component	Percentage composition as received (dry weight basis) Anticipated range	Nominal
Paper	37-60	55
Newsprint	7-15	12
Cardboard	4-18	11
Other	26-37	32
Metallics	7-10	9
Ferrous	6-8	7.5
Nonferrous	1-2	1.5
Food	12-18	14
Yard (leaves, etc.)	4-10	5
Wood	1-4	4
Glass	6-12	9
Plastic	1-3	1
Miscellaneous	<5	3
Total		100

*Moisture content: range, 20%-40%; nominal, 30%. Based on data contained in references 7 through 13. Source: Personal communication, Battelle Memorial Institute.

would be to shred the material in a way that reduces the tendency for agglomeration, that is, to cut rather than tear. The problem, of course, would be much less important in a larger sized column, if not totally eliminated.

Fluidizing velocities observed when the laboratory column was operated on selected pure components of refuse mixtures are summarized (Table 14). In this tabulation of experimental data, an attempt was made to show (for fibrous materials) the effects of the size of a particle and the sharpness of the edges of the shredded material. When fluidizing velocities for paper and cardboard in a 6-in. straight pipe are compared with those in the zigzag column, the straight-pipe velocities are approximately one-third lower than those in the column for the same material (dry, shredded newspaper and cardboard and dry, cut newspaper and corrugated cardboard rounds). Shredded and cut newspaper appear to differ little in fluidizing velocities in either the column or the straight pipe, and there is no observable difference in straight-pipe velocities for large- or small-cut paper specimens. On the other hand, cut cardboard requires a one-fourth to one-third greater velocity than the shredded material, and large squares require about 50 percent greater velocity for suspension than small rounds do. This is of considerable significance for separation; whereas there exists a 250 ft/min in velocity difference between cardboard and newspaper (about 50 percent of the lower fluidizing velocity) when finely shredded, a difference of 650 ft/min in velocity exists between large pieces (almost 200 percent of the lower fluidizing velocity) when they are cut to minimize the aerodynamic effect of torn edges. The greater air velocities would also permit greater particle agitation for removal of entrapped fine particles.

The performance of the laboratory unit on the eight samples of paper-containing wastes essentially involved only two test programs. In a number of respects, these two programs were not even mutually exclusive. The first program dealt with single-family domestic wastes from various sources. The second program dealt with domestic wastes from multiple-family dwellings and with commercial wastes. Recovery of a commercially usable grade of waste paper stock was the objective of both programs. Additionally, the first program was also directed toward removal of nonbiodegradable organic and inorganic material that interfered with composting, fermentation, and retorting from the usable cellulosic fraction. It was considered desirable to effect removal, if possible, so that the metal, glass, and plastic contaminants might also have a certain salvage value.

Evaluation of Laboratory-Scale Unit's Performance in Separating Solid Wastes. From the standpoint of paper recovery, results of classification experiments with the laboratory-scale unit were inconclusive. Accomplishment of the subobjectives of processing paper-containing waste—metal and glass removal, removal of nonbiodegradable material, and pretreatment for retorting—was easily demonstrated and would present no problem in commercial operation. In developing guidelines for the production of a usable recovered paper product, it was realized that recovery of secondary fiber for reuse does not require separation into the paper stock grades that are now offered in the salvage paper market. These grades are dictated more by paper salvage practices, such as segregation by source, and the opportunities for economical hand selection than by users' specifications. To be of maximum value, however, a recovered product should take full advantage of the potential that air classification offers for removing all noncellulosic fines from the collected material. Gritty contaminants are much more objectionable in paper making than water-soluble stains that the waste paper may have acquired as an ingredient of mixed refuse.

In the laboratory column, the degree of cleaning and separation considered suitable to permit paper salvage from mixed waste for reuse in the paper-making process was not achieved. Experience with

TABLE 13

HEATING VALUES OF VARIOUS TYPES OF MUNICIPAL REFUSE*

Source	Principal components	Approximate composition (% by weight)	Percentage moisture content	Percentage incombustible solids	Heating value of refuse, as fired (Btu/lb)	Auxiliary fuel (Btu/lb of waste)	Recommended minimum burner input (Btu/lb of waste)
Commercial and light industrial establishments	Highly combustible waste such as paper, wood, cardboard cartons, plastic, or rubber scraps	100% trash	10	5	8,500	0	0
Combined collection from domestic, commercial, and industrial sources	Combustible waste such as paper, cartons, rags, wood scraps, combustible floor sweepings, with some putrescible cooking residues and food wastes	80% trash	25	10	6,500	0	0
Combined collection domestic waste from residences only	Trash, garbage, and garden clippings	50% trash 50% vegetable matter	50	7	4,300	0	1,500
Markets; restaurant, hotel, club, and institutional kitchens	Food wastes, including animal, fruit, and vegetable residues from preparation and cooking of foods	65% garbage 35% trash	70	5	2,500	1,500	3,000

*A classification of wastes based on satisfactory incinerator operation is given in paragraph 2.1, section 3, of "Code of Recommended Practices for Non-Domestic Incinerators," a supplement to the City of Chicago's Air Pollution Control Ordinance as revised October 7, 1968. Adapted from Essenhigh, R. H. Incineration—a practical and scientific approach, Environmental Science and Technology, 2 (7): 530, July 1968.

the column provides, however, some guidance for future efforts in this area. Difficulties were due to the small particle size required by the laboratory classification column and the high aerodynamic drag of the finely shredded waste material. Thus, only very low fluidizing velocities and correspondingly weak separating forces (gravity and air velocity) resulted. Under these conditions, electrostatic forces also have a powerful influence. (To permit viewing, the sidewalls of the laboratory column are made of plexiglass, which is a good dielectric material and contributes to electrostatic interference.)

For removal of noncellulosic fines from dry waste samples, a combination of screening and air classification appeared to be effective. Screening was necessary because of the similarity in aerodynamic characteristics of the fine dust and grit and the paper constituents of the samples. Air classification of the coarser, paper-containing fractions after screening was difficult because of the small differences in density of the components (remaining fines, paper, cardboard, and plastic) and the intimate mixture produced by the shredding and screening operations. The overshredded material from a conventional hammermill tends to agglomerate, forming a floc of paper and cardboard that picks up and carries with it a great deal of other light and fine material.

Equipment for shredding and screening in commercial applications must be selected that minimizes the dry pulping and felting effects of these operations on a fibrous material. In a column designed for volume processing, the column throat and allowable particle size would be much larger than in the laboratory equipment, and these conditions would make more effective separation possible.

Performance of the air classification column on

TABLE 14

FLUIDIZING VELOCITIES FOR SELECTED PURE COMPONENTS OF REFUSE MIXTURES IN A STRAIGHT PIPE AND THE ZIGZAG COLUMN

Component	Velocity (ft/min) Zigzag classifier with 2-in. throat	Velocity (ft/min) Straight 6-in. diameter pipe
Plastic wrapping (shirt bags)	Less than 400 (electrostatic)	--
Dry, shredded newspaper (25% moisture)	400-500	350
Dry, cut newspaper		
1-in. rounds	500	350
3-in. squares	--	350
Agglomerates of dry, shredded newspaper and cardboard	600	--
Moist, shredded newspaper (35% moisture)	750	--
Dry, shredded corrugated cardboard	700-750	450-500
Dry, cut corrugated cardboard		
1-in. rounds	980	700
3-in. squares	--	1,000
Styrofoam packing material	750-1,000 (electrostatic)	--
Foam rubber (1/2-in. squares)	2,200	--
Ground glass, metal, and stone fragments (from automobile body trash stream)	2,500-3,000	--
Solid rubber (1/2-in. squares)	3,500	--

compost and automobile body trash, which is more granular than paper-type trash, was very satisfactory. Empirically obtained operating data appear sufficient to permit scale-up for the design and construction of a full-size unit, if desired. Process flow diagrams are presented and performance of typical commercial plants are discussed in the last part of this report. Minor variations of the preliminary designs developed from the current set of experimental data will be desirable, inasmuch as the objective of this research was simply to demonstrate the technical feasibility of air classification. Additional experimental data should be obtained before actual plants are designed or built to optimize the desired nonferrous metal concentrations for automobile body trash and to produce a quantity and quality of compost that satisfies both the compost marketing and refuse disposal requirements of a compost plant operator.

It can be concluded from these bench-scale experiments that air classification is technically feasible for processing semifibrous solid waste materials. For light, more fibrous materials, the results were favorable but inconclusive. Additional research is necessary to demonstrate a workable process for paper stock recovery from combined collections of municipal and commercial wastes. This work must include experiments with a larger sized air classification column and investigations into the performance of commercially available shredding and screening equipment on feeds with large paper contents. Improvement of commercially available feed preparation equipment (shredders and screens) may be necessary for use in an air classification system.

Pilot-unit Experiments

Need for Pilot-Scale Experiments for Recovery of Municipal Refuse

The degree of cleaning and separation considered suitable to permit paper salvage from mixed waste for reuse as secondary fiber was not achieved in the laboratory column. Experience with the small column provided, however, some guidance for future efforts. Difficulties were due to the small particle size required by the laboratory classification unit and the high aerodynamic drag of finely shredded waste material. Thus, only very low fluidizing velocities and correspondingly weak separating forces (gravity and air velocity) resulted. The overshredded material from a conventional hammermill tended to agglomerate, forming a floc of paper and cardboard that picked up and carried with it other light and fine material.

Additional experimentation was, therefore, recommended to indicate how air classification might be employed in a workable process for paper stock recovery from combined collections of municipal and commercial wastes. This work included experiments with a larger sized air classification column and investigations into the performance of commercially available shredding equipment on high-paper-content feeds.

Pilot-Scale Air Classification Unit

The pilot air classification unit designed and built especially for the recommended paper separation experiments is shown (Figure 8). It is a 10-stage column with viewports and a two-stage column section that can be used either at the top or the bottom of the main column. (This effectively permits feeding at alternate positions on the column.) The column throat is 6 by 12 in. in cross section; thus, shredded refuse can be handled in which maximum particle size of the paper fractions is somewhat more than 4 in. In developing design criteria for the column, this throat size was selected as the minimum practical size for separating refuse shredded in the same way it would be shredded for a commercial operation. Column appurtenances were provided that perform the same functions as those on the laboratory-scale unit described previously—induction blower; feed hopper with rotary, airlock feeder; a cyclone for separating overhead material from the airstream; and a manometer indicating pressure drop across the column. In addition, the 23-in. diameter Carter-Day high-velocity cyclone was equipped with an 8-in. rotary discharge valve that made possible the continuous operation of the unit, and a 12-in. portable belt elevator was provided for uniform delivery of material to the feed hopper. The 5-hp induction blower with slide-gate control permitted air velocities in the column throat to be varied between 300 and 2,500 fpm.

In all work reported herein, the column was operated with six stages above and four below the feed point.

Procurement of Shredded Samples and Their Characteristics

From experience in obtaining samples of material for laboratory-scale separations, it was believed that shredded municipal refuse for the pilot unit could be obtained locally (to eliminate shipping charge) and without cost for shredding. This was not true. It was found more difficult to obtain samples several cu yd in size and sufficient for continuous operation of the new column than it was to obtain the smaller samples (generally less than 50 lb or 0.1 to 0.3 cu yd) that were donated for batch operation of the small laboratory unit. It was originally estimated that a 150- to 200-lb sample would be required for each run of the large column and that reuse of samples was possible but that physical degradation of the samples by continuous handling and rehandling would be limiting. This also was not true. In practice 50- to 100-lb, or smaller, samples proved to be adequate, and the separated component could be remixed and rerun five or more times. Losses of material during feeding became a more significant limitation than physical degradation of the samples.

To fulfill the objectives of the proposed research it was necessary to obtain shredded samples of municipal solid waste that were representative of actual refuse and that exhibited the characteristic size reduction patterns produced by several types of commercial shredding equipment.

Procurement of Samples. Initially, only two samples were available. These were the following.

