Bulletin 683

Resource Recovery From Municipal Solid Waste

By Martin H. Stanczyk and Roger S. DeCesare

UNITED STATES DEPARTMENT OF THE INTERIOR
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu/ft³	British thermal unit per cubic foot	hp	horsepower
Btu/lb	British thermal unit per pound	in	inch
Btu/st	British thermal unit per short ton	lb	pound
°C	degree Celsius	lb/ft³	pound per cubic foot
cP	centipoise	min	minute
°F	degree Fahrenheit	oz/st	ounce per short ton
ft	foot	pct	percent
ft³	cubic foot	ppm	part per million
ft/min	foot per minute	psig	pound (force) per square inch, gauge
ft³/min	cubic foot per minute	r/min	revolution per minute
ft/s	foot per second	st	short ton
G	gauss	st/d	short ton per day
gal	gallon	st/h	short ton per hour
g/cm³	gram per cubic centimeter	V dc	volt, direct current
h	hour	wt pct	weight percent
h/d	hour per day	yr	year

RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTE

By Martin H. Stanczyk[1] and Roger S. DeCesare[2]

ABSTRACT

As part of its mission to investigate and encourage recovery and recycling technologies, the Bureau of Mines studied the feasibility of recovering metal and nonmetallic mineral values from municipal solid waste. This bulletin reviews Bureau research conducted primarily between 1966 and 1979, which covered various aspects of recycling municipal solid waste and included operation of both a municipal incinerator residue and a raw (unburned) refuse continuous-separation pilot plant. The report describes the products recovered from incinerated and raw refuse and research in upgrading, refining and/or utilizing the various metal and mineral products. The data are based on approximately 100,000 lb of residues and nearly 1 million lb of raw refuse processed in the pilot plants. Products recovered from incinerator residue included 20 to 30 wt pct ferrous metals, 2 to 3 wt pct nonferrous metals, and 30 to 40 wt pct glass; products from raw refuse included 4 to 8 wt pct ferrous metals, less than 1 wt pct nonferrous metals, 4 to 17 wt pct glass, and 63 to 83 wt pct combustibles. Use of the Bureau's technology at commercial plants in the United States and abroad is briefly described.

INTRODUCTION

Under provisions of the Solid Waste Disposal Act of 1965, the Bureau of Mines initiated a research program in 1966 to develop effective methods for reclaiming and recycling metal and nonmetallic mineral values contained in municipal solid wastes. Early in this work, a high priority was assigned to developing a process for reclaiming materials from municipal incinerator residues. The reasons for this were (1) at the time, there were approximately 300 incinerators operating in the United States, (2) these incinerators were largely concentrated in major metropolitan areas, which meant that large centrally located supplies of residues were available, and (3) the process of incineration results in an ash that is highly concentrated in metals and glass. Within a few years after the research began, a complete process was developed and a ½-st/h pilot plant was constructed for continuous mechanical separation of municipal incinerator residue into metal and glass products.

When development of the incinerator residue recovery process was almost complete, the Bureau turned its attention to developing a companion process for recovering the maximum amount of materials of value from raw (unburned) municipal refuse. Here again, a complete mechanical separation process was developed, and a continuous pilot plant capable of processing refuse at a rate of 5 st/h was constructed.

This report summarizes the results of the Bureau's research studies on municipal solid waste beneficiation, conducted between 1966 and 1979, and includes summaries of other Bureau research on methods to refine and/or utilize various products reclaimed from both incinerator residue and raw refuse.

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INCINERATOR RESIDUES

COMPOSITIONAL STUDIES

Incinerator residue is a complex, soaking wet mixture of metal, charred and unburned organics, and ash containing glass, dirt, and stones. Typical incinerator residue is shown in figure 1. Inasmuch as the exact composition and characteristics of residues were unknown at the beginning of the research, it was first necessary to establish an accurate characterization of the waste. Sampling methods were devised, and residue samples were collected at a number of incinerators operating in Metropolitan Washington, DC (*1-3*).[3] In those facilities built prior to 1960, refuse was burned on traveling grates at relatively low furnace temperatures; hence, as shown in table 1, the residue contained a considerable amount of unburned organic material. Figure 2 shows residue that was hand-separated into its various categories.

[3] Italicized numbers in parentheses refer to items in the list of references at the end of this bulletin.

Figure 1.—Typical incinerator residue.

Rotary kiln incinerators operated at temperatures 400° to 500° F higher than those discussed above, achieved a better burnout, and produced residues having physical characteristics very different from those of residues resulting from lower temperature furnaces. Thus a residue sample was also collected from a rotary kiln incinerator, characterized, and evaluated. Some changes were required in processing techniques in order to make clean separations. Considerable glass and slag were fused to the cans and other metallic parts. Shredding and magnetic separation liberated the iron to produce a clean metal product. Compositional data for the sample obtained from a rotary kiln incinerator are given in table 2.

Table 1.—Average dry weight composition of residue samples from traveling grate incinerators operated at relatively low temperatures[1]

Product	*wt pct*
Tin cans	17.2
Fine ferrous	6.8
Iron wire	.7
Massive iron	3.5
Nonferrous metals	1.4
Stones and bricks	1.2
Ceramics	.9
Unburned paper and char	8.2
Partially burned organics	.7
Ash	15.3
Glass	44.1
Composite	100.0

[1]Average moisture content, 33.4 wt pct.

Table 2.—Dry weight composition of residue sample from rotary kiln incinerator[1]

Product	*wt pct*
Shredded tin cans	19.3
Nonmetallics from shredded cans	6.5
Fine ferrous	10.7
Iron wire	.5
Massive iron	1.9
Handpicked nonferrous metals	.2
Ceramics	.3
Char	3.4
Fines, minus 8 mesh (ash, slag, glass)	35.9
Glass and slag, plus 8 mesh	21.3
Composite	100.0

[1]Average moisure content, 28.2 wt pct.

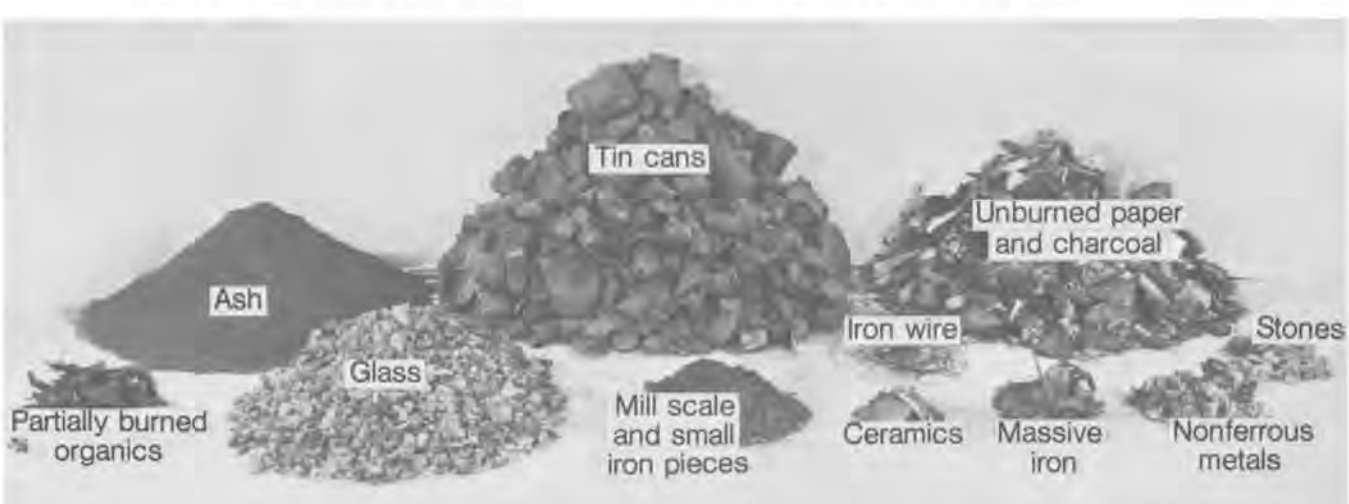


Figure 2.—Breakdown of typical incinerator residue.

Considering the heterogeneous characteristics of residues and the sampling problem they present, the data in both tables were surprisingly similar. The greatest difference appeared in the amount of unburned paper. It is interesting to note that, in table 1, ferrous materials consisting of tin cans, mill scale, wire, and massive iron accounted for about 28 wt pct of the total residue, and nearly one-half of the residue was glass. Metals and glass made up about 75 pct of the total dry weight. By comparison, the rotary kiln residue, table 2, contained about 32 wt pct iron, and much of the glass was present in the minus 8-mesh fraction and arbitrarily listed as fines. This residue had been thoroughly burned, and the amount of charred material was insignificant. When the figures in table 1 were extrapolated to simulate complete burnout, the amount of iron materials increased to about 33 wt pct, comparing favorably with the 32 wt pct found for the rotary kiln residue.

Nonferrous metal content was actually higher than reported in tables 1 and 2, owing to metallics contained in the ash and glass fractions. At the time these studies were made, there was no convenient method for making a clean separation of these particles in the laboratory.