Los Angeles Sample. A rigid-arm, 75 hp Williams shredder for shredding corrugated boxboard in a baling installation at a major supermarket warehouse was used to shred a synthetic mixed-paper sample to a nominal 4- to 5-in. particle size. Corrugated board (15 to 20 percent by weight) was supplied by the warehouse operator; newspaper (30 to 35 percent by

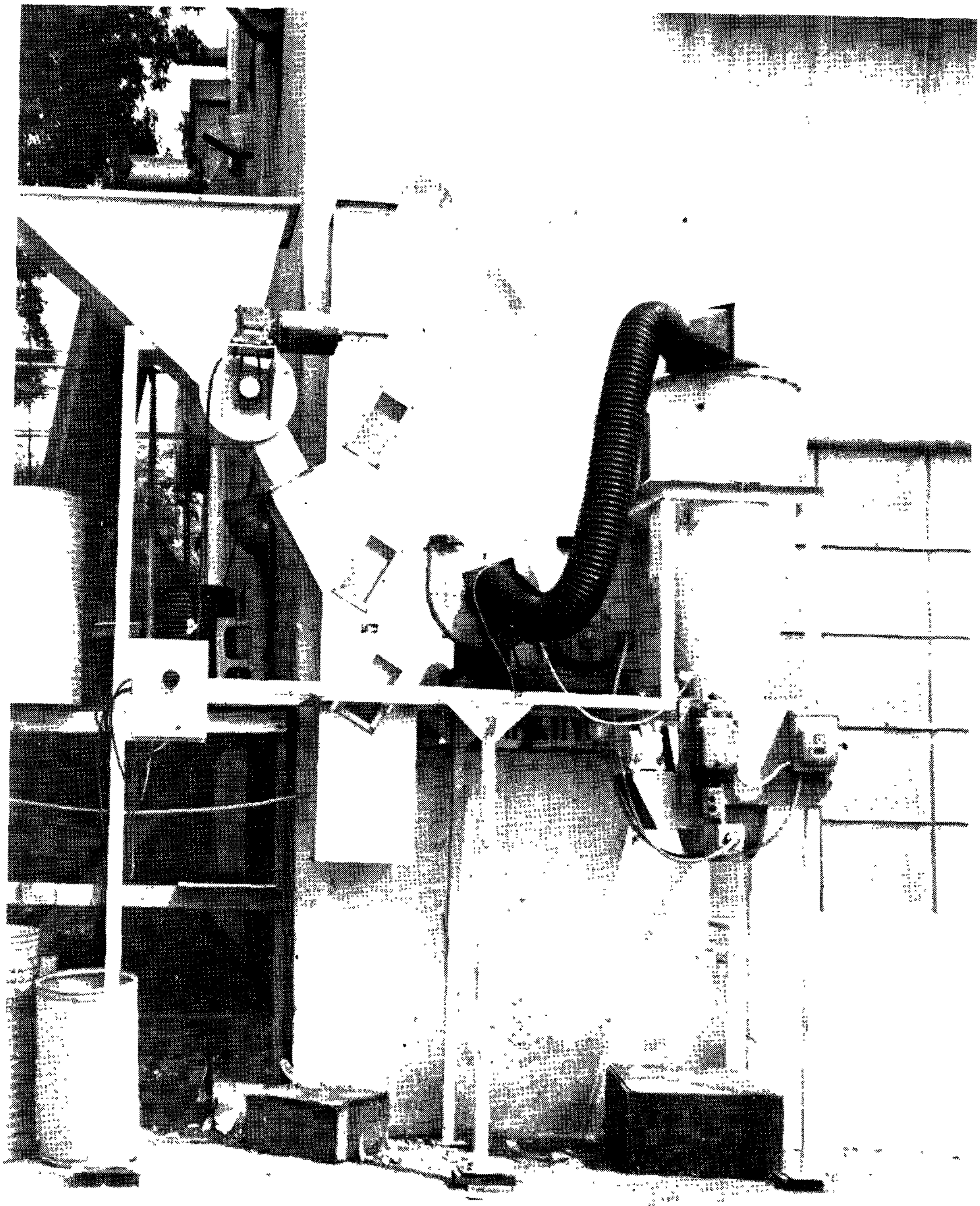

Figure 8. Scientific Separators pilot air classification unit.

weight) was supplied by SRI; miscellaneous paper (50 to 55 percent by weight) was handpicked at a local landfill. The combined mixed-paper sample, together with a small amount of film plastic, was shredded in the Williams mill. Refuse constituents other than paper were obtained also by picking a representative sample at a landfill. The County Sanitation Districts of Los Angeles, having a small experimental shredding plant at a landfill, shredded the heavy fraction. Heavy and light material were to be blended after shredding for runs in the air classification pilot-unit column.

Cincinnati Sample. A 450-lb sample of shredded municipal refuse was shipped by motor freight from the Cincinnati laboratory of BSWM. Ground in one pass (no screen or bar grate) by the laboratory's 100-hp Williams hammermill, the particle size of the paper and cardboard proved too large for separation in the air classifier. It became necessary, therefore, to hand separate paper from other refuse material for further size reduction.

Quantities of both samples were adequate, but the large maximum particle size of paper and cardboard made them unsuitable for continuous column operation. An attempt was made to reshred these samples in a forage chopper that employed a rotating cutterhead similar to a lawn mower, but this was unsuccessful. Other shearing devices that would produce the desired cleanly cut edges on paper particles, such as commercial brush chippers, were investigated; none of these was suitable.

Characteristics of Samples. Five different samples of shredded refuse representative of five different types of shredding equipment were eventually investigated. Two of these samples were preponderantly of the largest particle size (4- to 6-in. maximum dimension) that could be processed in the pilot unit, and three samples were generally of considerably smaller particle size. The fine-particle-size samples were provided by the PHS-TVA composting project and by the Eidal International Corporation, the refuse being obtained by them from Johnson City, Tennessee, and Albuquerque, New Mexico, respectively.

Data on the shredded refuse samples used for experimental purposes are summarized (Table 15). Size classification by components is shown for each sample (Tables 16-20). The size gradations are shown graphically (Figure 9). The Cincinnati and Los Angeles samples that were indicated as "coarse" material were really dissimilar. The former was well graded, having only 20 percent of the total sample weight in the 1/2- to 1-1/2-in. size range. The latter had more than 80 percent in this range and contained essentially no fines. Like the Cincinnati sample, the Albuquerque sample was well graded; only 45 percent was in the 1/2- to 1-1/2-in. size range, with 45 percent finer than and 20 percent coarser than the range. The Johnson City hammermill and rasp samples were very similar. Both contained approximately one-third (by weight) of material finer than the screened range; the balance was in this range with little or no material in excess of the 1-1/2-in. size. The screen sizes selected for sieve analysis corresponded with those used by the Forest Products Laboratory of the U.S. Department of Agriculture in preliminary work on dry separation of paper components from shredded municipal waste from Madison, Wisconsin. The material categories were those used by Black-Clawson Company Research Center and the Forest Product Laboratory in the work they are doing to reclaim usable grades of secondary paper fiber from municipal refuse.

TABLE 15

SHREDDING INFORMATION AND SOURCE OF MUNICIPAL REFUSE SAMPLES PROCESSED IN THE PILOT AIR CLASSIFICATION UNIT

Source	Supplier	Manufacturer and type of shredder	Particle size	Remarks
Johnson City, Tennessee				
Hammermill	PHS-TVA composting project	Gruendler, Model 48-4 (250 hp)	Fine	
Rasp	PHS-TVA composting project	Dorr-Oliver (80 hp)	Fine	Shredded wet
Los Angeles, California (Scholl Canyon Landfill)	SRI and L.A. County Sanitation	Williams, rigid-arm paper shredder (75hp)	Coarse	No cans or bottles
Cincinnati, Ohio	Bureau of Solid Waste Management	Williams, swinging-arm refuse shredder (100 hp)	Coarse	
Albuquerque, New Mexico	Eidal International Corp.	Eidal Model 400, coarse grind (400 hp)	Fine	Shredded wet

TABLE 16

DESCRIPTION OF SHREDDED MUNICIPAL SOLID WASTE, JOHNSON CITY, TENNESSEE, PHS-TVA COMPOSTING PROJECT, SHREDDED BY GRUENDLER SWING HAMMERMILL, MODEL 48-4

Material	Description of material in size range indicated		
	More than 1-1/2 in.*	1/2 to 1-1/2 in.†	Less than 1/2 in.‡
Total,** general appearance	Mostly paper, generally similar to rasper material but less stringy and twisted		Approximately same as rasper material
Group I (includes metals, glass, and dirt)	Negligible††	Negligible††	Significant amount of dirt and very fine glass‡
Group II (film plastic)	Significant amount but very small compared with paper	Significant amount, but very small compared with paper	Trace only
Group II, other (includes food waste, heavy plastic, yard waste, cloth, wood, and lint)	Negligible	Negligible	Probably most of this fraction. Much of it fine, unidentified fibrous material
Group III, general appearance	Approximately same as rasper material but paper fragments less twisted and rumpled		
Newspaper	Significant but less than in middle cut	Possibly half of total cut	Lots of finely shredded paper, not identifiable as to kind
Magazines	Significant amount	Significant amount	Lots of finely shredded paper, not identifiable as to kind
Brown paper bags, corrugated containers, etc	Significant amount	Significant amount	Lots of finely shredded paper, not identifiable as to kind
Miscellaneous paper, food wrappers, and cartons	Possibly half of total cut	Significant amount	Lots of finely shredded paper, not identifiable as to kind

*By weight 4.6 percent by volume negligible.
†By weight 55.5%; 74% by volume.
‡By weight 39.9%; 26% by volume.
**Moisture content, 20%-25% (dry basis); weight screened 21.7 lb; volume, 2.75 cu ft; bulk density, 8.0 lb/cu ft.
††Ferrous metal apparently removed magnetically before shredding.

TABLE 17

DESCRIPTION OF SHREDDED MUNICIPAL SOLID WASTE, JOHNSON CITY, TENNESSEE, PHS-TVA COMPOSTING PROJECT SHREDDED BY DORR-OLIVER RASP

Material	Description of material in size range indicated		
	More than 1-1/2 in.*	1/2 to 1-1/2 in.†	Less than 1/2 in.‡
Total,** general appearance	Very small amount; rumpled, dirty	Finely and uniformly shredded, with stringy, twisted appearance	Dense, dark-colored, fibrous matter, much of it unidentifiable
Group I (includes metals, glass, and dirt)	None visible††	Trace only of metals and glass†† (glass pieces to 3/4 in.)	Trace only of metals and glass†† (significant amount of fine dirt and glass to 1/8 in.)
Group II (film plastic)	Significant amount, but only small fraction of total	Significant amount but only small fraction of total	Trace only
Group II, other (includes food waste, heavy plastic, yard waste, cloth, and wood)	Trace only (several large pieces of heavy plastic)	Trace only (some leaves evident)	More than 50% of fraction probably in this category
Group III, general appearance	Probably more than 90% of the fractions consists of assorted paper 1/2 to 1-1/2 in. size	Mostly newsprint, but much unidentifiable	Much of fibrous material finely shredded paper
Newspaper	Probably more than any other single type of paper		At least 1/4 of this cut finely shredded paper but not classifiable as to kind
Magazines	Negligible	Negligible	At least 1/2 of this cut finely shredded paper but not classified as to kind
Brown paper bags, corrugated containers, etc	Negligible	Negligible	At least 1/2 of this cut finely shredded paper but not classifiable as to kind
Miscellaneous paper, food wrappers, cartons (waxed), kleenex, and other very light paper	At least half of total paper content	At least half of total paper content	At least 1/4 of this cut finely shredded paper but not classified as to kind

*By weight 2.0%; percent by volume negligible.
†By weight 65.0%; 73% by volume.
‡By weight 33.0%; 27% by volume.
**Moisture content, 45% (dry basis); weight screened 30.0 lb; volume, 2.75 cu ft; bulk density, 10.9 lb/cu ft.
††Ferrous metal apparently removed magnetically before shredding.

TABLE 18

DESCRIPTION OF SHREDDED MUNICIPAL SOLID WASTE, LOS ANGELES, CALIFORNIA, SCHOLL CANYON LANDFILL SHREDDED BY WILLIAMS RIGID-ARM PAPER SHREDDER

Material	Description of material in size range indicated		
	More than 1-1/2 in.*	1/2 to 1-1/2 in.†	Less than 1/2 in.‡
Total,** general appearance	Miscellaneous paper, fairly uniform in size; little evidence of crumpling; all very clean		Trace of dust and some glass, resembling floor sweepings
Group I (includes metals, glass, and dirt)	None	None	Trace
Group II (film plastic)	None	None	None
Group II, other (includes food waste, heavy plastic, yard waste, cloth, and wood)	None	None	None
Group III, general appearance	Entire sample was made up of paper and cardboard, chopped to size with fairly minimal fraying; very few pieces more than 5 in. in largest dimension.		None
Newspaper	20% in this size range	80% in this size range	None
Magazines	None	None	None
Brown paper bags, corrugated containers, etc	20% in this size range	80% in this size range	None
Miscellaneous paper	Present	Present	None

*By weight 17.0%.
†By weight 83.0%.
‡By weight 0%.
**Moisture content, approximately 10%; synthetic dump stock composed of: 1 part (15%-20% by weight) corrugated cardboard; 2 parts (30%-35% by weight) newspaper; 3 parts (50%-55% by weight) miscellaneous paper hand picked from refuse; weight screened, 3.90 lb; original shredded sample contained significant quantity of paper requiring hand tearing before material could be fed to air classifier.

Performance of the Pilot-Scale Unit on High-Paper-Content Feeds

As mentioned previously, only limited experimentation was possible with the 6- by 12-in.-throat-size pilot unit because of feeding limitations and difficulty in obtaining shredded municipal refuse samples. A further constraint was the lack of procedures for analyzing the recovered paper fractions. The scope of the project did not include development of these procedures; consequently, results of the degree of separation obtainable are reported primarily as descriptions of the materials contained in the various fractions. Some work toward quantitative analysis was done by a commercial client, the St. Regis Paper Company Technical Center, on air-classified fractions of municipal refuse produced under conditions identical to those reported herein. Their quantitative results are considered proprietary, but qualitative generalizations are reported where this information has been released to us.

Operating Procedure. No operation other than air classification was employed in making separations of the five commercially shredded municipal refuse samples described previously. The operating procedure consisted of conducting a number of runs with 30- to 60-lb raw feed samples, and fractions separated therefrom, at constant superficial velocities in, and uniform feed rate to, the air classification column. The purpose was to determine the following data for each shredding method:

Velocity required to effect potentially useful separations
Weight percentage yields of the separated frac-

TABLE 19

DESCRIPTION OF SHREDDED MUNICIPAL SOLID WASTE, CINCINNATI, OHIO,
BSWM LABORATORY
SHREDDED BY WILLIAMS HAMMERMILL*

Material	Description of material in size range indicated		
	More than 1-1/2 in.†	1/2 to 1-1/2 in.‡	Less than 1/2 in.**
Total,†† general appearance	Overwhelmingly paper and fairly clean		Coarser than corresponding fraction from other samples screened
Group I (includes metals, glass, and dirt)	Trace only (several battered tin cans)	Trace only	Mostly dirt; some glass very finely ground
Group II (film plastic)	Very little	Very little	Negligible
Group II, other (includes food waste, heavy plastic, yard waste, cloth, and wood)	Very little	Very little	Wood especially present; other fine, unidentified fibrous material
Group III, general appearance	Very little evidence of twisting, rumpling, or fraying of pieces; many very large pieces, more than 5 in. in largest dimension		Possibly more paper than in corresponding fraction from other samples
Newspaper	About 1/2 of total fraction	About 1/2 of total fraction	Some paper present but undifferentiated
Magazines	Present	Present	None
Brown paper bags, corrugated containers, etc.	Present	Present	None
Miscellaneous paper	Present	Present	None

*Close breaker bar setting; no grate.
†By weight 47.5%.
‡By weight 24.2%.
**By weight 28.3%.
††Moisture content, 10%-15%; weight screened, 13.3 lb: original shredded sample contained significant quantity of paper requiring hand tearing before material could be fed to air classifier.

tions, for process design material balance calculations

Maximum allowable feed rate for column throat size calculations

Combined influence of feed rate and air velocity on degree of separation obtainable

Results from the five different methods of shredding were compared and overall results evaluated from the standpoint of future process design.