As improvements were added to the continuous mechanical separations made in the pilot plant, samples of residue obtained from about 1972 through 1976 reflected the increased burning efficiency being achieved in new incinerators (*4-5*). Many of the older, low-temperature incinerators had been closed by this time, and residue samples were obtained from a number of new, improved, European-designed incinerators that were constructed and operated in various parts of the country. Much of the glass in the residue was fused into a slag, and many of the cans had oxidized so badly that large areas of the metal were burned through entirely. As a result, the percentages of reclaimed products had changed. As shown in table 3, the ferrous metal and glass fractions typically amounted to only about 20 and 30 wt pct of the residue, respectively.

Results of the composition studies consistently indicated that the mineral values contained in incinerator residues were of sufficient quantity and quality to warrant recovery; therefore, research was directed toward assembling a pilot plant to effectively separate these wastes into viable products for recycling.

Table 3.—Average dry weight composition of additional residue samples from modern incinerators operated at higher furnace temperatures

Product	wt pct
Large ferrous metal	15.0
Fine ferrous	5.0
Aluminum	1.75
Heavy nonferrous metal	.75
Clean glass	30.0
Slag	25.0
Fine ash and tailings from mineral jig and flotation cells	22.5
Composite	100.0

PHYSICAL BENEFICIATION FLOWSHEET

Various combinations of mineral beneficiation techniques were investigated between 1966 and 1979, and approximately 100,000 lb of residues were processed (*6-12*). A flowsheet of the most promising procedure that evolved to recover ferrous metals, nonferrous metals, and glass suitable for recycling is shown in figure 3. The continuous-separation pilot plant that was assembled to process incinerator residues at a rate of 1/2 st/h is shown in figure 4. It should be noted that the process flowsheet was designed on the basis that the residues would contain a minimum of unburned paper, rags, and organic matter.

Residue samples were collected in tared 30-gal drums according to procedures developed earlier (*2*). These were transported to the laboratory and weighed. A continuous feeding system was simulated by dumping the wet residues on a large metal apron and raking the material to a feed conveyor at a nominal rate of 1/2 st/h.

Description

Trommel

The first processing step as shown on the flowsheet (fig. 3) consisted of screening the residue in a 3-ft-diam by 10-ft-long punched-plate trommel having 1-1/4-in-diam holes. The trommel (fig. 5) had internal lifters that improved screening efficiency by imparting a tumbling action to the residue. During screening, the residue was sprayed continuously with wash water. The plus 1-1/4-in material was composed primarily of cans, wire, large iron, and some large pieces of nonferrous metal, paper, glass, and some other nonmetals. This trommel oversize material amounted to less than 25 wt pct of the feed, and constant operator surveillance was required to remove occasional items that could damage equipment downstream in the process.

Primary Vibrating Screen

The minus 1-1/4-in material was screened and washed on a 30-in-diam primary vibrating screen having both 4- and 20-mesh screen decks. The plus 4-mesh material consisted principally of bottle caps, nails, glass, ceramics, nonferrous metals, and slag. The minus 4- plus 20-mesh fraction contained glass, other nonmetals, and fine ferrous and nonferrous metals. The minus 20-mesh material, composed principally of carbon, dirt, some fine glass, other nonmetals, and the wash water, was pumped to the water reclamation system in the pilot plant that is described later.

Hammer Mill

All of the plus 1-1/4-in material, except the more massive pieces of iron, was blended with the minus 1-1/4-in plus 4-mesh fraction. This composite from the primary screening operation was then shredded in a 30-hp hammer mill having 32 swing hammers rotating at a peripheral speed of about 8,500 ft/min. The hammer mill had a discharge grate with 4-in-square openings.

Secondary Vibrating Screen

The minus 4- plus 20-mesh fraction from primary screening was joined with the shredded material, and the combined product was transferred to a secondary screening operation where it was again washed on a 30-in-diam vibrating screen equipped with both 4- and 20-mesh screens. The minus 20-mesh material was pumped to the water reclamation system.

The processing of the plus 4-mesh material will be described next, followed by the processing of the minus 4-plus 20-mesh fraction.

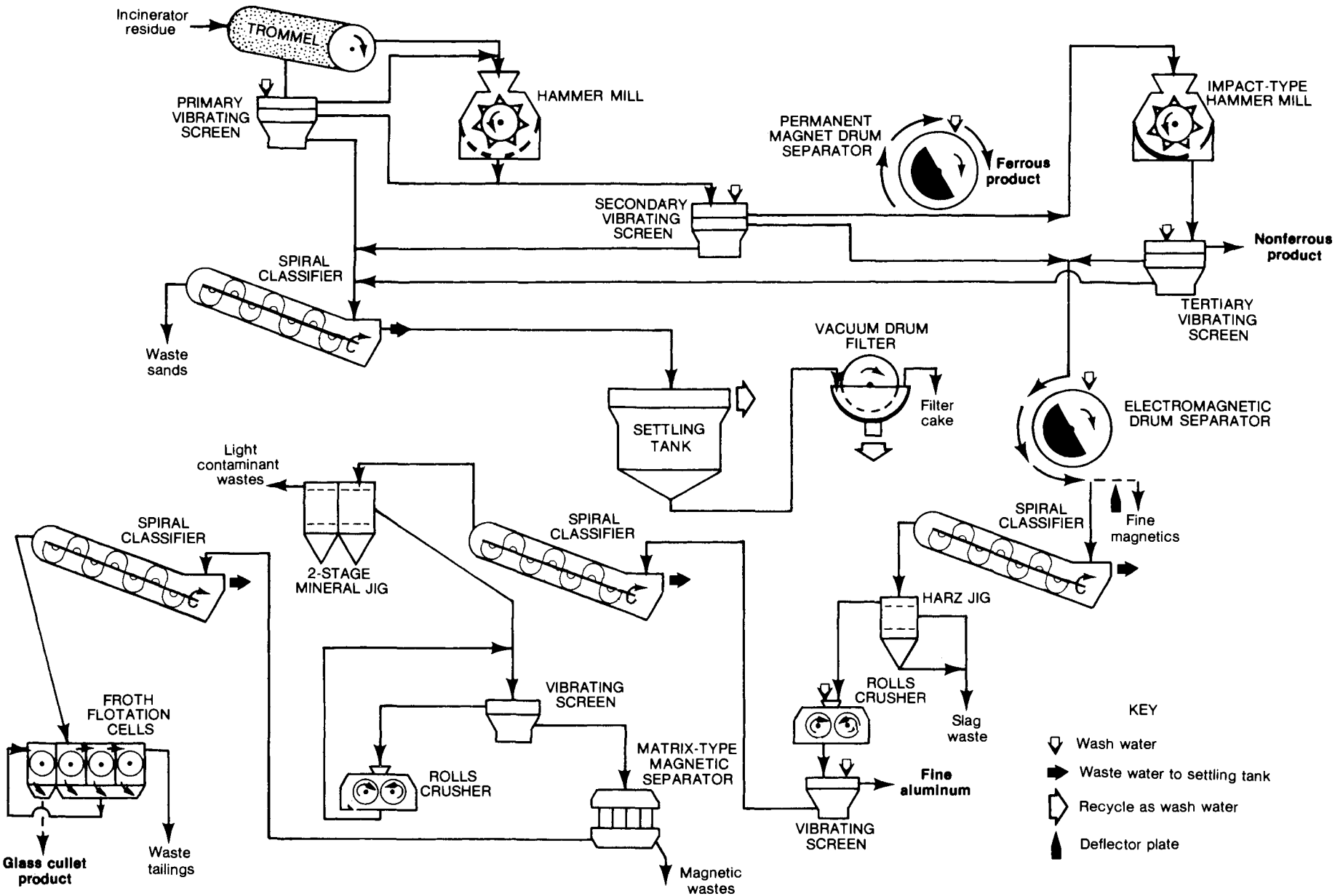


Figure 3.—Incinerator residue processing flowsheet.