The general procedure employed was to make two runs on a sample to recover a paper-rich middle fraction: a deducting run to separate light fines and film plastic and a run to separate heavy constituents such as metal, rocks, glass, rubber, heavy plastic, and wood. These separations were followed by experiments to split the paper fraction into chemically and mechanically pulped material, corresponding roughly to (1) containers, which would include cardboard boxes, grocery bags, milk cartons, and similar items, and (2) newsprint.

At low velocities the column loading, that is, pounds of solids per pound of air, had little influence on the separations produced at low feed rates. Consequently, runs to establish separating velocities for splitting the paper fractions were made initially at low feed rates. As the feed rate was increased, the sharpness of separation decreased until the column operation became unstable and the column became choked because of overloading. The maximum allowable feed rate for full-size column design, therefore, will be selected in practice to produce column loadings between these two limiting values. The number of experimental runs possible for determining feed rates was, however, insufficient in this series of experiments, to establish limiting column loadings with any degree of reliability. Assessment of potentially useful separations of the paper fraction probably can be quantified best by producing and strength testing a hand sample of paper from the recovered material. Paper industry standards cover the necessary laboratory procedures, since this type of testing is used routinely to check mill "furnishes," that is, blends of paper-making ingredients.

It is realized that the strength properties of paper produced from recycled material are subject to degradation both by contamination with foreign material in refuse and by biological action. The degree of biological degradation depends on the activity of compost-type organisms, moisture content, and time. In laboratory experiments, the time between collection of a refuse sample and production of a test sheet of paper from suitable recovered fractions is considerably longer than the corresponding production cycle would be if the process were commercialized. To minimize degradation in samples provided to St. Regis Paper, a sterilant was added to the refuse samples when received and again when separated fractions were sent to St. Regis for

TABLE 20

DESCRIPTION OF SHREDDED MUNICIPAL SOLID WASTE, ALBUQUERQUE, NEW MEXICO, EIDAL INTERNATIONAL CORP.
SHREDDED BY EIDAL MODEL 400, COARSE GRIND*

Material	Description of material in size range indicated		
	More than 1-1/2 in.†	1/2 to 1-1/2 in.‡	Less than 1/2 in.**
Total,†† general appearance	Primarily paper; moderately twisted and rumpled; 1/2 to 1-1/2 in. same appeared finer than middle cut from other samples		Very fine and uniform
Group 1 (includes metals, glass, and dirt)	Negligible	Negligible	Present (mostly dirt)
Group II (film plastic)	Small, but significant amounts		Negligible
Group II, other (includes food waste, heavy plastic, yard waste, cloth, and wood)	Negligible	Present	Much unidentified fibrous material; some wood definitely present
Group III, general appearance	Very conspicuous difference between coarse and medium cuts	Fragments look a lot more twisted and rumpled than those in coarse cut	
Newspaper	All kinds of paper present in about equal amounts		Undifferentiated, finely shredded paper probably about 1/2 of this fraction
Magazines	All kinds of paper present in about equal amounts		Undifferentiated, finely shredded paper probably about 1/2 of this fraction
Brown paper bags, corrugated containers, etc	All kinds of paper present in about equal amounts		Undifferentiated, finely shredded paper, probably about 1/2 of this fraction
Miscellaneous paper	All kinds of paper present in about equal amounts		Undifferentiated, finely shredded paper probably about 1/2 of this fraction

*Shredded with water spray.
†By weight 18.8%.
‡By weight 35.9%.
**By weight 45.3%.
††Moisture content, 8%-13%; weight screened, 2.7 lb (sample too small for accurate volumetric measurement).

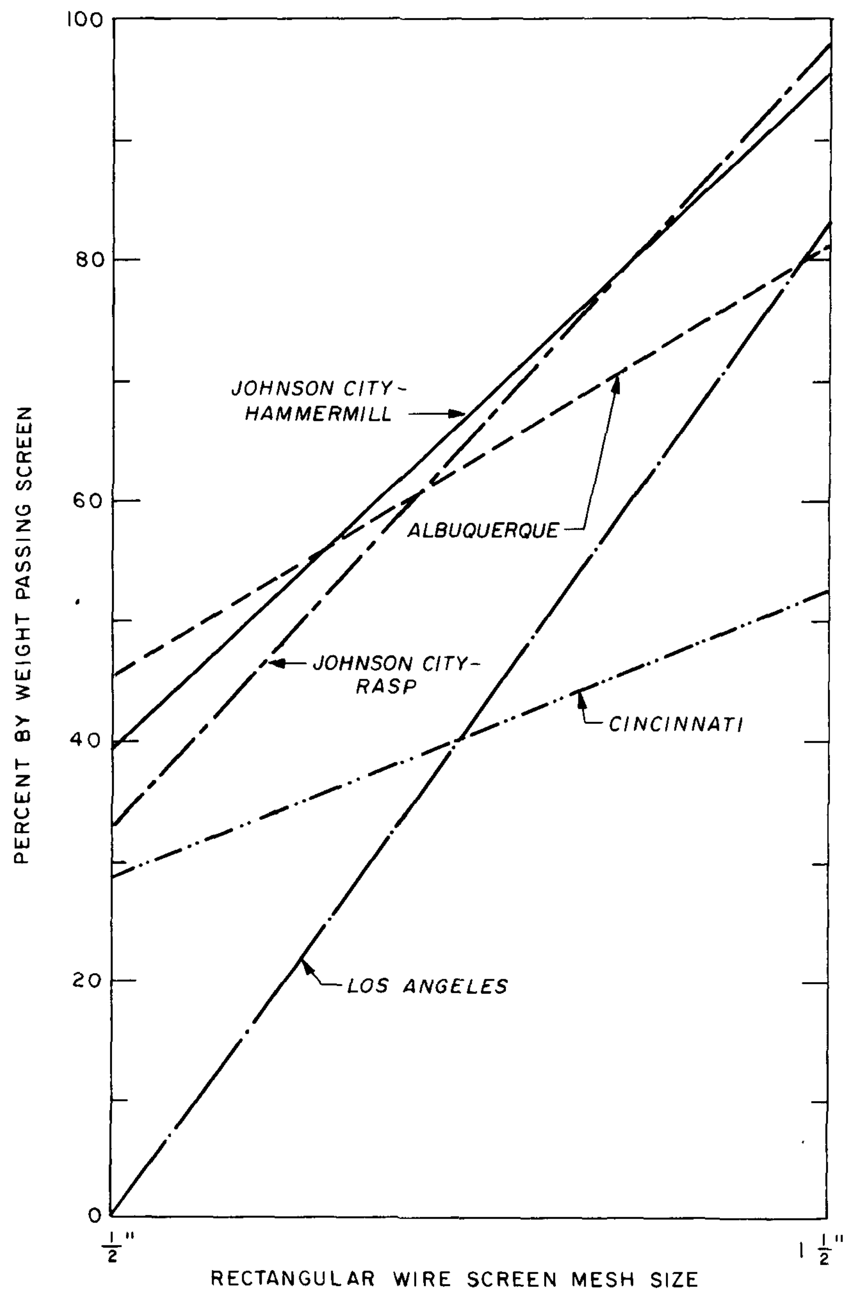

Figure 9. Mechanical analysis diagrams representative of various methods of shredding municipal solid waste. See Table 15 for manufacturer and type of shredding used. See Tables 16-20 for additional detail on refuse samples and gradation by components.

TABLE 21

AIR CLASSIFICATIONS CONDUCTED ON JOHNSON CITY (HAMMERMILL) REFUSE

Run Number	Feed	Weight of feed sample (lb)	Bulk density of feed sample (lb/cu ft)	Column's air velocity (fpm)	Feed rate (lb/min)	Light overhead fraction: Percent of feed By weight	Light overhead fraction: Percent of feed By volume	Light overhead fraction: Sample taken for St. Regis analysis of paper content†	Heavy bottom fraction: Percent of feed By weight	Heavy bottom fraction: Percent of feed By volume	Heavy bottom fraction: Sample taken for St. Regis analysis of paper content†
3/11-1*	Raw refuse (air dried)	46.0	8.0	2,000	--	95.0	--	--	5.0	--	--
3/11-2	Lights from Run 3/11-1	40.0	--	500	--	7.7	--	--	92.3	--	--
3/11-3*	Raw refuse (as received)	64.0	--	2,000	--	95.0	--	--	5.0	--	--
3/11-4	Lights from Run 3/11-3	61.0	--	400	--	3.0	--	--	97.0	--	--
3/12-1	Heavies from Run 3/11-4	22.0	--	1,100-1,200	--	86.0	96	--	14.0	4	HM-A
3/12-2	Lights from Run 3/12-1	18.5	--	800	--	84.0	82.5	--	16.0	17.5	HM-B
3/12-3	Lights from Run 3/12-2	13.0	--	650	--	8.0	27	HM-D	92.0	73	HM-C
4/8-19(1)	Wetted raw refuse	25.8	--	1,800	--	93.0	--	-	7.0	--	19-1H
4/8-19(2)	Lights from Run 4/8-19(1)	24.4	--	1,000	--	74.0	--	--	26.0	--	19-2H
4/8-19(3)	Lights from Run 4/8-19(2)	18.0	--	600	--	17.0	--	19-3L	83.0	--	19-3H

*Moisture contents: Run 3/11-1, 20%-25%.
Run 3/11-3, 35%-40%.
†Designations in column assigned by St. Regis.

analysis. The sterilant selected was a commercial grade of chloripicrin (nitro chloroform) a lachrymator sold under the trade name of Larvacide 100 by the Morton Chemical Company. It is a heavy liquid that vaporizes readily when sprinkled into a barrel or plastic bag containing a sample of refuse. Its toxicity is intermediate between chlorine and phosphine. In agricultural practice, it is used as a soil sterilant and a fumigant for grain.

Discussion of Results. The 45 air classification runs made on the five samples of shredded municipal refuse are summarized (Tables 21 through 25). The most nearly comprehensive series of runs is that made on Cincinnati refuse (Runs 4/10-1 through 4/10-5). Two other series that could be considered typical in that they might be adapted to commercial processing are those designated Runs 4/9-1 through 4/9-3 made on air-dried Albuquerque refuse and Runs 4/9-4 through 4/9-6 made on wetted raw refuse from Albuquerque. These runs will be described to illustrate the sorting procedure and to indicate the separations achieved. The 4/10 series of runs started with a dedusting run at a velocity of 300 to 400 fpm (Table 24). This classification removed overhead a small quantity of very light fines, dust balls, and a major portion of the film plastic contained in the raw feed sample. The next separation, in which the feed consisted of the column bottom cut from the 300-to 400-fpm run, was made at 700 to 800 fpm. This overhead fraction was very clean, containing only small amounts of fine material, and was predominantly news and magazine stock, that is, groundwood papers. There was a somewhat lesser amount of

TABLE 22

AIR CLASSIFICATIONS CONDUCTED ON JOHNSON CITY (RASP) REFUSE

Run Number	Feed	Weight of feed sample (lb)	Bulk density of feed sample (lb/cu ft)	Column's air velocity (fpm)	Feed rate (lb/min)	Light overhead fraction: Percent of feed By weight	Light overhead fraction: Percent of feed By volume	Light overhead fraction: Sample taken for St. Regis analysis of paper content†	Heavy bottom fraction: Percent of feed By weight	Heavy bottom fraction: Percent of feed By volume	Heavy bottom fraction: Sample taken for St. Regis analysis of paper content†
3/11-1*	Raw refuse (air dried)	--	10.9	2,500	--	Not satisfactory			--	--	--
3/11-2	Raw refuse (air dried)	56.4	10.9	2,000	--	87.5	--	--	12.5	--	--
3/11-3	Raw refuse (air dried)	56.0	10.9	1,500	15.0	80.4	--	--	19.6	--	--
3/11-4	Lights from Run 3/11-2	45.0	--	500	--	14.0	--	--	86.0	--	--
3/11-5*	Raw refuse (as received)	91.0	--	2,000	--	87.4	--	--	12.6	--	--
3/11-6	Lights from Run 3/11-5	76.0	--	500	--	3.0	--	--	97.0	--	--
3/12-1	Heavies from Run 3/11-4	15.0	--	1,000-1,200	--	65-70	80	--	30-35	20	Rasp-A
3/12-2	Lights from Run 3/12-1	10.0	--	800	--	56.0	62	Rasp-C	44.0	38	Rasp-B

*Moisture contents: Run 3/11-1, 45%.
Run 3/11-5, 50%-55%.
†Designations in column assigned by St. Regis.