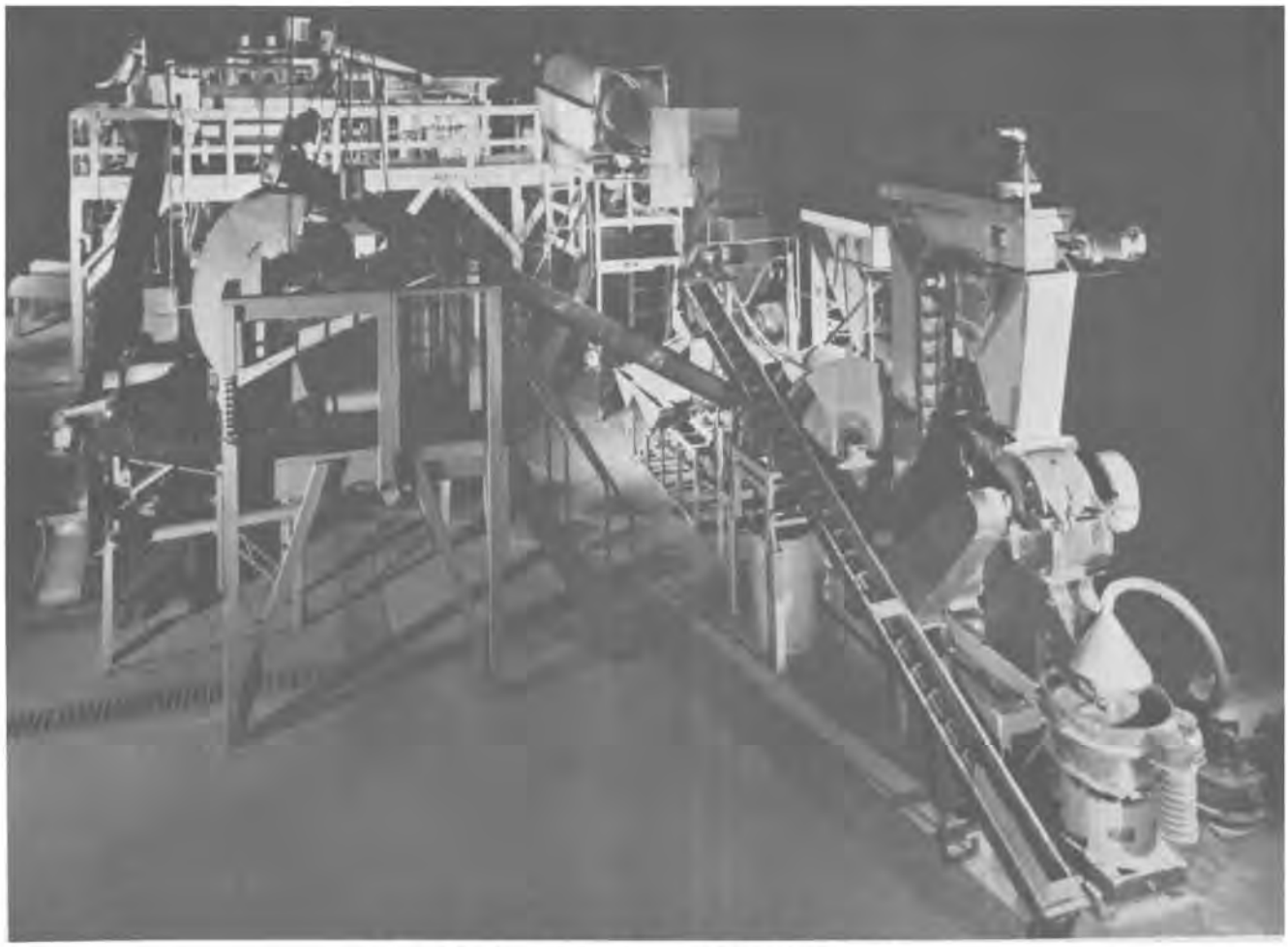


Figure 4.—Overall view of residue processing plant.

Figure 5.—Trommel used for wet-screening incinerator residue.

Permanent Magnet Drum Separator

The plus 4-mesh material was discharged onto a vibrating conveyor that spread out the material and underfed a 30-in-diam by 14-in-wide, alternating-pole, permanent magnet, drum-type separator. The magnetic separator had a field strength of 500 G measured 2 in away from the shell. A water spray gave the material adhering to the magnet a final wash, leaving a clean product.

Secondary Hammer Mill

The nonmagnetic fraction from the magnetic drum separator was composed of relatively large pieces of nonferrous metal, glass, and other nonmetals. To recover the nonferrous metals, this fraction was fed to a 10-hp hammer mill having 20 swing hammers rotating at a peripheral speed of about 8,500 ft/min. The hammer mill, which had only one 2- by 8-in discharge opening, reduced most of the nonmetallics to minus 4 mesh. The mill was modified to operate more effectively as an impact mill by replacing the four rows of swing hammers with four swinging breaker bars.

Figure 6.—Screening and washing nonferrous metals.

Tertiary Vibrating Screen

The mill discharge was screened and washed on a 24-in-diam tertiary vibrating screen having both 4- and 20-mesh screen decks. The minus 20-mesh material was pumped to the water reclamation system. The plus 4-mesh material, shown in figure 6, was recovered as a nonferrous metal concentrate.

After a few years of pilot plant operation, the efficiency of the three vibrating screens was improved by replacing the 4-mesh wire screen decks with punched plate having 1/4-in-diam holes.

Separate Heavy-Medium Tests (not included in flowsheet)

The plus 4-mesh fraction from the tertiary screen represented about 75 wt pct of the recoverable nonferrous metals and, when derived from well-burned residues, contained at least 96 wt pct metallics. A series of tests was conducted in processing the nonferrous metals concentrate in a laboratory-built, heavy-medium separator containing a ferrosilicon-water slurry having a specific gravity of 2.95. Two separate streams exited from the separator: the float product, containing about 96 wt pct aluminum, and the sink product, containing about 50 wt pct copper and 40 wt pct zinc.

Electromagnetic Drum Separator

The minus 4- plus 20-mesh fractions from the secondary and tertiary screens were combined and conveyed to a 30-in-diam by 18-in-wide alternating-pole, electromagnetic drum separator using an overfeed system. The field intensity of this separator was 1,200 G measured 2-in away from the shell. A water spray directed on the drum face washed away nonmagnetic material. The magnetic concentrate was a dense mixture of small ferrous articles (e.g., nails, pins, wire) and highly magnetic slag. The nonmagnetic product, which contained an appreciable quantity of nonferrous metals mixed with glass, ceramics, and other nonmetals, was dewatered to about 60 wt pct solids in a spiral classifier.

Initial Rod-Mill Tests (not included in flowsheet)

In this part of the pilot-plant research, several processing methods were tested and the choice of equipment used was governed to a large extent by the specific market for the glass portions of the residue. Initially, the dewatered solids from the electromagnetic drum separator were ground in a 16-in-diam by 4-ft-long peripheral-discharge rod mill. The glass and ceramics, being friable, were reduced to minus 20 mesh in size by the rod mill, whereas most of the nonferrous metals, being malleable, were flattened. The rod-mill product was washed and screened at 20 mesh on a 24-in-diam vibrating screen to recover a nonferrous metal oversize product. The minus 20-mesh product was deslimed and processed through a wet, high-intensity (3,000 G), matrix-type magnetic separator to remove the fine magnetic slag. As described in the section "Products Recovered From Refuse," the glass product resulting from this process was used to make brick, tile, and rock wool insulation.

Harz Jig

Another method for processing glass was installed in the pilot plant after a series of batch froth-flotation tests showed that high-quality cullet could be obtained from glass-rich aggregates of incinerator residue. To modify the pilot plant for producing cullet-grade glass continuously, the rod mill mentioned above was removed and the minus 1/4-in dewatered solids from the electromagnetic drum separator were fed to a Harz jig where most of the heavy slag was separated from the glass. Fine slag passed into the jig hutch, and coarse slag was discharged from the cup. The two slag fractions were combined into a single waste product. Heavy nonferrous metal accumulated in the jig bed and was removed periodically as a copper-zinc product. Glass, aluminum, and light contaminants were floated from the jig. The float fraction was passed through a rolls crusher and screened on 8 mesh to recover aluminum. The minus 8-mesh material was fed to a spiral classifier to remove unwanted fines. The overflow from the spiral classifier was sent to a thickener in the water reclamation system while the classified fraction was fed to a mineral jig.

Mineral Jig

In this second jig, additional fine slag collected in the hutch. Glass, aluminum, and ceramics discharged from the cup and light contaminants were floated from the jig. The glass recovered from the mineral jig was fed to another stage of rolls crushing followed by screening on 20 mesh to reclaim a small amount of fine aluminum.

High-Intensity Magnetic Separator

The minus 20-mesh material was next fed to the wet, high-intensity, matrix-type magnetic separator. The fine magnetic slag removed by this separator contained appreciable quantities of iron oxide.

Froth-Flotation Cells

The nonmagnetic fraction was pumped to a spiral classifier to remove the minus 150-mesh solids and fed to a series of froth-flotation cells to produce a clean glass cullet product. Amine or diamine acetates derived from coconut

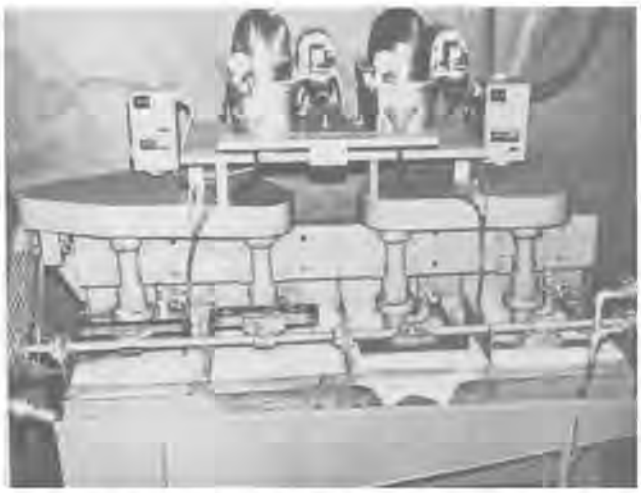


Figure 7.—Continuous flotation cells used for glass recovery.

oil and/or tallow were used as the collecting reagents (*13-14*) in the froth flotation cells shown in figure 7.

Water Reclamation System

This completes the description of the metal recovery portions of the pilot plant and two processing methods for recovering glass. The wash water used throughout the process (fig. 3) received the following separate treatment to remove suspended solids. All minus 20-mesh fractions from the primary, secondary, and tertiary vibrating screens were combined and classified in a 10-in-diam by 7-ft-long spiral classifier to remove slimes and to produce a waste sands product. The waste water then was flocculated and the sediment thickened in a 3-ft-diam by 3-ft-deep settling tank. The settled sludge was filtered on an 18-in-diam by 12-in-wide vacuum drum filter, and clean overflow was recycled as wash water. Both the waste sand and filter cake products contained significant amounts of carbon, alumina, potash, and phosphorus.