TABLE 23

AIR CLASSIFICATIONS CONDUCTED ON LOS ANGELES REFUSE

Run Number	Feed	Weight of feed sample (lb)	Bulk density of feed sample (lb/cu ft)	Column's air velocity (fpm)	Feed rate (lb/min)	Light overhead fraction: Percent of feed by weight	Light overhead fraction: Bulk density (lb/cu ft)	Light overhead fraction: Sample taken for St. Regis analysis of paper content*	Heavy bottom fraction: Percent of feed, by weight	Heavy bottom fraction: Bulk density (lb/cu ft)	Heavy bottom fraction: Sample taken for St. Regis analysis of paper content*
4/6-2	Synthetic dump stock	18.0	2.0	600	0.5	55.0	--	2-L	45.0	--	2-H
4/6-3	Synthetic dump stock	18.0	2.0	900	0.7	67.0	--	3-L	33.0	--	3-H
4/6-4	Synthetic dump stock	8.0	2.0	1,100	1.4	65.0	--	--	35.0	--	--
4/6-5	Synthetic dump stock	22.0	--	800-900	1.0	56.0	--	5-L	46.0	--	5-H

*Designations assigned by St. Regis.

TABLE 24
AIR CLASSIFICATIONS CONDUCTED ON CINCINNATI REFUSE

						Light overhead fraction			Heavy bottom fraction		
Run Number	Feed	Weight of feed sample (lb)	Bulk density of feed sample (lb/cu ft)	Column's air velocity (fpm)	Feed rate (lb/min)	Percent of feed, by weight	Bulk density (lb/cu ft)	Sample taken for St. Regis analysis of paper content*	Percent of feed, by weight	Bulk density (lb/cu ft)	Sample taken for St. Regis analysis of paper content*
4/8-9	Raw refuse	12.0	--	700	2.0	43.5	--	9-L	56.5	--	9-H
4/8-11	Raw refuse	12.0	--	500-600	--	38.0	1.6	--	62.0	5.3	--
4/8-12	Heavies from Run 4/8-11	7.0	5.3	1,800	--	75.0	--	--	25.0	--	12-H
4/8-13	Lights from Run 4/8-12	4.5	--	800	--	39.0	--	13-L	61.0	--	13-H
4/8-16	Wetted raw refuse	11.0	--	500-600	--	25.0	--	16-L	75.0	--	--
4/8-17	Heavies from Run 4/8-16	7.9	--	1,000	--	56.0	--	17-L	44.0	--	--
4/8-18	Heavies from Run 4/8-17	3.5	--	1,800	--	29.0	--	18-L	71.0	--	18-H
4/10-1	Raw refuse	28.5	--	300-400	--	2.0	--	A	98.0	--	--
4/10-2	Heavies from Run 4/10-1	28.0	--	700-800	--	28.0	--	B	72.0	--	--
4/10-3	Heavies from Run 4/10-2	20.25	--	900-1,000	--	14.0	--	C	86.0	--	--
4/10-4	Heavies from Run 4/10-3	17.5	--	1,100-1,200	--	17.0	--	D	83.0	--	--
4/10-5	Heavies from Run 4/10-4	14.5	--	1,200-1,300	--	3.0	--	E	97.0	--	F

*Designations assigned by St. Regis.

chemically pulped paper consisting of approximately equal quantities of bleached material (bleached carton stock, bleached kraft paper toweling, tissue, and writing paper) and unbleached material (board, bag, and general unbleached paper). The overhead fraction also contained some large shreds of film plastic and light styrofoam. At 900 to 1,000 fpm, the overhead fraction still contained small amounts of film plastic and was contaminated by fine dust, glass, and small wood splinters. The proportions of groundwood and chemically pulped papers were essentially reversed from those observed in the 700- to 800-fpm overhead fractions. There was very little corrugated material in this sample.

At a separating velocity of 1,100 to 1,200 fpm, the overhead, paper-containing fraction obtained from the heavy fraction from the 900-to 1,000-fpm run was very similar to the previously obtained overhead fraction, with a decreasing amount of news and an increasing proportion of currugated board. This trend was continued in the light fraction at the 1,200- to 1,300-fpm velocity, the heavy fraction from this run containing almost entirely corrugated stock, contaminated with more than 50 percent (by weight) of shredded metal, wood chips, heavy plastic, glass, and other, similar high-density materials. These contaminants were predominantly of small particle size and probably could have been removed quite easily from the paper by a 2-in. screen. They were also very effectively removed by air classification at 1,800 fpm, as observed in Run 4/8-12 on a sample of the same refuse.

The effect of wetting the refuse feed before separation, tried in the hope that wetting might improve the removal of film plastic, is best demonstrated by Runs 4/9-1 through 4/9-3 and Runs 4/9-4 through 4/9-6 on Albuquerque refuse (Table 25). Essentially the same procedure was followed as that used for the Cincinnati refuse, in which the heavy fractions were successively rerun at higher separating velocities. As expected (compare the light fraction from Run 4/9-4 with the light fraction from Run 4/9-1), a greater proportion of material (18 percent compared with 11 percent) was removed in the dedusting cut, because this cut could be made at a higher velocity without removing excessive amounts of newspaper. Thus, the film plastic contamination of subsequent paper cuts was reduced. The wetted feed material required a somewhat higher velocity (1,000 to 1,100 fpm compared with 900 fpm) to remove the overhead fraction containing newspaper, but the percentages were essentially the same (33 percent and 34 percent, respectively, for dry and wetted feed separations). Both newpaper fractions were slightly contaminated with fine dirt; there was no particular evidence, however, that wetting caused dirt to adhere to the recovered paper. Both final cuts for recovery of kraft and corrugated paper fractions could be made at 1,400 fpm, and recoveries were similar (57 percent dry and 60 percent wetted). The heavy, non paper fraction from the 1,400-fpm separation in both cases contained aluminum, shredded tire fragments, shreds of inner tube, glass, tin cans, and the like.

The air classification procedure described for Cincinnati and Albuquerque refuse appeared to produce better separations than a procedure wherein heavy material was separated initially at high velocity and the overhead from each separation was run at successively lower velocities. (Refer to Runs

TABLE 25

AIR CLASSIFICATIONS CONDUCTED ON ALBUQUERQUE REFUSE

Run Number	Feed	Weight of feed sample (lb)	Bulk density of feed sample (lb/cu ft)	Column's air velocity (fpm)	Feed rate (lb/min)	Light overhead fraction: Percent of feed, by weight	Light overhead fraction: Bulk density (lb/cu ft)	Light overhead fraction: Sample taken for St. Regis analysis of paper content*	Heavy bottom fraction: Percent of feed by weight	Heavy bottom fraction: Bulk density (lb/cu ft)	Heavy bottom fraction: Sample taken for St. Regis analysis of paper content*
4/7-5	Raw refuse	21.5	7.0	1,100-1,200	1.0	56.0	---	---	44.0	---	---
4/7-6	Raw refuse	47.0	7.0	900	7.0	27.0	---	6-L	73.0	---	---
4/7-7	Heavies from Run 4/7-6	34.5	---	1,100-1,200	7.0	22.5	---	---	87.5	---	---
4/7-8	Heavies from Run 4/7-6	34.0	---	1,200-1,300	15.0	14.0	---	8-L	86.0	---	8-H
4/7-10	Lights from Run 4/7-7	7.0	---	850-900	2.3	30.0	---	10-L	70.0	---	10-H
4/9-1	Raw refuse	54.0	---	500-750	---	11.0	---	---	89.0	---	---
4/9-2	Heavies from Run 4/9-1	48.0	---	900	---	33.0	---	---	67.0	---	---
4/9-3	Heavies from Run 4/9-2	32.0	---	1,400	---	57.0	---	---	43.0	---	---
4/9-4	Wetted raw refuse	60.0	---	700-800	---	18.0	---	---	82.0	---	---
4/9-5	Heavies from Run 4/9-4	45.0	---	1,000-1,100	---	34.0	---	---	66.0	---	---
4/9-6	Heavies from Run 4/9-5	27.0	---	1,400	---	60.0	---	---	40.0	---	---

*Designations assigned by St. Regis.

4/8-19(1) through 4/8-19(3) on Johnson City hammermilled refuse.) It appears useful, especially on low-velocity runs, to have heavy fractions in the feed to prevent column clogging by a sort of reflux action. Although not tried, experimental results indicate that the addition of heavy material such as gravel could be beneficial for improving separating efficiency and increasing throughput. The recommendation can be made that, of the two separations needed for isolating a paper-rich middle fraction from domestic and commercial solid waste, separating the light material and then removing the heavy fraction normally will be found most effective.

Regarding removal of the heavy fraction, indications are that the sharp separation provided by air classification may not be required simply to separate heavy contaminants from the corrugated and other strength grade papers left with the bottom product of prior air classifier separations. In the process design of an integrated recovery system, other dry separating methods—such as screening, ballistic techniques, or even a simple air cascade—that have lower separation efficiencies might be acceptable if their costs are sufficiently lower. It will also be desirable to investigate removal of all heavy material initially by air classification (alone or in combination with another method, or methods, that will meet the desired recovery objective) and in subsequent cleaning and separation of the paper fractions by air classification to use synthetic heavy material, such as gravel, for reflux.

A very simple process for paper recovery based on these principles can be visualized in which the shredder serves primarily to break apart the compacted refuse as delivered by packer-type collection trucks, producing a paper component particle size in the 6- to 12-in. range. A screen would be employed to remove the same 6-in. material, which would be largely cans, broken bottles, and dirt. The screen would employ a dust removal system designed so as to remove film plastic also, and the recovered paper would then be air classified for separation into usable grades. If necessary to remove large plastic bottles screened out with the recovered paper mixture, a simple ballistic device could be incorporated as an appurtenance in the air classifier's feeding mechanism.

Conclusions and Recommendations Regarding Air Classification of Municipal and Commercial Waste

Most of the conclusions reached concerned the effect of shredding on separation of municipal and commercial waste by air classification. In addition, certain recommendations can be made regarding future work needed to provide data for the rational design of full-scale air classification equipment. A complete pilot plant that would employ air classification and would operate as a research facility to develop an economical recovery process is visualized as the proper vehicle for accomplishing these further design developments. This research facility might best be incorporated into a demonstration facility in which municipal solid waste was being shredded routinely for landfill, compaction, incineration, or other purposes.

Effect of Shredding. Characteristics of shredded refuse have a predominant effect on the separability of components to be extracted from it for recovery, the process by which recovery can be effected, and often, on the ultimate use to which recovered material can be put. Size characteristics of the shredded municipal refuse samples from Johnson City, Los Angeles, Cincinnati, and Albuquerque were prepared to provide data on the output product (not only for the paper fraction but also for all other components of the refuse) that is representative of the particular type of shredder used. Differences in the overall range of particle size have been discussed previously. Regarding specific materials, it will be useful to note first the similarities in the output product from all four types of shredders and then to note their differences.

Regarding glass, it can be said that any impact mill produces fine particles from a brittle material. All glass was in the minus 1/2-in. size range, most of it reduced to a coarse sand. The rasper produced the largest glass size, with noticeable quantities approximately 1/8 in. in size and some pieces to 3/8 in.

Ferrous metal had been removed from the Johnson City and Los Angeles samples, and so little can be said regarding the performance of the rasper, the rigid-arm Williams, and the Gruendler mills on tin cans. Generally, hammermills shred and crumple light metal into medium-bulk density balls that are in the 1/2- to 1-1/2-in. size range. The large Williams swinging-arm mill, operating without a grate, battered but did not shred most cans in its single-pass reduction of Cincinnati refuse.

Film plastic is a difficult contaminant to remove from recovered paper. Shredder output of this material is, therefore, important. It would be desirable to reduce this material to small fragments and at the same time to produce large-size particles of paper. There was a great deal of film plastic material larger than 1-1/2 in. in the output of all shredders except the Eidal. Although this machine also produced relatively small-size particles of paper, these paper particles were twisted and crumpled, and this condition increased their bulk density and permitted better separations from the small particles of film plastic.

Most of the miscellaneous Group II material (food waste, heavy plastic, yard waste, cloth, and wood) is heavier than paper and appears in the rejected bottoms fraction from air classification. Thus, it is desirable that it be as large a particle size as possible. All shredders appeared to deliver a large quantity of this material in the less than 1/2-in. size range. With the exception of the rasper products the amounts delivered represented essentially the total quantity of such material.

It is difficult to identify the origin of individual particles of paper in a shredded refuse sample. This was done, however, by St. Regis Paper in their proprietary studies on air-classified fractions of paper separated from municipal refuse. In the SRI study, an attempt was made to estimate from the general appearance of a sample the relative amounts of four different categories of paper products present in three different size ranges, after shredding. There was little apparent difference in the behavior of different types of paper in a given mill. The size distribution and the nature of the shredded material were generally the same for all types of paper products. An exception was noted, however, in the case of newspaper shredded by the Williams mills: because they were being operated without bar grates or discharge screens, both the rigid-arm and swinging-arm mills passed large pieces of folded newspaper that had been torn to only one-half or one-third of their original size.

The following conclusions were reached regarding the effect on air classification of the five methods of shredding employed.

1. The method of shredding has little effect on the separation velocities for which a full-size air classification column would be designed, because a considerable degree of operating flexibility must be provided.

2. The method of shredding has little effect on the separation of heavy materials from the paper fraction.

3. The method of shredding influences the separation of film plastic from paper. Separation is more effective when the material is wetted before shredding and when the shredding action is of the rasp type or by roller-bit hammers, as in the Eidal mill.

4. The method of shredding may have an influence on cleanliness of the paper fraction and ability of air classifications alone to produce a product that can be inexpensively cleaned by wet screening after repulping. It appears that the Williams hammermills have some advantage in this respect.