Costs

The incinerator residue pilot plant was operated to obtain engineering data necessary for scaling up to commercial size, and several detailed economic evaluations were made of the process (*15-17*). The estimated capital and operating costs of four plant sizes made using mid-1974 cost data are given in table 4. The operating costs, which do not include credits for recovered metal and glass, indicate that incinerator residues could be processed economically using conventional minerals beneficiation procedures.

Table 4.—Estimated capital and operating costs[1] for four incinerator residue plant sizes

Separation plant size (dry feed basis)		Fixed capital cost	Operating cost per short ton of incinerator residue (dry basis)
st/d	h/d		
250	8	$2,337,500	$7.41
400	8	2,792,500	5.40
670	24	2,280,700	4.71
1,000	24	2,630,900	3.46

[1]Based on mid-1974 data.

RAW REFUSE

COMPOSITIONAL STUDIES

In contrast to incinerator residue, which is mostly inert, unburned municipal refuse contains considerable quantities of organics that decompose readily; consequently, all raw refuse samples brought to the Bureau's facilities for evaluating required immediate processing. In addition, all organic products separated from the refuse that were not analyzed or further processed were disposed of within 24 h. Most of the refuse used in the Bureau research was obtained from the Washington, DC, metropolitan area. From 1971 to 1979, over 300 samples weighing 1,600 to 2,600 lb each, representing various segments of the Washington DC, metropolitan area, were collected during different seasons of the year for testing. They were individually processed, and compositional analyses were made.

The composition of individual refuse samples varied widely and was not necessarily indicative of the refuse composition for the municipal area as a whole. Quantities of such items as wet grass clippings, office waste, specific light industrial scrap (e.g., plastic, rubber, leather) in any one sample strongly influenced the percentage compositions for that sample of refuse. Therefore, the ranges in refuse compositons processed in the pilot plant are more useful than averages calculated from the data. A number of municipalities in the country that were considering implementation of resource recovery also sampled their own refuse (many using Bureau-developed sampling instructions) and transported larger samples to the Bureau pilot plant for detailed analyses. These samples ranged in size from 4,000 to 8,000 lb. In addition to determining composition, detailed analyses of these larger samples included evaluating products separated in the pilot plant. Thus, bulk density, size measurements, and product characterizations were made, and the heating values of the combustible products were determined. Some of the municipalities participating in this work included Pinellas and Hillsborough Counties, FL; Tulsa, OK; Monroe County, NY; Harrisburg, PA; Montgomery and Baltimore Counties, MD; New Castle, DE; and San Juan, PR. The range in compositions of refuse processed from these larger samples is given in table 5 (*18*). As discussed in the next section, "Physical Beneficiation Flowsheet," processing municipal refuse resulted in a partial drying of the organic fractions; thus, the weight of combustibles shown in table 5 includes that moisture contained in the recovered products. Since the metallic content of raw refuse was 5 to 9 wt pct and the combustible content 63 to 83 wt pct, economics dictated a higher priority on recovering quality products from the high-volume combustible fraction. Therefore, the Bureau made modifications to certain portions of the pilot plant specifically to improve the quality of combustibles recovered at the facility; however; the Bureau's major research efforts in municipal resource recovery were devoted to investigating metal and mineral recovery.

Table 5.—Compositional range of municipal refuse processed at raw refuse pilot plant[1]

Product	wt pct
Ferrous metals	4.4- 7.6
Aluminum	.6- 1.1
Copper-base and zinc-base metals	.1- .2
Glassy aggregate	4.2-16.5
Combustibles	62.8-83.0
Grit and dirt	2.0-13.9

[1]Percentages listed include moisture contained in the recovered products.

PHYSICAL BENEFICIATION FLOWSHEET

As in the research on incinerator residues, various combinations of mineral processing techniques were utilized to recover products for recycling. Wherever possible, the raw refuse processing plant was constructed utilizing commercially available machinery (*18-21*). The system was patented (*22*) by the Bureau and has gained wide acceptance nationally as well as internationally. The basic flowsheet that evolved during the processing of nearly 1 million lb of raw refuse is presented in figure 8, and an overall view of the pilot plant is shown in figure 9. The design capacity of the plant was 5 st/h; however, refuse samples were usually fed at an overall average rate of 1 to 2 st/h.

Description

Flail Mill

Refuse was raked from the laboratory floor as shown in figure 10, onto a 2-ft-wide belt conveyor that fed the primary shredder, a double-opposed flail mill with each rotor powered by a 40-h variable-speed drive. To a large extent, overall pilot plant performance was affected by the size distribution of the shredded refuse. Particle size of the shredded fraction was in turn a function of flail mill rotor speeds. Early tests were conducted with the rotor speeds set at 800 r/min (7,960 ft/min tip speed) to yield the maximum quantity of large particles of glass for optical sorting into flint and mixed-color concentrates. When the optical color-sorting process was determined to be uneconomic and eliminated from the flowsheet, the rotor speeds were increased to 1,500 r/min (14,925 ft/min) to shred the light combustibles into smaller pieces and thereby improve the efficiency of the air classifiers. Since the mill had no grates, massive metal pieces in the refuse passed through the flails virtually intact without damaging the mill and were separated downstream. Cans and other light-gauge objects were dented or cut but underwent only a minimum of folding and balling.

Light Air Classifier

The exhaust hood at the shredder discharge (fig. 11) was redesigned several times to act effectively as an air classifier for which the airflow rate was usually adjusted to 7,500 ft^3/min (40 ft/s in the duct). At this flow rate, only the lightest (and generally the cleanest) paper and plastic were separated from the top of the moving bed of shredded refuse, and entrained glass, grit, or dirt was able to fall back through the airstream onto the conveyor for processing downstream. The light combustible fraction was recovered in cyclone 1 where it was discharged into a compactor and baled.

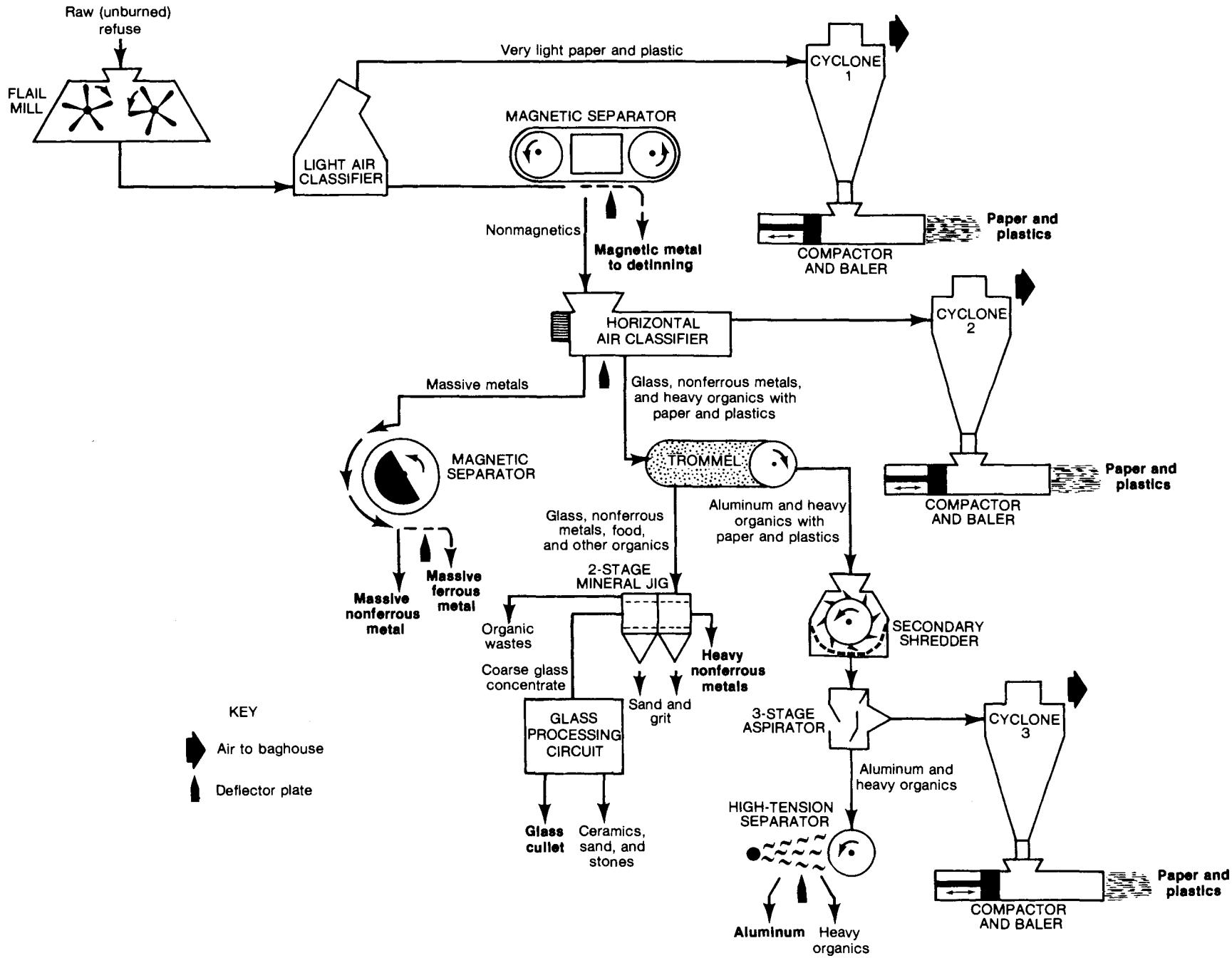


Figure 8.—Raw refuse processing flowsheet.