5. The methods of shredding investigated apparently do not have significant influence on paper separations that can be effected by air classification, which in any case are not complete but should rather be regarded as "beneficiations." Sharply sheared edges are not essential when paper fragments are large. Excessive recirculation in a shredder is, however, to be avoided since it produces a "dry pulped" paper product. There is indication that the rigid-arm hogger used by paper balers may produce a paper fraction that can be most easily separated, but the feed sample shredded in this type of unit for experimentation with the air classifier contained only the paper fractions of refuse, and so these observations are not conclusive.

Public Health Service Report No. 1908[6] presents cost and performance characteristics of equipment for various unit operations involved in refuse processing. It does not, however, provide a basis for estimating the characteristics of various components of mixed municipal solid waste when the waste is shredded by mills employing different grinding principles. It would be desirable to determine for a given mill the effects on product characteristics of rotating speed, grate or screen size, and feed rate to the mill in order to be able to specify the grinding principles to be employed or the characteristics desired in the shredded product. Because of the empirical nature of the problem, apparently only full-scale tests would yield significant information. A program of this sort might be set up with the cooperation of interested shredder manufacturers as a follow-on study.

Scale-Up Considerations. Once satisfactory separation has been achieved at either laboratory or pilot scale, the single most important factor in scale-up to commercial-size operations is the permissible column loading. Satisfactory separation of wastepaper from municipal refuse was not obtained in the laboratory unit, but it was achieved in the pilot unit. In addition, some information was developed on column loadings in pilot-unit experiments; however, data from which to draw general conclusions were insufficient.

Column-loading data abstracted from Tables 21 through 25 are summarized (Table 26). The calculated column loadings all represent feed rates at which satisfactory column operation was being achieved. With the exception of Run 4/7-5 on Albuquerque refuse, all loadings are believed to be near the maximum that could be used for design purposes. From these data there appears to be some correlation between allowable column loading and feed bulk density for material similar to municipal refuse.

Intuitively, it is believed that an expression might be developed for feed rate, w (lb/min per sq ft of throat area), in terms of column air velocity, V (fpm), and bulk density, BD (lb/cu ft), of the form:

$$w = K. V. (BD)$$

where K is a dimensionless constant related to the experimentally determined column loading. Such an expression would be dimensionally correct. Bulk

TABLE 26

SUMMARY OF COLUMN-LOADING DATA FROM TABLES 21 THROUGH 25

Source of refuse, Run Number	Feed material	Column's Air Velocity–V (ft/min)	Feed rate–w (lb/min/ft² of throat area)	Estimated feed bulk density–BD (lb/cu ft)	Calculated loading (lb solids/lb air)
Johnson City (rasp)					
3/11-3	Raw refuse, air dried	1,500	30.0	10.9	0.27
Los Angeles					
4/6-2	Synthetic dump stock	600	1.0	2.0	0.02
4/6-5	Synthetic dump stock	800-900	2.0	2.0	0.03
4/6-3	Synthetic dump stock	900	1.4	2.0	0.02
4/6-4	Synthetic dump stock	1,100	2.8	2.0	0.03
Cincinnati					
4/8-9	Raw refuse	700	4.0	4.0-5.0	0.08
Albuquerque					
4/7-6	Raw refuse	900	14.0	7.0	0.21
4/7-5	Raw refuse	1,100-1,200	2.0*	7.0	0.02
4/7-7	73% bottom fraction from Run 4/7-6	1,100-1,200	14.0	8.0-10.0	0.16
4/7-8	73% bottom fraction from Run 4/7-6	1,200-1,300	30.0	8.0-10.0	0.32
4/7-10	22.5% overhead fraction from Run 4/7-7	850-900	4.6	2.0-3.0	0.07

*Low feed rate to check efficiency of separation.

density is, however, an extremely unreliable parameter as presently determined for refuse. A more usable empirical expression for feed rate should be achievable with additional experimentation employing other parameters of greater precision that are functions of shape, size, and physical properties of the refuse particles.

Work with rational design formulas should be included in any future program of research on air classification. Such research would be desirable to investigate basic separation relationships for predicting not only allowable feed rates but also separation efficiency as related to feed rate and the number of stages above and below the feed point; column appurtenances more suitable to high-capacity columns than the rotary, airlock devices used as airseals for the feed and overhead discharge streams; and similar design variables.

Possible Role of Air Classification in Processing Solid Wastes

Supplemental Equipment Needed for Mechanical Processes of Solid Waste Reclamation

Air classification alone is a complete separation process only for certain specialized operations, such as the cleaning or density grading of seeds. For many product separations it is necessary to prepare a material to some extent before it is classified. For solid wastes, these preparatory steps are likely to be shredding, screening, and drying.

Shredders. Research results confirm the importance of shredding to successful air classification. The problem of interpreting laboratory results is related to the scale of the operation, since wastes must be shredded to a considerably smaller size for laboratory processing than for commercial processing. Some manufacturer's literature was obtained on shredders recommended for, or presently being used on, solid wastes, and a report on one shredding project[14] being conducted under Federal solid waste program sponsorship was reviewed. This information was supplemented by readings[15] in the current literature and communication with compost plant operators who were shredding domestic solid waste. The purpose was to obtain a better understanding of the scale-up problem related to shredding and to develop costs that might be useful in preliminary assessments of economic feasibility. The information obtained on shredders is summarized (Table 27).

TABLE 27

SUMMARY OF DATA OBTAINED ON COMMERCIAL SHREDDING EQUIPMENT FOR MUNICIPAL WASTES*

Manufacturer	Shredder designation	Operating or rated Capacity (tons/hr)	Horsepower	Weight (lb)	Equipment Cost	Total estimated operating cost (dollars/ton)
Gondard	Hammermill	5-10 (operating; less than capacity)	150 (estimated)	--	$127,000 (includes conveyors)	$2.00-$6.00 (test operation) $1.00-$1.50 (estimated for production operation)
Eidal International	SW-200 shredder	80 (rated)	1,400 or 2,000	200,000	--	--
	SW-100 shredder	40 (rated)	700 or 1,000	100,000	$100,000	--
	SW-20 mini-mill	3 (rated)	80	7,000	--	--
Centriblast Corporation	Crusher-disintegrator (Joy, Model CDM 4830HD)	20 to 100 (rated)	300-1,500	--	$40,000 and up without motor $70,000 for 20 ton/hr unit at Gainesville, Florida	$1.00-$1.50, exclusive of maintenance, at Gainesville, Florida (high maintenance cost reported)
Williams Patent Crusher & Pulverizer Company†	Hammermill, Model 475 GA (primary)	60 (operating)	500	37,000	$50,000	$0.65 (operation) $0.10 (maintenance)
	Hammermill, Model 80 GA (secondary)	50	300	21,000	$30,000	$0.50 (operation and maintenance)
Francis & John S Trace Company	Lanway pulveriser (hammermill)	40-50	450	44,800	$100,000	--

(Continued next page)

TABLE 27 (Concluded)

SUMMARY OF DATA OBTAINED ON COMMERCIAL SHREDDING EQUIPMENT FOR MUNICIPAL WASTES*

Manufacturer	Shredder designation	Operating or rated capacity (tons/hr)	Horsepower	Weight (lb)	Equipment cost	Total estimated operating cost (dollars/ton)
American Pulverizer	Hammermill	Recommended for municipal wastes only if sorting could be accomplished prior to grinding				
Von Roll, Ltd.	Bulky waste crusher (Jaw shear)	15	50	89,600	$90,000	--
The Heil Co.	Tollemache (vertical hammermill with ballistic rejection)	15	200	--	$75,000	--
Jeffrey Mfg. Company	G-28-B garbage grinder (wet hammermill)	50-60	200	28,000	--	--
Jeffrey Mfg. Company	Impact crusher (hammermill)	80-1,000	75-1,250	14,900 110,500	--	--
Koehring Co.	Fox heavy-duty forage harvester (reel-type shear)	80	15-150	--	--	--
The Pettibone Companies	Bulldog refuse shredder	35 (rated)	--	--	--	--
Gruendler Crusher and Pulverizer Co.	Stationary and portable refuse-pulverizing plants	15 to 300 (rated)	--	--	--	--

*See also Waste volume reduction by pulverisation, crushing, and shearing. Paper presented by P.K. Patrick, Department of Public Health Engineering (Refuse Disposal Branch). Greater London Council, at the 69th Annual Conference of the Institute of Public Cleansing (British), June 1967.

†Data from Metro-Waste compost plant, Houston, Texas, and from San Diego, California, study of refuse baling.

With the exception of Eidal and Von Roll machines and the reel-type agricultural product chopper, all the shredders identified in Table 27 appear to be versions of conventional hammermills. The Eidal mill is reported to be a vertical-shaft, roller-bit shredder. The Gondard and Tollemache units are claimed to incorporate an effective method of heavy metal separation by ballistic action.

Estimated shredding costs claimed are found to be comparable with those reported in the APWA rail haul study (80¢ per ton minimum), the USPHS Fresno, California, solid wastes management project ($0.90 to $1.40 per ton), and shredding costs estimated in connection with the San Diego, California, refuse baling transfer station. The latter costs are based on actual cost experience at the Lone Star Organics (Metro-Waste, Inc.) composting plant in Houston, Texas. At this location, shredding costs that initially were as high as $2.00 per ton have been reduced to approximately 65¢ per ton by improving maintenance practices, increasing throughput, and decreasing the time between shutdowns. The current target at this plant for secondary shredding costs is 35¢ to 40¢ per ton.

Screens and Driers. Information on available screens and driers can be obtained from References 1, 2, and 3. The type of lightweight, low-cost equipment developed for cleaning and drying of cotton may have application to processing of municipal wastes. In particular, the reel-type cleaner-drier for seed cotton appears to be well suited to the removal of fine material prior to air classification and to be economical, in that it can also be used for drying when needed.

Scale-Up Procedure

The theory of air classification has already been discussed briefly. In the discussion of the test program, mention was made of factors that influence the performance of an air classification unit. These factors are elaborated (Table 28), both those related to the material being processed and those related to the variables in column operation. Moreover, the units of measurement used in this report are given and certain qualitative effects associated with various factors are indicated (Table 28).

Because of the empirical nature of the relationships among the factors that influence air classifier operation, it is necessary to establish experimentally those relationships of importance for any desired separation. This involves (1) determination that the mixture of materials can be processed satisfactorily and (2) establishment of the degree of separation that is desirable or possible. When a satisfactory separation has been achieved at small scale, it is then possible to expand the operation to the scale at which commercial processing is contemplated.

For compost, both requirements could be satisfied; the material could be handled in the laboratory unit and, by comparison with other acceptable compost materials (such as dried sewage sludge and dairy manure), performance criteria for the quality requirements of commercial separation could be approximated. Thus, it was possible, on the basis of results obtained in this study, to estimate the performance of a full-scale plant for compost processing. A process flow diagram for a 30-ton/hr plant is presented on page 57. Calculations for this flow diagram were based on the scale-up factors given (Table 29).

As an example of scale-up procedure, the follow-

TABLE 28

LIST OF FACTORS AND RELATIONSHIPS OF IMPORTANCE IN AIR CLASSIFICATION

Factor	Units	Remarks on qualitative effects
Material being processed		
Bulk density		
Feed	Lb/cu ft	Often not determined for pilot column operation. Column loading is more important operating parameter
Overhead		
Bottoms		
Particle size		
Feed	Max and min sieve sizes	
Overhead		
Bottoms		
Particle gradation		
Feed	Percentage passing and retained on sieves of various sizes	
Overhead		
Bottoms		
Particle shape		
Feed	Length/diameter ratio	Influences column clogging due to "bridging"
Overhead		
Bottoms		
Moisture content		
Feed	Percentage, by weight	Drying can be effected by using heated air; air recirculation is possible
Overhead		
Bottoms		
Tendency to agglomerate	--	Squeezing, in feed mechanism, and impacting or electrostatic charges, in column, may produce sticky surfaces on material that cause particle agglomeration or surface buildup. Overshredding of fibrous materials also causes agglomeration
Feed	--	
Overhead	--	
Bottoms		

(Continued next page)

TABLE 28 (concluded)

Factor	Units	Remarks on qualitative effects
Column operation		
Fluidizing velocity	Superficial velocity, cfm/throat area	Most important parameter. Must be maintained for scale-up.
Column loading	Solids-to-air ratio, (lb solids/lb air)	Important factor in column capacity. Varies between 0.2 and 0.8 for light materials. May be as low as 0.02 for shredded paper.
Effectiveness of separation	Overlap in particle gradation between overhead and bottoms	Close separations require light column loadings
Column capacity	Lb/hr	Related directly to maximum possible loading at acceptable separating effectiveness
Column pressure drop		
No load	In. of water	Characteristic of column
At given loading	In. of water	Depends on solids-to-air ratio

ing calculations are presented for a 30-ton/hr classifier for use on compost:

Quantity to be processed	
Stockpile material	30 ton/hr
Dried material	20 ton/hr
Compost bulk density	
Stockpile at 80% -100% moisture content	32.7 lb/cu ft
Stockpile air dried to approximately 20% moisture content	19.0 lb/cu ft
Quantities to be air classified (see Figure 4)	
Coarse screenings	42.5% x 20 ton/hr = 8.5 ton/hr
Middlings	27.5% x 20 ton/hr = 5.5 ton/hr
Fluidizing velocities (from laboratory column results)	
Dedusting of coarse screenings	550-600 ft/min
Separation of middlings	850-900 ft/min

Required air quantities

Coarse screenings: 8.5 ton/hr = $\frac{8.5 \times 2{,}000}{60}$ = 284 lb/min

284 lb/min ÷ 1.0 lb solids/lb air = 284 lb air/min

284 lb air/min ÷ 0.075 = 3,790 cfm air

Middlings: 5.5 ton/hr = $\frac{5.5 \times 2{,}000}{60}$ = 183 lb/min

183 lb/min ÷ 0.8 lb solids/lb air = 229 lb air/min

229 lb/min ÷ 0.075 = 3060 cfm air

Required throat cross sections

Coarse screenings: $\frac{3{,}790 \text{ cfm}}{550}$ = 6.9 sq ft = 994 sq in

Middlings: $\frac{3{,}060 \text{ cfm}}{850}$ = 3.6 sq ft = 518 sq in

TABLE 29

SCALE-UP FACTORS
BASED ON DATA OBTAINED WITH LABORATORY AIR CLASSIFIER

	Ratio or Unit	Remarks
Throat ratios		
Total area	Throat area of prototype/throat area of pilot unit	Column capacity scale-up factor
Column width	Width of prototype/width of pilot unit	Variable, to give desired column capacity at necessary fluidizing velocity
Throat width	Throat of prototype/throat of pilot unit	Variable, widening throat increases column height. Actual prototype throat width determines maximum particle size (oversize) that can be fed
Column height ratio	Height of prototype/height of pilot unit	Geometrical scale-up; wider throat requires taller column for same number of flow reversals or "plates." Reduced number of effective "plates" reduces separation efficiency
Flow ratio	Cfm of prototype/cfm of pilot unit	Numerically the same as throat area ratio, since same superficial velocity must be maintained
Pressure drop	In. of water	For same throat velocity and loading, column pressure drop of prototype is *same as for pilot unit. Add approximately* 2-in. water for prototype cyclone
Power requirement	Horsepower	Calculated from prototype blower cfm and pressure drop. Not determined for pilot unit

(Use 12 in. x 82 in. for coarse screenings and 8 in. x 65 in. for middlings.)