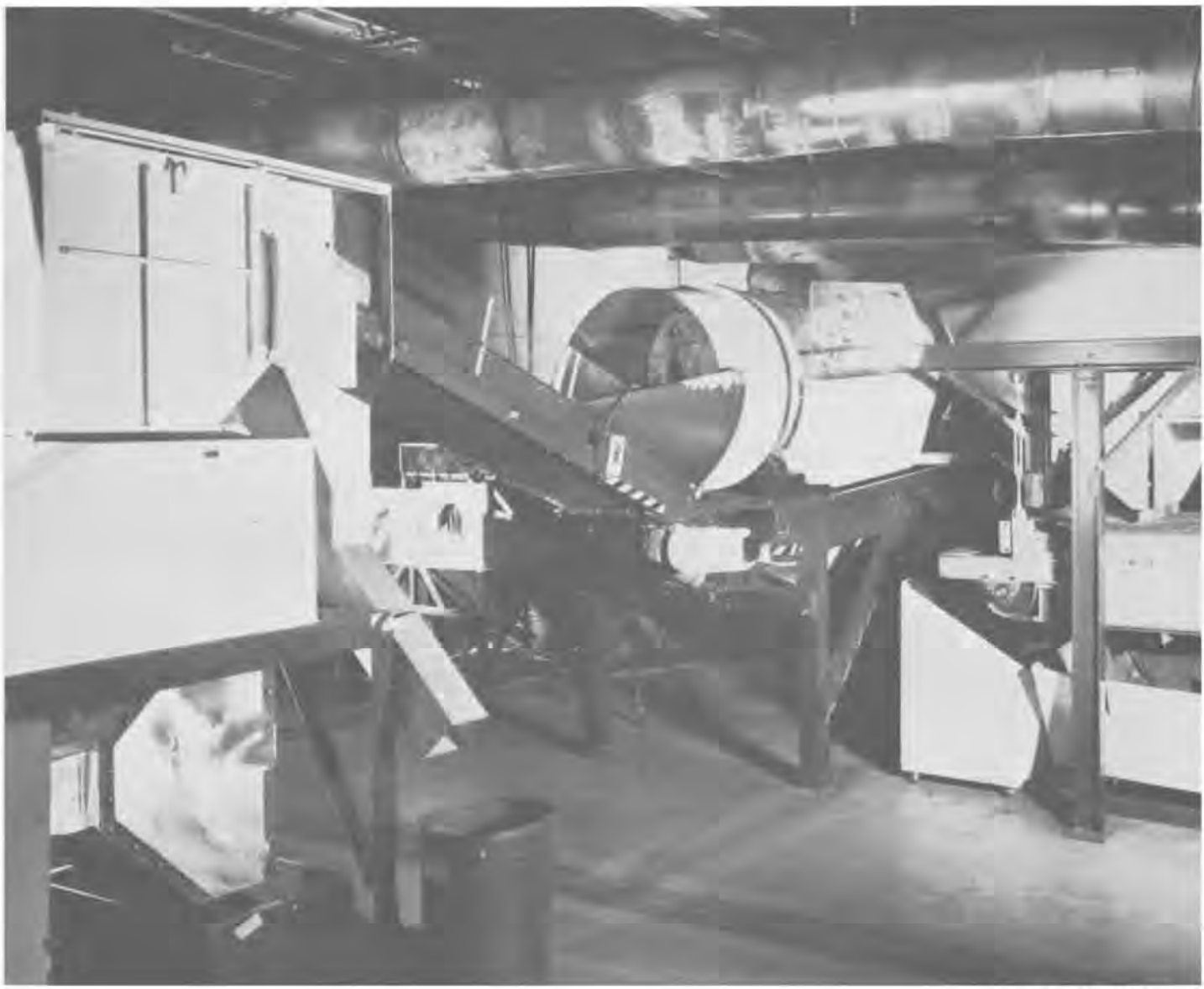


Figure 9.—Overall view

Magnetic Separator

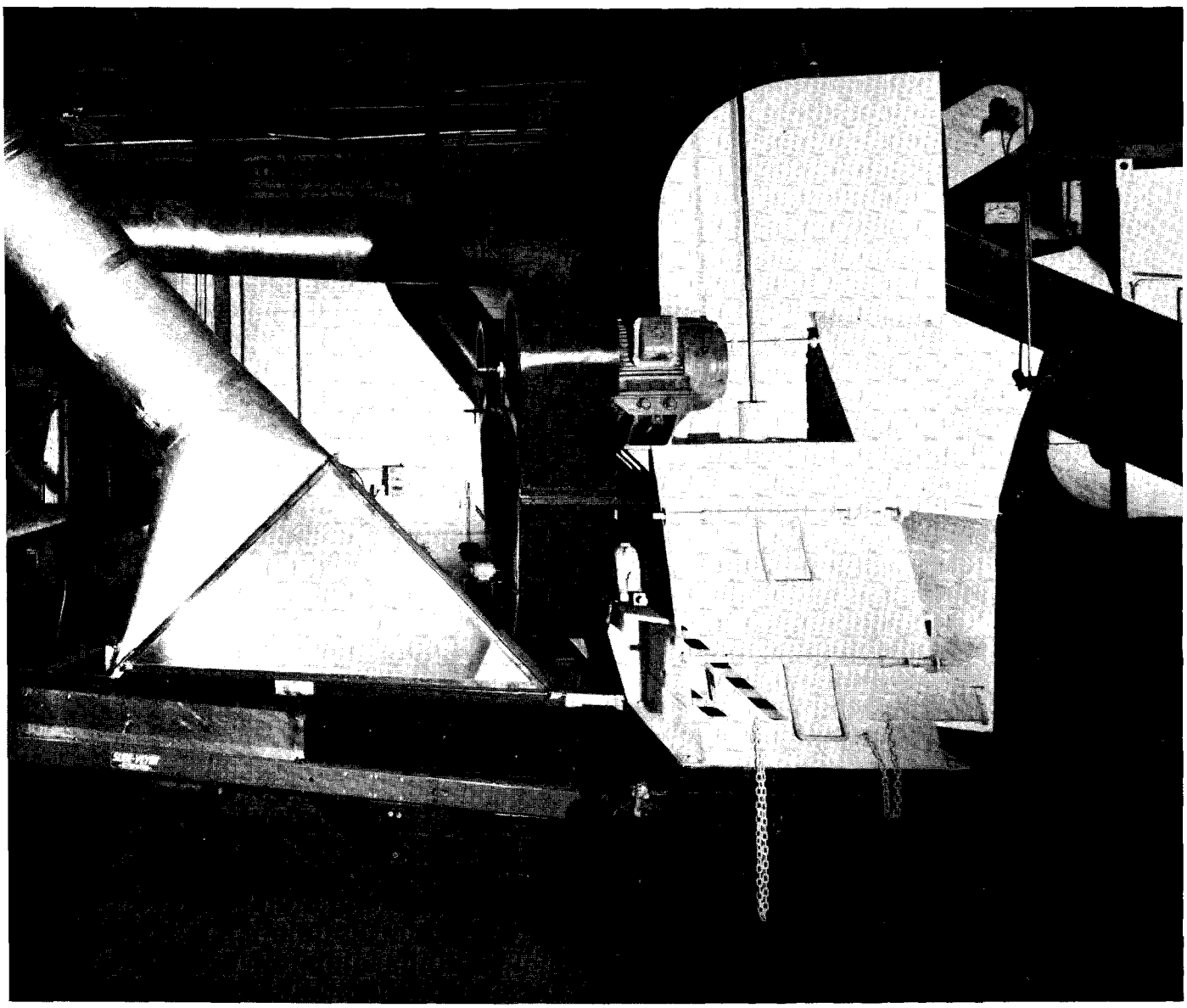
An overbelt magnetic separator (fig. 12) was used to recover a product that, after further shredding and air classification, was suitable feedstock for commercial detinning plants.

Horizontal Air Classifier

The nonmagnetic material was conveyed to a horizontal air classifier patterned after one developed in other Bureau research (*23-24*). As shown in figure 13, the refuse entered through the top at the feed end of the classifier and dropped into a horizontal airstream of about 7,900 ft³/min (42 ft/s). The heaviest or most massive objects fell vertically through the airstream to a belt conveyor. Most of the dry paper and film plastic not removed at the light air classifier entered the airstream and were carried to cyclone 2 where they were discharged into a compactor and baled. The food and yard waste, glass, aluminum, heavy combustibles, grit, and dirt fell a short distance past a divider where they dropped onto a belt conveyor feeding a trommel screen.

Trommel

The trommel (fig. 14) was 4 ft in diam with a 6-ft-long screen section, and the rotational speed was variable. Various screen hole sizes were used; 1-in-square holes are pictured, whereas 3/4-in-diam holes were later selected as optimal at a screen rotational speed of 13 r/min. The trommel undersize and oversize products were intermediate products, each of which required a considerable amount of additional treatment. The trommel undersize contained essentially all of the glass and ceramics, a small amount of nonferrous metal, and more than 90 wt pct of the food and yard waste contained in the refuse sample. The range in compositions of the trommel undersize products is given in table 6 (*18*).



efuse processing plant.

Table 6.—Compositional range of trommel undersize material recovered at raw refuse pilot plant (dry basis)

Product	wt pct
Ferrous metals	0.2- 0.7
Aluminum	0.0- 0.4
Copper-base and zinc-base metals	0.1- 0.6
Glassy aggregate	26.2-62.5
Combustibles	30.3-69.7
Grit and dirt	6.5-19.4
Moisture	17.2-43.1

[1]Percentages listed include moisture contained in the recovered products.

Mineral Jig

The undersize was fed to a mineral jig by a belt conveyor equipped with a magnetic head pulley to remove any remaining fine ferrous metal. The jig (fig. 15) was the first wet operation in the flowsheet and was effective in separating food and other light organic wastes (putrescibles) from the heavy fraction. The organic wastes floated from the jig as a light fraction and were dewatered on a vibrating screen, becoming suitable feed to a dewatering press that could reduce the moisture content to 50 wt pct, a necessary requirement if this product were to be used for fuel. Heavy nonferrous metals fed to the jig settled to the bottom of the bed on a screen having 1/8-in openings and were recovered after each refuse sample was processed at the pilot plant. Fines passing through the 1/8-in openings contained some unrecoverable glass but consisted primarily of grit and dirt, and thus was considered a waste product. The heavy fraction that continuously discharged from the bed of the jig was a glass aggregate contining up to 10 pct ceramic material, stones, bones, a small amount of aluminum, and other nonglass items.

Glass Processing Circuit

The heavy fraction was processed by rolls crushers and

Figure 10.—Feed conveyor at raw refuse plant.

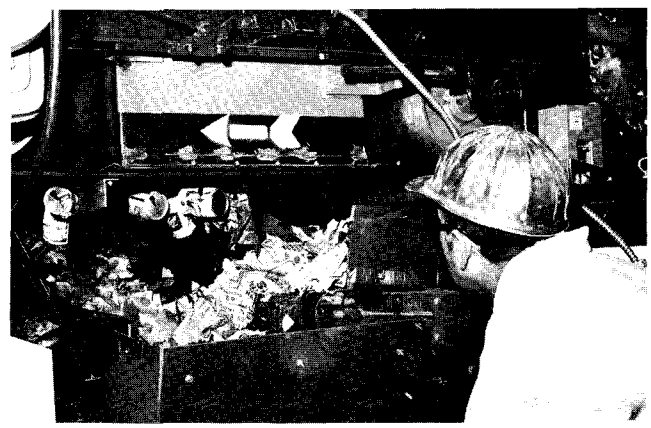


Figure 12.—Magnetic separator removing cans and other light metal.

froth flotation cells, a method identical to that used for 1/4-in material fed to the Harz jig at the incinerator residue pilot plant described previously.

Secondary Shredder

The plus 3/4-in trommel oversize material was shredded in a 75-hp knife-type shredder equipped with a grate having 2-in-diam holes. (Various grate openings were tested and a 2-in diam was determined to be optimum.) The shredded product discharged directly into another air classifier known commercially as a three-stage aspirator.

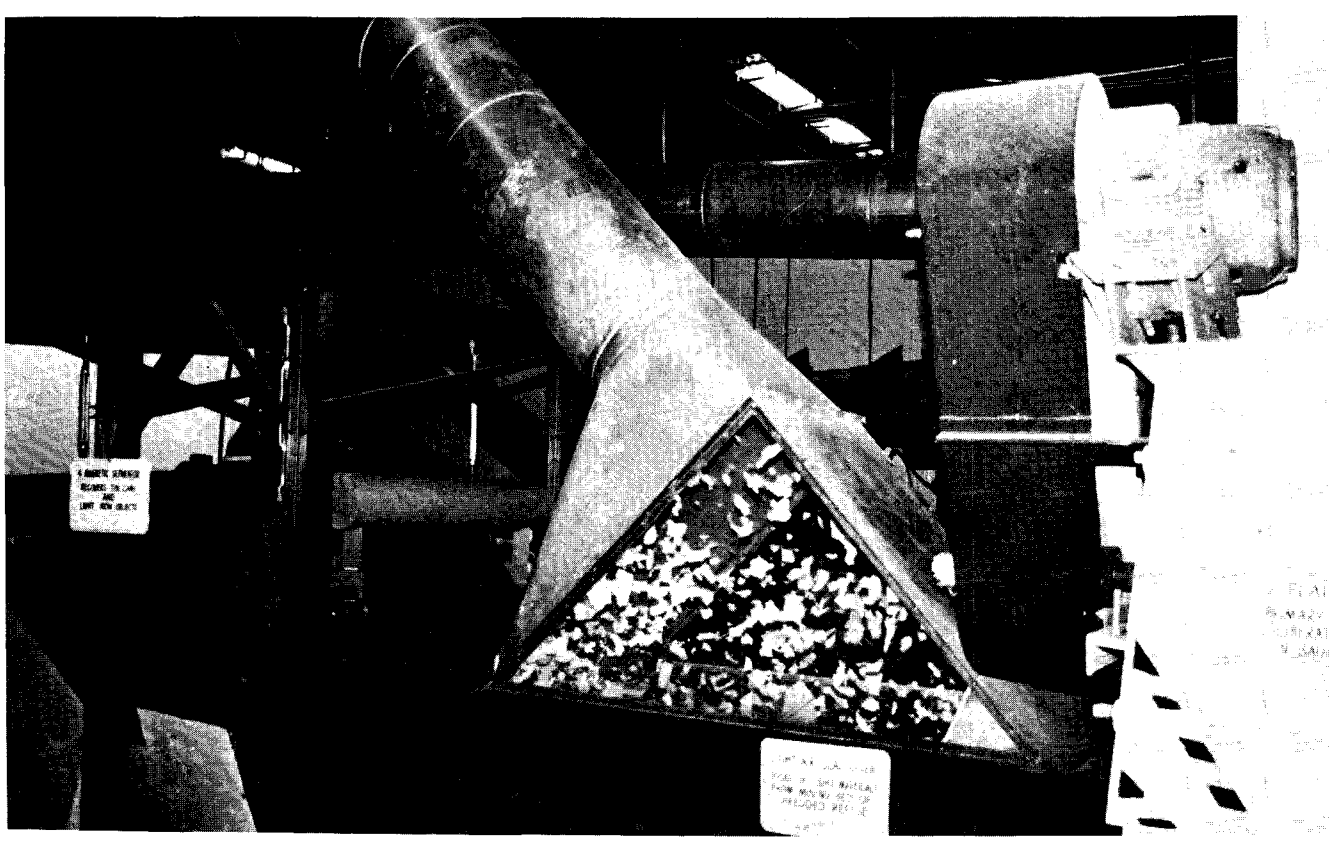


Figure 11.—Light air classifier separating refuse from the flail mill.

Figure 13.—Horizontal air classifier making a three-way separation.

Figure 14.—Trommel screen separating small material for wet processing.

Figure 15.—Mineral jig used to recover a coarse glass concentrate.

Three-Stage Aspirator

The aspirator (fig. 16) was controlled by an exhaust blower that created a 3,300-ft³/min (23-ft/s) suction in the duct located at the center left of the unit and pulled air from three places: (1) through the shredder grates, effectively air-sweeping the shredder, (2) through the opening on the front (right) side of the aspirator, and (3) through the open bottom. As the shredded material entered the aspirator, the re-

Figure 16.—Three-stage aspirator separating paper and light plastic from aluminum and heavy combustibles.