Column height for 8-in. throat width

$8 \div 2 \times 42$ in. (height of laboratory column) = 168 in. = 14 ft for 12-stage unit (8-stage unit would be two-thirds this height)

Pressure drop and blower horsepower requirements

Column pressure drop	0.6 in. of water (from lab column results at 1.5 x $\Delta\rho$ for air only)
Cyclone separator pressure drop	*1.4 in. water* (estimated)
Total pressure drop	2.0 in. water

Blower horsepower for 3,790 cfm at 3-in. static pressure = 4.0 hp

Middlings

column pressure drop	2.0 in. water (from lab column results at 1.5 x $\Delta\rho$ for air only)
Cyclone separator pressure drop	*2.0 in. water* (estimated)
Total pressure drop	4.0 in. water

Blower horsepower for 3,060 cfm at 4-in. static pressure = 3.4 hp

For automobile body waste, only one of the conditions required for scale-up was satisfied. The waste could be separated satisfactorily in the small laboratory column, but no information was provided on the beneficiated feedstock requirements for subsequent processing for nonferrous-metal recovery. Determination of these requirements was outside the scope of this research. Consequently, the process flow diagram (Figure 10), though typical of a recovery process employing air classification, would require additional laboratory work to optimize the separations in a particular crushing method and with a specified objective for nonferrous-metal recovery.

Experimentation with the recovery of wastepaper stock from combined refuse did not produce satisfactory separation in the laboratory air classification unit, because of the combined problems of shredding and the small throat size of the laboratory unit. Special scale-up difficulties are created when it is not possible to classify a material that is of the same particle size and aerodynamic characteristics as those that will exist in the full-scale prototype equipment. If the reduced-size particles can be satisfactorily classified, the fluidizing velocity for the prototype particle size must be estimated from laboratory results and used in calculations of the column's cross section, capacity, air requirements, and horsepower. Whereas theoretical relationships between particle size and density and the terminal velocity are of some assistance in making such estimates,* they are of limited practical usefulness because of the differences (acceleration effects and turbulence) discussed previously. Since satisfactory classification could not be effected, the process flow diagram developed for paper recovery processing is indicative only of the conditions anticipated for a full-size column and larger size particles with more sharply cut edges (relative to the size of particle) than were obtained in the laboratory shredder.

Estimated Full-Scale Performance of Air Classifier Unit in Processing Solid Waste

Compost from Municipal Refuse. Based on the calculations presented previously, two 14-ft air classifiers have been selected for a 30-ton/hr compost plant. The classifier for removing plastic and other light material from the coarse screenings before recycling or bulk sale is an 8-stage unit with a throat size of 12 by 82 in. The column for separating glass and other heavy contaminants from horticultural-grade compost is 12 stage and has a throat size of 8 by 65 in. On each column, 5-hp blowers would be required, but the operating power requirement would normally be less than 7.5 hp for both units. The two columns, complete with blowers and cyclones, would cost approximately $42,500. A complete processing plant would also require equipment for shredding and screening as well as facilities for in-plant materials handling. The makeup of such a plant is shown by the conceptual process flow diagram (Figure 10). This plant would handle 30 tons of stockpile compost per hour at 80 to 100 percent moisture content, after it had been air dried to a maximum moisture content of 20 percent. The actual plant throughput of air-dried compost is 20 tons/hr. When the unit's capacity on air-dried material is used as a base, an estimate of cost suitable for preliminary comparison with other methods of compost processing indicates that the capital investment in such a plant, excluding land, would approximate $5,000/ton/hr capacity in this size range. The plant's operating cost, including depreciation, is estimated to be 50¢/ton (dry basis) for a single-shift operation and 30¢/ton for three-shift operation. Of the latter figure, approximately 20¢/ton is attributable to the cost of shredding.

Automobile Body Trash. The process for nonferrous metal recovery from automobile body trash could not be developed to the extent possible for compost. Experimentation for design of a complete reclamation process was outside the scope of the research program. Air classification runs on automobile body material demonstrated only that close separations could be made; there was no attempt to optimize these separations or to concentrate any particular metallic constituent. The results achieved were, however, sufficient to permit comparisons to be made of conceptual air classification processing with the process currently being employed for ferrous metal separation and a proposed process for nonferrous recovery. Process diagrams are given (Figures 11,12, and 13).

A typical automobile body-shredding operation is diagrammed (Figure 11). Because of air pollution regulations, upholstery and other combustibles cannot be removed by burning before shredding. Consequently, magnetic separation leaves this material in the nonferrous stream. Also as a consequence of not being able to burn is an explosion hazard from the dust resulting from the shredding and all subsequent material-handling operations; this dust must be collected to prevent air pollution as well as to control the explosion hazard.

Air classification could improve the conventional separating process (Figure 12). Magnetic separation is still employed; however, its effectiveness is increased by the prior removal of all fibrous material by air classification, which also eliminates handpicking to remove contaminants such as rags, rubber, and copper

*In actual practice on a larger experimental column, fluidizing velocities would be obtained for separation of several sizes of particles and extrapolated to the prototype particle size.

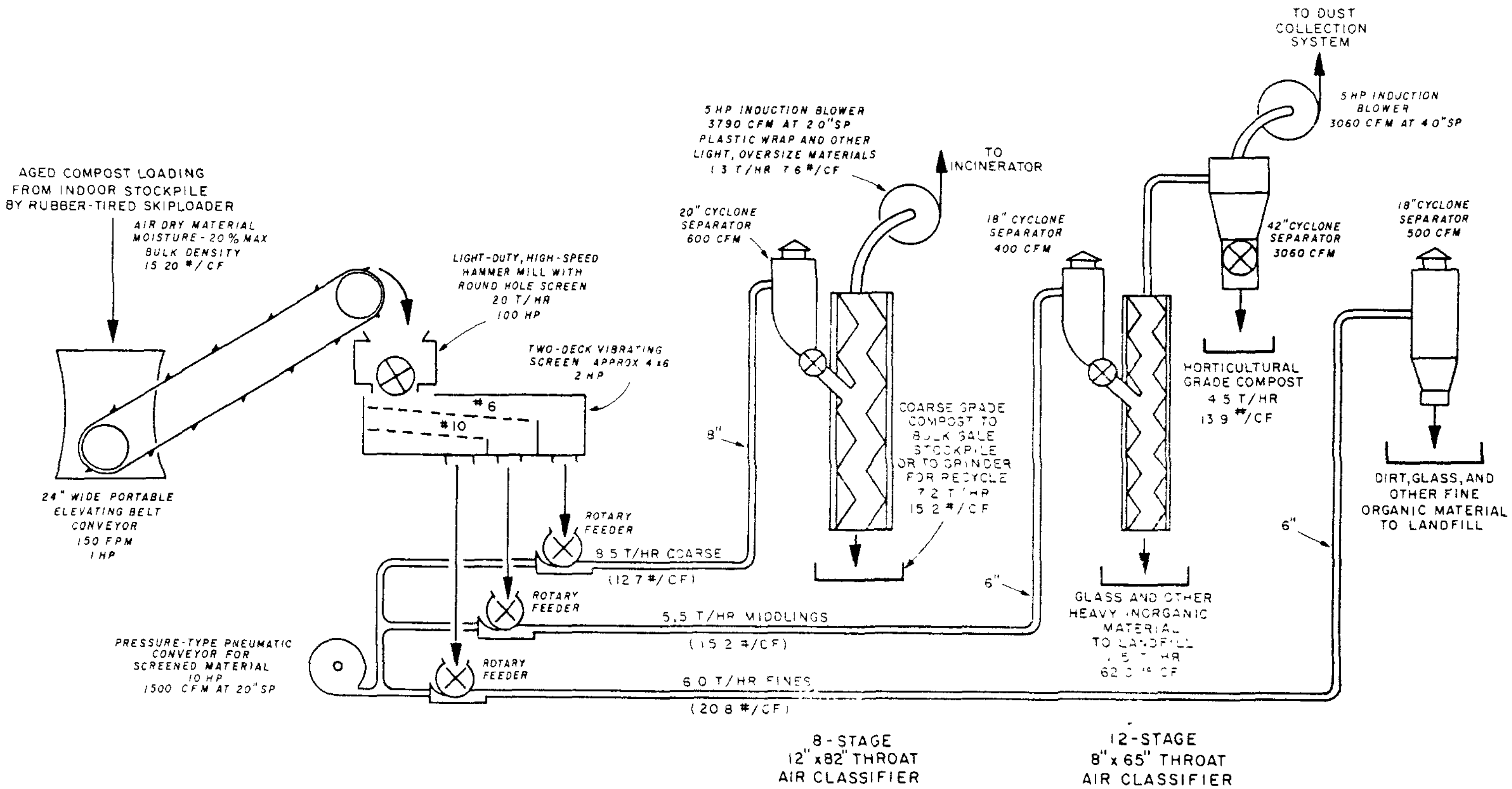

Figure 10. Conceptual process flow diagram: air classification system for production of horticultural-grade compost from aged stockpile material. The 30-ton/hr material from outdoor stockpile (80%-100% moisture) was air dried to 20% moisture for processing. All horsepower requirements are estimates.

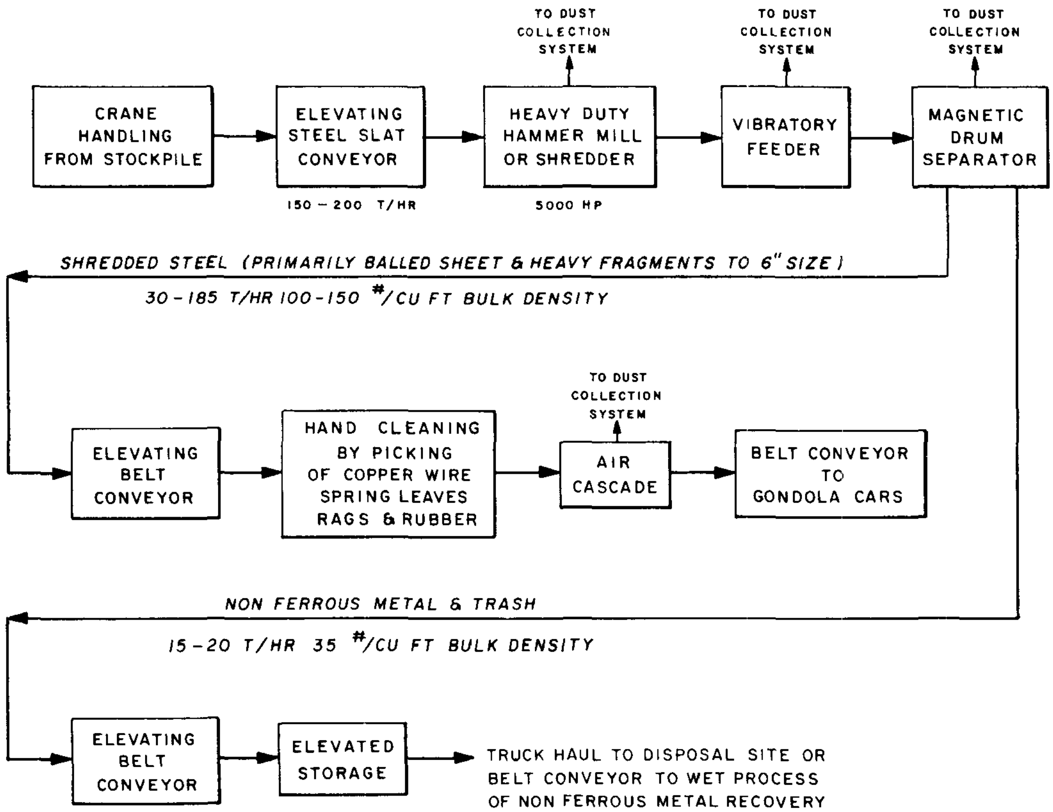

Figure 11. Process flow block diagram: conventional automobile body shredding system.