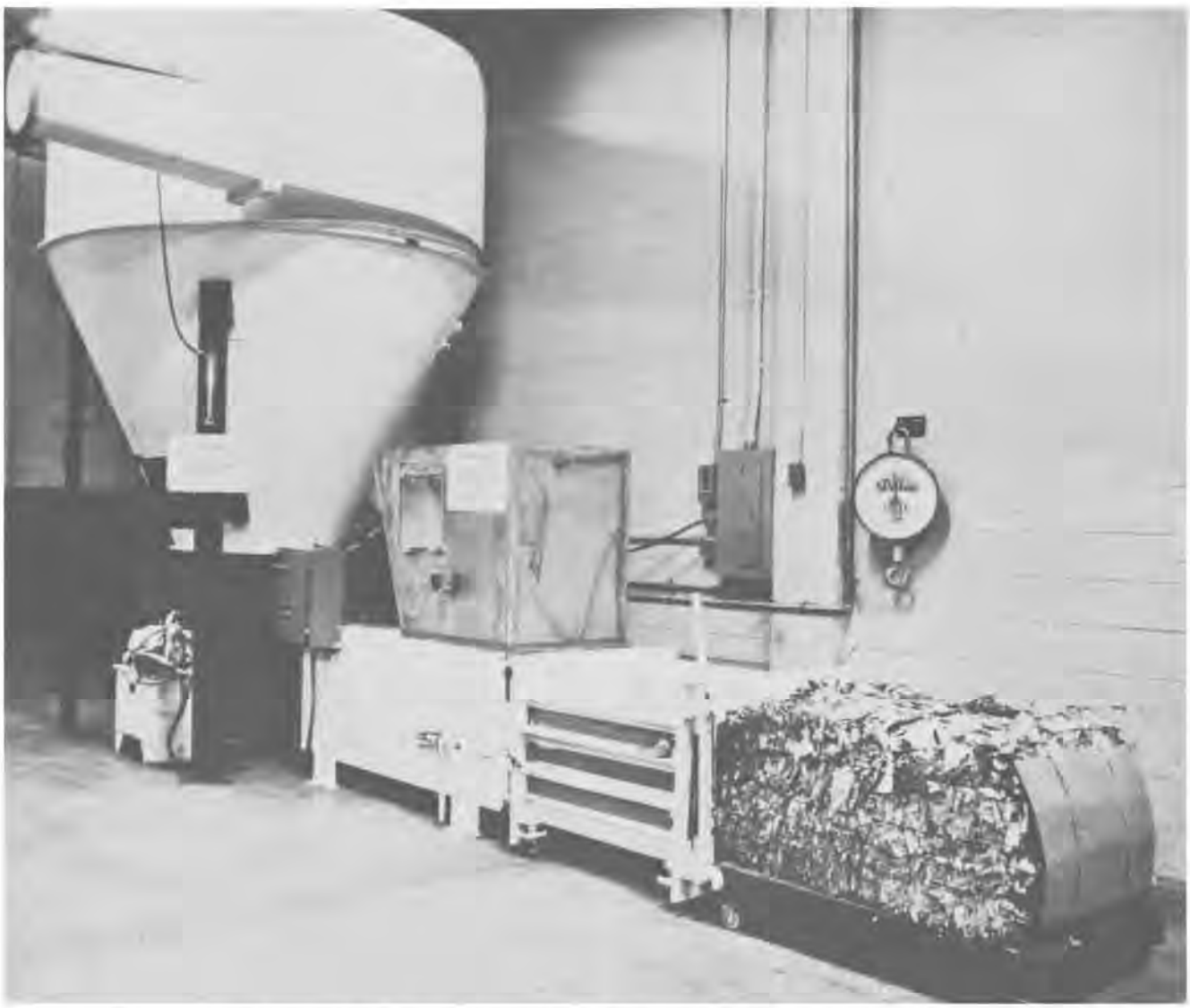


Figure 17.—Cyclone, compactor, and baler used to recover combustibles.

maining paper and light plastic in this fraciton were entrained in the airstream and recovered in cyclone 3, where they were discharged into a compactor and baled as shown in figure 17. The nonferrous metals and heavy combustibles that fell through the three airstreams were collected in a bin located below the aspirator. The range in compositions of the three-stage aspirator heavies products is given in table 7 (*18*). The aspirator used in the pilot plant was specifically designed to concentrate aluminum in this heavies product, which primarily contained combustibles such as wood, leather, rubber, heavy fabric, corrugated board, and thick plastics.

Table 7.—Compositional range of three-stage aspirator heavies recovered at raw refuse pilot plant (dry basis)

Product	*wt pct*
Ferrous metals	0.1- 1.7
Aluminum metal	2.4- 9.5
Aluminum foil	.7- 1.7
Copper-base and zinc-base metals	.1- 4.3
Glass	.0- 4.4
Combustibles	82.6-95.2
Moisture	18.7-36.5

High-Tension Separator

The heavies were then thoroughly dried and fed to a high-tension separator, which electrostatically removed the heavy combustibles from the metal. The high-tension separator used in the pilot plant was a two-stage commercial unit (fig. 18) that consisted of vibrating feeders, electrically grounded rotating drums, splitter plates, and bronze brush electrodes having 0.004-in-diam bristles charged with up to 40,000 V dc. As the material passed between the ionizing electrodes and the grounded drum, electrical nonconductors (combustibles) were caused to adhere to the drum while the conductors (primarily aluminum) were pulled toward the electrodes and diverted by a splitter plate. The nonconductors were automatically wiped off the grounded drum behind the splitter.

Variable Air Systems

Each of the air classifiers used in the pilot plant had its own air system, comprised of a varispeed exhaust blower, a baghouse filter, and a cyclone collector. As the paper and

Figure 18.—Two-stage, high-tension separator used to recover aluminum.

light plastics were being separated in the cyclones, the exhausted air was filtered to remove dust and particulates before being discharged to the atmosphere. In all processing steps, including air classifying, shredding, trommelling, and conveying, the refuse was aerated and appreciable drying occurred. While it was not possible to get an accurate measurement of the amount of drying that occurred, material balances indicated that as much as 25 to 35 wt pct of the moisture contained in the incoming refuse was removed during processing.

Costs and Product Balance

The raw refuse separation pilot plant was operated to obtain engineering data necessary for scaling up to commercial size. A detailed economic evaluation was made of the process (*25*), and a cost estimate was prepared for a plant capable of processing 1,000 st/d of raw urban refuse. The fixed capital cost, based on 1976 equipment costs, was approximately $14.5 million. The estimated operating cost was $8/st of refuse processed. The value of the recovered products was estimated to be $12.60/st of refuse processed.

An average product balance for refuse samples from Washington, DC, is given in table 8. The pilot plant separated refuse continuously into the following major fractions: magnetics, heavy metals from the horizontal air classifier, trommel undersize, aspirator heavies, air-classified products from cyclones 1, 2, and 3, and baghouse dust. A view of typical products recovered from municipal waste is shown in figure 19. The massive metal product separated at the horizontal air classifier usually amounted to less than 0.5 wt pct of the total refuse from any community and generally contained some stainless steel, small electric motors, automobile engine parts, heavy nonferrous metal, or other massive ferrous metal missed by the magnetic separator. The amount of baghouse dust collected was also normally less than 0.5 wt pct.

Table 8.—Average as-recovered product balance from 100 raw refuse samples collected in Washington, DC[1]

Product	*wt pct*
Magnetics	6.2
Horizontal classifier heavies	.2
Trommel undersize (minus ¾ in)	27.0
Three-stage aspirator heavies	5.6
Cyclone:	
1	18.5
2	25.6
3	16.5
Baghouse dust	.4
Composite	100.0

[1]Total weight of the 100 raw refuse samples processed at the pilot plant was 213,208 lb.

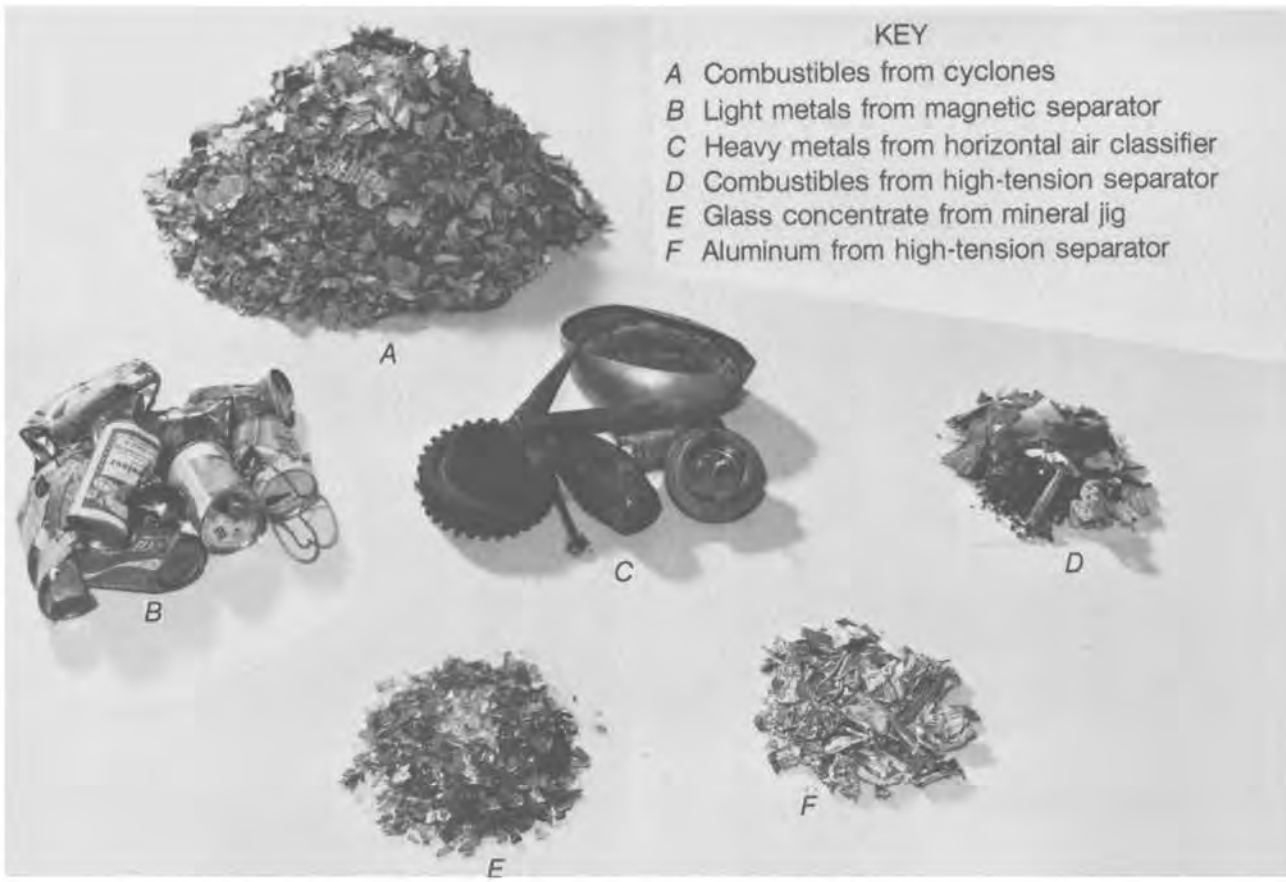


Figure 19.—Raw refuse processing plant products.