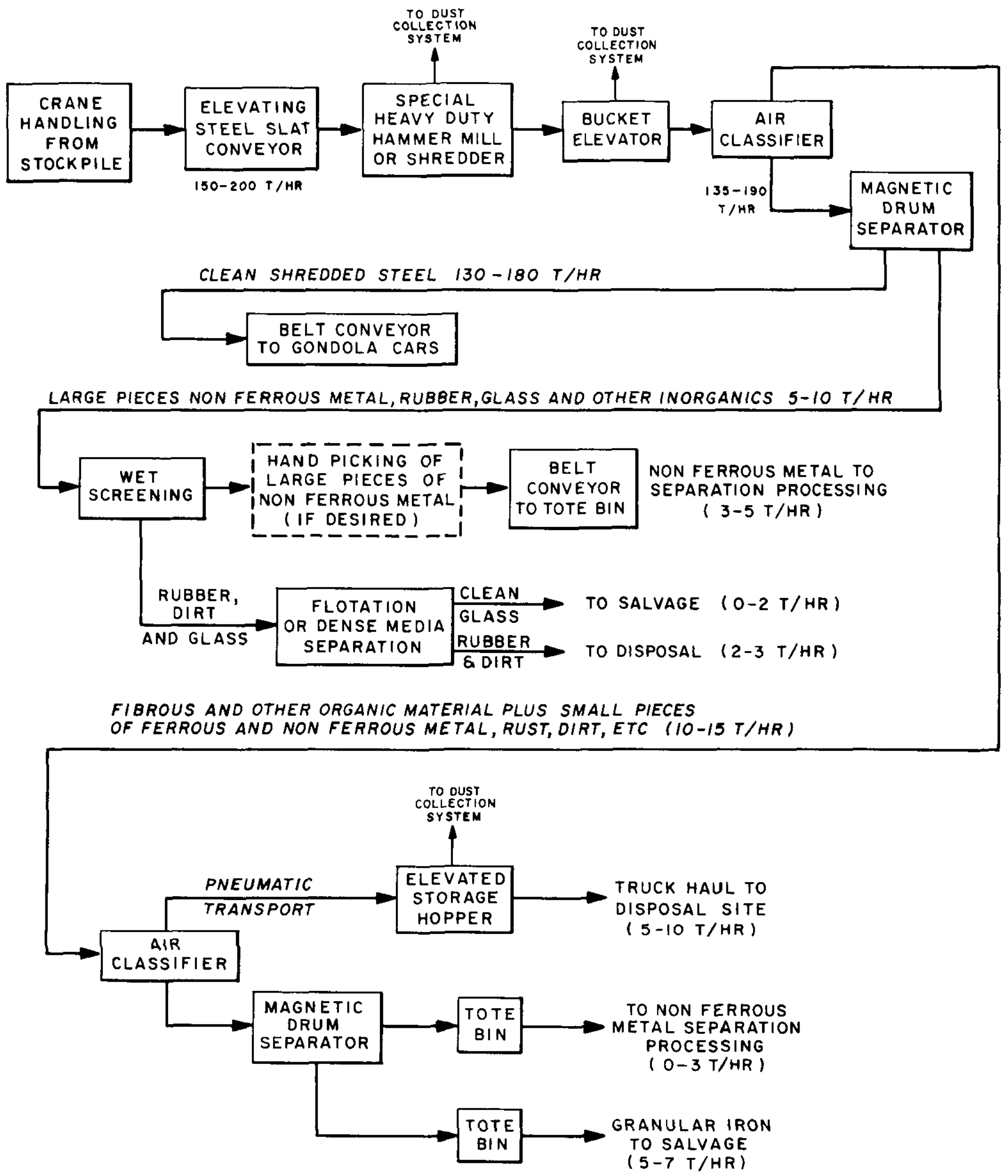

Figure 12. Process flow block diagram: modified system for automobile body shredding employing air classification and including nonferrous metal recovery.

wire. Air classification also more effectively dedusts the ferrous stream than the air cascades frequently employed for this purpose do.

Further advantages of air classification are evident when the processing system is expanded to include the recovery of nonferrous metals. A wet process under construction for separating rubber, aluminum, zinc, copper, and stainless steel from the trash stream currently disposed of to landfill is shown (Figure 13). Even though approximately 15 tons of material is recovered per hour, the weight of material requiring disposal is not reduced (and disposal costs remain unchanged), because the fibrous material has become water soaked in the process. When air classification is employed (Figure 12), the wet screening and flotation is done on a smaller stream of material, and this circumstance reduces the required size of new equipment or increases the capacity of an existing installation. The material for landfill disposal is dry, having been removed by air classification rather than wet screening, and its weight is less by approximately 50 percent.

In summary, advantages of the modified processing system employing air classification are as follows:

It improves efficiency of magnetic separations by removal of fibrous material from magnetic separator feed.

It eliminates handpicking for final cleanup of steel.

It reduces dust content of steel.

It reduces cost of dust collection installation.

It reduces amount of material requiring landfill disposal.

It permits simple, hand salvage operation on larger fragments of nonferrous metal, if desired, by separation from fibrous trash.

It increases capacity of wet screening and flotation equipment.

Municipal Refuse. Because of the size limitations of the laboratory air classification column and the accompanying problems of shredding the refuse to be processed, as discussed previously, it was not possible to demonstrate conclusively that the salvage of a usable grade of paper from municipal refuse was technically feasible. It is believed, however, that a new grade of clean and uniformly shredded paper consisting of mixed newspaper, kraft paper stock, and corrugated cardboard—with little or no styrofoam packing and sheet plastic and only small percentages of paper or paperboard that is highly filled (such as magazine stock) or that contains waterproofing (such as waxed paper, butter cartons, and the like)—could be produced economically on a commercial scale from combined domestic wastes. Such a reclaimed product would have value, and might open up a new market for secondary fiber in the paper industry.

The recycling of wastes can have important effects on waste management costs. In the United States, paper currently accounts for about 50 percent, by weight, of municipal solid wastes. Secondary fiber (wastepaper) represents the second largest supply of fibrous raw material, following wood pulp, for the U.S. paper industry. Between 10 and 20 percent of this paper is now salvaged and reused, according to one source.[16]

On the assumption that there is a market for recycled paper, this same source estimates waste management costs for each level of recycling. In New York City, for instance, where paper not recycled is disposed of with other solid wastes by incineration, subsequent disposal of the incinerator residue being by sanitary landfill, it is estimated that the annual disposal cost for 20 percent recycle is about one and one-half times the cost for 80 percent recycle, a difference of approximately $100 million annually for the New York region.

Another source[17] estimates that, in 1966, 10 million tons of paper stock (wastepaper) were recycled and became raw material for new products. The U.S. Forest Service predicts the volume will reach 17 million tons by the year 2000. Employment in 1958 to collect this material and get it to market involved 10,000 employees with a payroll of $45 million. Wastepaper provides about 25 percent of the raw material for the paper and paperboard industries. The total value of paper stock (wastepaper to consuming mills) is greater than $300 million per year. A beneficial effect on conservation was the fact that 12,800,000 cords (13 million acres) of trees did not have to be cut in 1966, because of the 10 million tons of wastepaper that were used in place of wood (that is, raw material).

Comparative paper reuse in the United States and foreign countries for which data are available is estimated to be:

United States	10% (minimum estimate)
	25% (maximum estimate)
United Kingdom	27%
West Germany	33%
Japan	46%

U.S. prices of wastepaper stock are given (Table 30).

New markets are probably essential for a new recycled paper product because of the quantities involved. The city of Los Angeles, excluding the smaller cities of the metropolitan area and commercial collectors in the unincorporated areas of Los Angeles County, picks up approximately 5,000 tons of domestic waste daily. During the 1970s, a number of municipal transfer stations to serve this area will become justified on the basis of transportation economics alone; the minimum size of the transfer station will be 300 ton/d. Los Angeles basin cities,

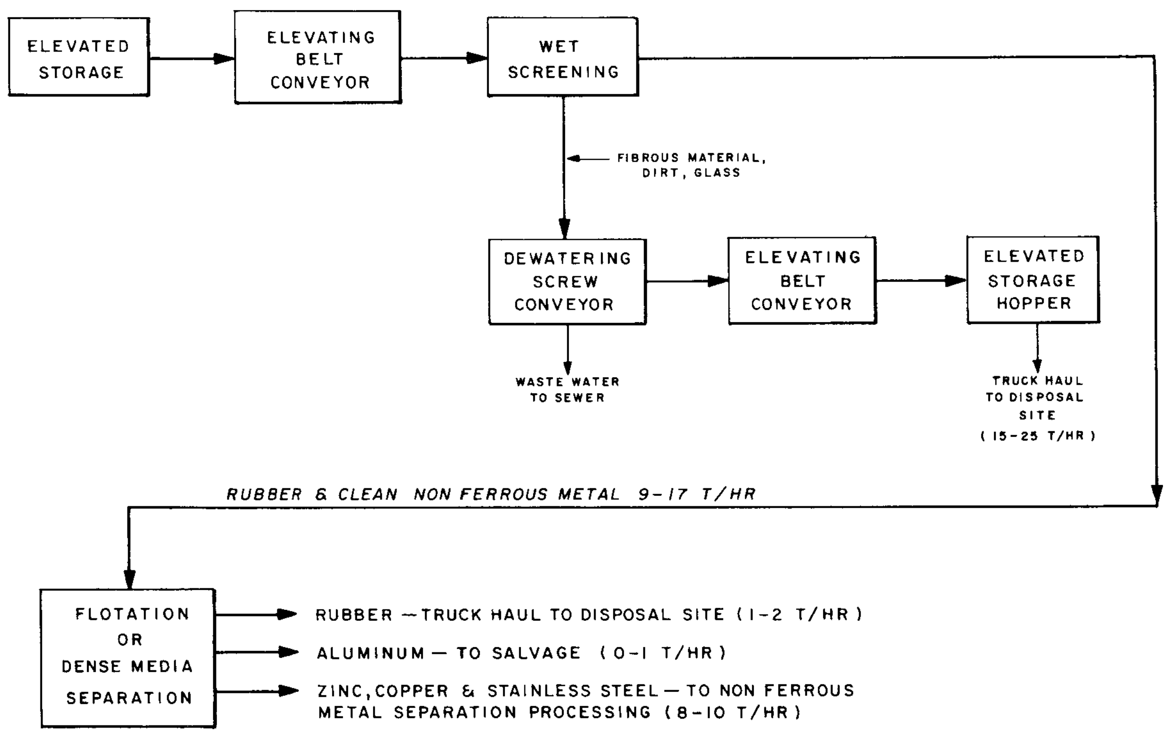

Figure 13. Process flow block diagram: proposed wet system of nonferrous metal recovery from automobile body trash. (For use with conventional automobile body shredding system.)

such as Santa Monica and Beverly Hills, have been operating refuse transfer stations for a number of years. In Orange County, two transfer stations have operated since 1964 and each now processes more than 500 tons/day. A third transfer station recently has been completed. Future expansion of these stations to a capacity of 800 to 1,000 tons/day is possible. Thus, if only facilities already in operation or contemplated in the greater Los Angeles area are considered, a minimum of 3,000 tons of refuse per day will probably be handled through municipally built transfer facilities by 1975. If salvage contractors were to operate these stations under no-cost contracts and process the refuse to recover only 25 percent of the incoming material as mixed paper, an assured supply of 750 tons/day would result. At a price of only $5.00 per ton, the dollar value of the recovered paper would be more than $1 million per year. In addition, Los Angeles and Orange counties and their municipalities would save the present cost of transfer station operation, haul costs would be reduced 25 percent, and landfill life would be extended.

Related Applications

The ease with which noncombustible material can be removed from municipal refuse has been demonstrated in the laboratory. Air classification is being incorporated in the process flow diagrams of the 400-ton/day combustion power unit now under development. This unit will produce electrical power in a gas turbogenerator from solid waste that has been gasified by combustion or pyrolysis in a high-pressure, fluidized bed retort.

When refuse is already shredded, as for composting or fluidized bed combustion, glass, dirt, rubber, metallics, and wood and heavy plastics (which typically represent 20 to 25 percent by weight of municipal refuse) can be removed for less than 10¢ per ton by air classification.* This opens up many possibilities for recovering usable materials such as ferrous metal and glass. It is known that secondary-materials processors are keenly aware of, and are interested in, all developments related to new salvage opportunities. The Sanitary Engineering Research Laboratory of the University of California at Berkeley is interested in salvage as a facet of solid wastes management.[18]

One further application that appears to merit investigation by researchers working with refuse incineration is the removal of heavy materials from the incinerator feed by shredding and air classification. Besides the salvage possibilities that would be created, incinerator operation and maintenance costs might be reduced by such removal. New methods of combustion, such as fluidized-bed and grateless systems employing injection of shredded material by blowers or ram-type packers, become worthy of consideration. In conventional incineration, the recovery of materials from the ashed residue by air classification, though not yet investigated by the Institute or others, appears to offer some promise for economical recovery and reuse of secondary materials.

*The primary air classifier in the pneumatic conveying system between the shredder and the drum dryer of Figure 13 would perform this separating function in any process requiring shredded refuse.

TABLE 30

PRICES (PER TON) OF WASTEPAPER STOCK IN MAJOR U.S MARKETS*

Market	Folded news	No. 1 mixed	Old corrugated	Other grades of paper stock† Number of other grades available	Price range‡
New York	$19.00-$28.00 (3 grades)	$11.00	$13.00-$14.00	36	$2.00-$65.00
Chicago	$16.00-$18.00	$3.00-$4.00	$11.00-$13.00	8	$2.00-$55.00
Boston	$12.00-$13.00	$5.00-$6.00	$15.00-$16.00	None	-
Pittsburgh	$18.00-$20.00	$6.00-$8.00	$16.00-$18.00	15	$5.00-$50.00
Philadelphia	$24.00-$31.00 (3 grades)	$7.00	$16.00-$17.00	11	$2.00-$57.50

**Secondary Raw Materials*, 11 (6): 59, Nov. 1968.

†See Paper stock standards and practices. Circular PS-66, Paper Stock Institute of America. January 1966.

‡Low grade is typically mixed books and magazines, and high grade is either bleached, unprinted sulfite cuttings or No. 1 hard, white envelope cuttings.

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Appendix A

INTERVIEW RECORD FOR SELECTION OF WASTES
TO BE PROCESSED IN PHASE I

APPENDIX A

INTERVIEW RECORD FOR SELECTION OF WASTES TO BE PROCESSED IN PHASE I

Date	Individual and organization	Suggested waste	Remarks
September 4, 1968	Harry Faversham, vice president, and James W. Moberg, chief engineer, Clean Steel Inc., division of National Metal & Steel Corp.	Trash stream from automobile body shredding Municipal waste for steel recovery	Supplied sample of automobile body trash
September 6, 1968	Joseph Edberg, engineer, Pan-American Resources, Inc. (by phone)	---	Interested in separating glass and metal from retort char and in recovering pigments from paint sludge
September 6, 1968	Nathan Berman, industrial waste enforcement engineer, Los Angeles County engineer's staff	Trash stream from automobile body shredding	Suggests grant application to develop automobile body nonferrous recovery process
September 6, 1968	Frank Dair, division engineer, solid waste disposal, Los Angeles County Sanitation Districts	Domestic waste Demolition waste Cabinet shop wood waste	Recovery of cellulose, steel, and wood for paper pulp and rubble for core aggregate
September 10, 1968	Richard P. Stevens, president, Universal By-Products, Inc.	Three municipal waste streams of decreasing quality for paper salvage: Retail store collections Apartments collections Single-family collections	Universal By-Products can supply samples of all three suggested wastes
September 12, 1968	John Gault, project engineer and Henry Giles, refuse superintendent, City of Pasadena	---	Made reference to Los Angeles By-Products
September 13, 1968	Don Hoffman, technical studies coordinator, Fred Meyer and Mike Noe, San Diego Utilities Department Laboratory, San Diego, California	Domestic trash to remove glass, metal, and other incombustible material for better retorting	Made reference to Kelso Kelp Products
September 17, 1968	Robert B. Laursen, senior engineer, Utilities Division Department of Public Works, Sacramento County, California	---	Sacramento County took over collection in northern area of county from contractor as of July 1, 1968
September 17, 1968	Steven Klein and Clark Weddle, University of California at Berkeley, Sanitary Engineering Research Laboratory, Richmond, California	---	Working with Dr. C. Golueke on anaerobic digestion of solid wastes
September 18, 1968	Professor P. H. McGauhey, director, University of California at Berkeley, Sanitary Engineering Research Laboratory, Richmond, California (by phone)	---	Will put SRI on mailing list for field station research reports

Date	Individual and organization	Suggested waste	Remarks
September 18, 1968	Peter A. Rogers, State of California, Department of Public Health, Bureau of Vector Control, Berkeley, California	Shredded municipal refuse for separation of compost and noncompost materials	Suggests contact with SIRA Corp., Los Gatos
September 18, 1968	D. M. Keagy, regional representative, USPHS, solid waste program, San Francisco, California	Airplane salvage Ash from aluminum smelting	Suggests contacting Davis-Monthan Air Force Base, Tucson, Arizona
September 20, 1968	Professor A. Bush, sanitary engineering, University of California at Los Angeles (by phone)	Paper from municipal waste for production of alcohol by fermentation of carbohydrates	Questions economics of shredding and classifying
September 23, 1968,	Jack Betz, assistant director, and C. Imel, research engineer, City of Los Angeles, Department of Public Works, Bureau of Sanitation	Grading of finished compost; initial separation into fractions for composting and retorting, plus uncompostable fraction.	---
September 23, 1968	Tom Conrad and Bob Stearns, Ralph Stone Engineers, Los Angeles, California	Industrial waste probably has greatest potential for economic feasibility	Can supply costs on shredding
September 24, 1968	Frank Bowerman, Aerojet-General Corp., El Monte, California	Industrial waste, paper salvage and compost	Dense compaction is new direction for disposal
September 30, 1968	Paul Maier, Bureau of Vector Control, California Department of Public Health, Fresno, California (by phone)	Agricultural wastes such as nut hulls (i.e., walnuts and almonds)	---
October 14, 1968	Victor Brown, president, Metro-Waste, Inc., Wheaton, Illinois (by phone)	Mechanical extraction of all salvage now handpicked from domestic refuse	Will supply shredded samples from Houston plant of Lone Star Organics
'October 22, 1968	Harry Armstrong, works manager, U. S. Gypsum Paper Mill, Southgate, California	Recovery of clean mixed paper from grades presently purchased	Desires assured supply without metal or plastic contamination; additional cost for clean paper is difficult to justify
October 29, 1968	Jerry Vaughan, plant manager, Lone Star Organics, Houston, Texas (by phone)	Compost separation into salable grades. Salvage and removal of noncompost material from feed to plant	---
November 14, 1968	John Siracusa, president, Sira Corp., Los Gatos, California	Domestic refuse	Sira system does not contemplate salvage; package unit available for burning of pulverized refuse (can be used as drier)

Appendix B

REPORT OF SAN DIEGO UTILITIES DEPARTMENT
ON RETORTING OF AUTOMOBILE BODY MATERIAL

TABLE B-1

RUN NO. 156 (MATERIAL RETAINED ON 1-in. SCREEN)

	Gas data, by constituent						
	H_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	Total
Composition (%)	33.70	20.24	18.60	17.58	5.63	1.71	97.46
Metered gas (cu ft)	2.800	1.682	1.546	1.461	0.468	0.142	8.099
Cu ft gas at standard temperature and pressure	2.539	1.525	1.402	1.325	0.424	0.129	7.344
Gram factor	2.547	20.268	35.385	55.598	35.438	37.985	- -
Mass (g)	6.467	30.908	49.609	73.667	15.026	4.900	180.577
Handbook Btu/cu ft–low	290	963	341	- -	1,631	1,703	- -
Evolved gas (Btu)	736	1,469	478	- -	692	220	3,595

Material pyrolyzed: 2,308 g ÷ 453.59 g/lb = 5.088 lb

Cu ft gas/lb material pyrolyzed = 1.443

Btu/lb material: 3,595 Btu ÷ 5.088 lb = 707

Gas (Btu/cu ft). 3,595 Btu ÷ 7.344 cu ft = 490

Lb gas evolved: 180.577 g ÷ 453.59 g/lb = 0.398

Lb gas evolved/lb material pyrolyzed: 0.398 lb ÷ 5.088 lb = 0.078

Barometric pressure (corrected for elevation): 29.42 in. Hg

Room temperature: 23 C

Volume correction factor to standard temperature and pressure: 0.9069

Mass balance

Pyrolysis products	Amount (g)	Percentage
Inerts*	820.000	35.53
Char†	864.000	37.44
Condensables	400.000	17.33
Gas	180.577	7.82
Total	2,264.577	98.12

Material pyrolyzed. 2,308.000 g

Mass accounted for. 98.12%

*Before calorimetry, pyrolysis residue passed through a No. 25 sieve to remove gross particles of metal and glass. Material retained on No. 25 sieve designated as "inerts" and so shown in Mass Balance.

†Material passing No. 25 sieve.

Pyrolysis residue passing No. 25 sieve

Proximate analysis (moisture-free basis) - ASTM D271-58

Volatile material (%)	9.12
Fixed carbon (%)	19.02
Ash (%)	71.86
	100.00

Calorimetry (Parr bomb)

Heating value (Btu/lb) 3,840

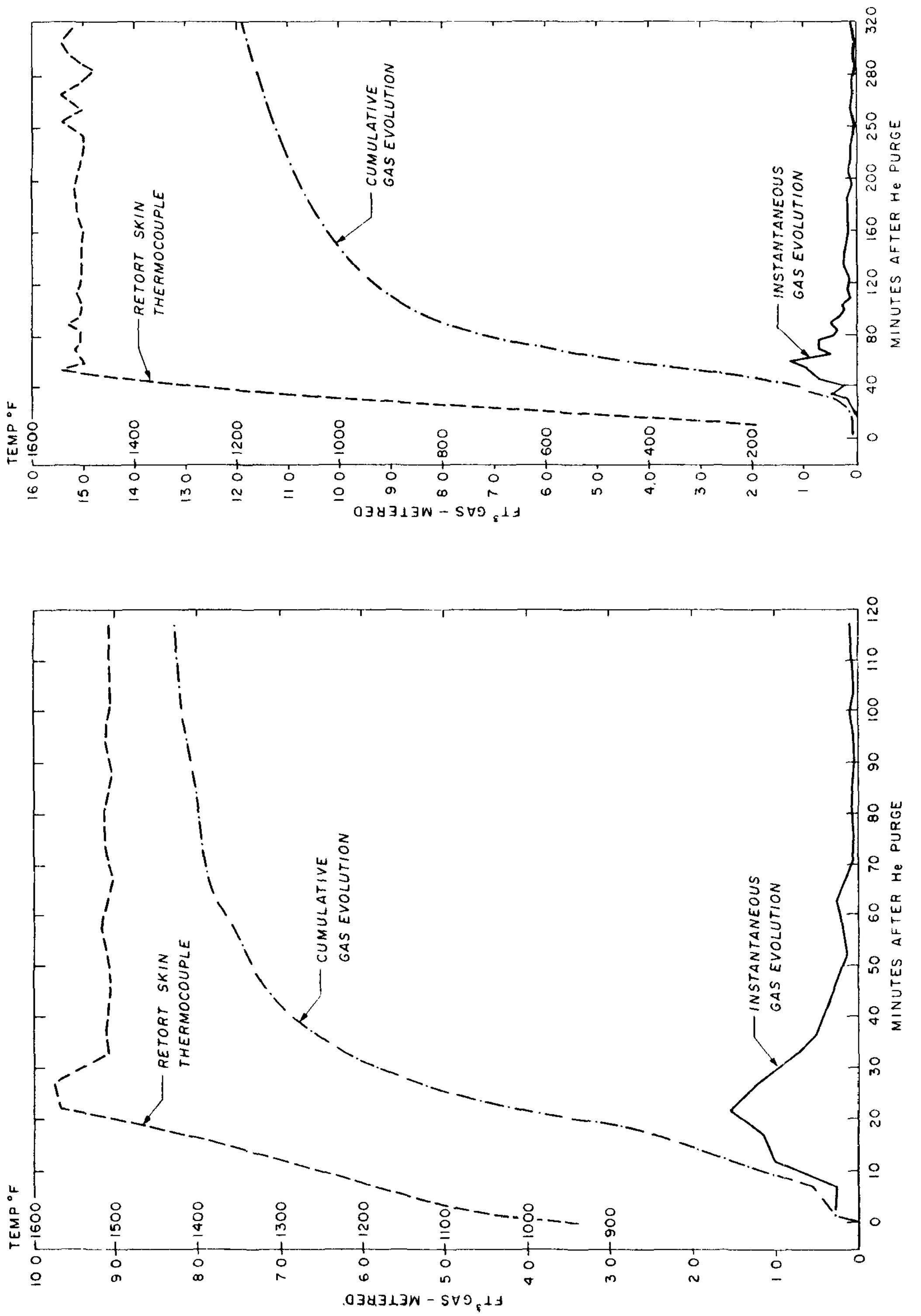

Figure B-1. Material retained on 1-in. screen, Run 156.

TABLE B-2

RUN NO. 157 (MATERIAL PASSING 1-in. SCREEN)

	Gas Data, By Constituent						
	H_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	Total
Composition (%)	37.73	16.55	14.75	22.33	5.86	1.14	98.36
Metered gas (cu ft)	4.490	1.969	1.755	2.657	0.697	0.136	11.704
Cu ft gas at standard temperature and pressure	4.104	1.800	1.604	2.428	0.637	0.124	10.697
Gram factor	2.547	20.268	35.385	55.598	35.438	37.985	--
Mass (g)	10.453	36.482	56.758	134.992	22.574	4.710	265.969
Handbook Btu/cu ft–low	290	963	341	--	1,631	1,703	--
Evolved gas (Btu)	1,190	1,733	547	--	1,039	211	4,720

Material pyrolyzed: 2,770 g ÷ 453.59 g/lb = 6.107 lb

Cu ft gas/lb material pyrolyzed = 1.752

Btu/lb material: 4,720 Btu ÷ 6.107 lb = 773

Gas (Btu/cu ft): 4,720 Btu ÷ 10.697 cu ft = 441

Lb gas evolved: 265.969 g ÷ 453.59 g/lb = 0.586

Lb gas evolved/lb material pyrolyzed: 0.586 lb ÷ 6.107 lb = 0.096

Barometric pressure (corrected for elevation): 29.55 in. Hg

Room temperature: 22 C

Volume correction factor to standard temperature and pressure: 0.9140

Mass Balance

Pyrolysis Products	Amount (g)	Percentage
Char*	1,650.600	59.59
Condensables	455.600	16.45
Gas	265.969	9.60
	2,372.169	85.64

Material pyrolyzed: 2,770 g

Mass accounted for: 86.64%

* Pyrolysis residue

Proximate analysis (moisture-free basis)–ASTM D271-58

	Percentage
Volatile material	5.26
Fixed carbon	2.08
Ash	92.66
	100.00

Calorimetry (Parr bomb)

Heating value (Btu/lb) 1,073

μσ319

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