PRODUCTS RECOVERED FROM REFUSE

FERROUS METALS

One of the Bureau's prime research objectives in treating raw refuse and incinerator residue was to develop effective methods for recycling the ferrous fractions recovered from these two wastes. While developing its research program, the Bureau realized that steelmakers were reluctant to use both forms of this scrap (*26*) because of a lack of reliable supplies and the deleterious effects of contaminants such as aluminum, copper, and tin. With these deterrents in mind, a concerted effort was made to develop improved methods for reusing these recovered ferrous fractions.

Ferrous metals contained in incinerator residue were concentrated into coarse and fine magnetic products at the pilot plant. As shown in table 9, these products typically contained 0.3 wt pct copper and 0.2 wt pct tin, whereas the accepted upper limits for these residuals in many finished steel products are 0.05 and 0.02 wt pct, respectively. Magnetic products from the raw refuse pilot plant contained tin from food cans and aluminum from bimetallic beverage cans as major contaminants. After each raw refuse sample was processed in the pilot plant, the entire magnetic product was hand-sorted to determine the percentage distribution of tin cans, bimetallic cans, tin-free cans, and miscellaneous items. An average distribution of the magnetic fraction of refuse sampled from the Washington, DC, area is given in table 10. The data show that 72 wt pct of the magnetic product was tin-plated cans. Data for refuse from other municipalities that was processed in the pilot plant show that the amount of tin-plated cans ranged from 48 to 79 wt pct of the magnetic fraction (*18*).

The Bureau conducted research to develop a process for removing the copper contamination in the magnetic fractions of municipal refuse, which also has been a serious problem with other types of ferrous scrap (e.g., shredded automobile scrap). A pyrometallurgical process was developed that removed copper from molten iron as copper sulfide dissolved in a sodium sulfide matte. In laboratory tests, sodium sulfate additions were made to molten scrap in a graphite crucible, generating the sulfide matte. Early studies with this process, involving the addition of sodium sulfate onto the surface of molten iron, showed that copper could be removed to below 0.1 wt pct if sufficient sodium sulfate was used (*27*).

Upon establishing the technical feasibility of removing copper by surface additions of sodium sulfate, the Bureau conducted a pilot plant study of this process using a 1-st arc furnace for melting the ferrous scrap and a 1-1/2-st treatment ladle (fig. 20). Results of these tests showed that the copper removals obtained in laboratory tests could be achieved on a pilot plant scale when excess carbon was added with the sodium sulfate (*28-29*). Additional laboratory research resulted in significant process improvements by (1) lance injection of the sodium sulfate below the molten iron surface (*30*), (2) removal of the matte as it formed, and (3) oxidation of the matte to regenerate fresh sodium sulfate for reuse. The lance injection technique resulted in significant reductions in the amount of sodium sulfate required for a given decrease in the copper content of the iron. Removal of 75 wt pct of the copper (to obtain 0.1 wt pct or less) required about 27 wt pct sodium sulfate (percent of metal charge) by lance injection, with slag removal. A similar copper reduction by surface additions with no matte removal required 45 wt pct sodium sulfate.

Pyrometallurgical removal of tin by chlorination using additions of solid materials such as hexachloroethane (HCE) and polyvinyl chloride (PVC) in place of gaseous chlorine was investigated (*31*). Results of this research showed that when tin removal was compared as a function of available chlorine, the two materials had equivalent removal efficiency. As much as 90 wt pct of the tin was removed by the chlorination procedure.

Research also was conducted on the removal of copper and tin from the incinerated ferrous scrap using hydrometallurgical techniques (*32*). The study showed that the scrap containing from 0.2 to 0.5 wt pct copper could be leached with ammonium hydroxide to reduce the copper content to 0.06 wt pct, provided an oxidant such as peroxide was present. Aqueous leaching of the scrap with sodium hydroxide to remove the tin gave very little extraction. However, hydrochloric acid leaching did reduce the tin content of the scrap from 0.3 to 0.1 wt pct. Attempts to reduce the tin to lower levels resulted in dissolution of the iron. Studies on the leached scrap revealed that the solder inside the seam of the cans contained much of the residual tin. This tin was physically shielded from the acid solution and could not be extracted.

The applicability of commercial detinning practices to the raw refuse ferrous fraction was evaluated (*33*). Results from laboratory and pilot tests established the technical feasibility of detinning scrap recovered from household refuse. Detinned products of commercial quality containing less than 0.03 wt pct residual tin were produced.

The tin removal studies then were extended to include evaluations under commercial conditions (*34*). Tests using 5.5 st of the ferrous fraction showed that magnetic products from unburned urban refuse can be commercially detinned to an acceptable level provided they are first upgraded. This upgrading includes a shredding step that serves to loosen and separate all contaminants (e.g., food wastes, dirt, paper labels, aluminum from bimetallic cans) as well as to cut open

Table 9.—Typical analyses of ferrous metal recovered from incinerator residue products, weight percent

Sample	C	Cr	Cu	Mn	Mo	Ni	P	Pb	S	Si	Sn
Coarse:											
1	[1]1.62	<0.03	0.37	<1.0	<0.01	<1.0	<0.02	<0.01	0.03	0.13	0.20
2	.02	.01	.44	.01	.02	.10	.03	.10	.03	NA	.16
3	.04	NA	.22	.02	NA	NA	<.01	NA	.06	.10	.24
4	.04	NA	.32	.01	NA	NA	<.01	NA	.04	.10	.21
Fine:											
5	.20	<.03	.38	<.1	<.01	<1.0	<.02	<.01	.12	<.05	.20
6	[1]1.35	.05	.24	.10	<.01	.35	.06	<.01	.04	.11	.17

NA Not available.
[1]Carbon probably picked up from clay-graphite crucible used in smelting.

Table 10.—Average composition of magnetic products recovered from refuse samples collected in Washington, DC

Product	wt pct
Tin cans	61.0
Bimetallic tin cans	11.1
Bimetallic tin-free cans	3.3
Bottle caps	2.7
Miscellaneous iron	18.3
Paper containers with metal ends	1.2
Paper	2.4
Composite	100.0

Figure 20.—Test ladle (1½ st) receiving molten iron from arc furnace.

whole cans. The contaminates, if not removed, consume the hot caustic solutions used at commercial detinning operations and thus adversely affect the economics of the process. Cleaning and cutting the can scrap not only permits the detinning solution to react with the maximum surface area exposed, but also allows the rinse solutions used in the process to drain thoroughly, thereby minimizing retention of this tin-bearing solution in the scrap when the scrap is removed from the treatment tanks. Results of these studies showed that the washed metal product contained 0.06 wt pct residual tin, and the subsequent melt tests showed a ferrous metal yield of 91.4 wt pct. Based on these studies, full-scale (10-st) commercial demonstrations were conducted during which a detinned product comparable to current commercially detinned bales was achieved, with a concurrent recovery of up to 5 lb of tin per gross short ton of scrap (*34*).

Under contract to the Bureau, a study was conducted by Authur D. Little, Inc., to provide additional information that could be used in commercial-scale detinning of municipal solid waste magnetics (*35*). The study was undertaken because of concern that the ferrous scrap fraction was not fully acceptable to the detinning industry and the fact that many detinning plants may not be located within economical shipping distances of municipal solid waste processing plants. In addition, the ferrous scrap output of the waste processing operations might possibly be too small to justify construction of new conventional detinning plants. The study reviewed existing detinning processes as well as new concepts. Preliminary economic evaluations of these concepts were also undertaken. The principal findings of the study are summarized as follows:

- It is not economically feasible to use conventional detinning technology to process raw refuse magnetics on a small scale.
- It is unlikely that as-recovered magnetic scrap from municipal solid waste can be detinned economically.
- If the magnetic scrap is upgraded to reduce the nonmetallic tramp materials to a low level, small-scale detinning can be accomplished with reasonable process economics by a number of processes, including alkali chemical oxidation, acid chemical oxidation, alkali electrolysis, and abrasion (oxidation followed by sand abrasion).

The Bureau also investigated on a laboratory-scale an electrolytic method using a mixture of stannous fluoborate and fluoboric acid for removing tin from upgraded municipal ferrous scrap (*36*). This electrolytic process can be operated at room temperature with both a wide range of tin content in the scrap and a wide range of acid concentrations. Promising results were obtained in these studies. The tin content of the magnetic refuse scrap was reduced from 0.18 to 0.017 wt pct with current efficiencies above 90 pct.

As an alternative to treating scrap for the removal of contaminants, a variety of studies were conducted by the Bureau to determine problems associated with the use of as-recovered refuse ferrous fractions for steelmaking and to evaluate the resulting stel products (*37-41*). Ferrous scrap from several sources was used, including incinerator residue ferrous fraction, both unprocessed and commercially detinned can stock, and a magnetic product from a commercial raw refuse processing operation. Melts were made from each of the various types of refuse scrap individually and in combination with heavy melting scrap and automobile scrap. In these studies, 50-lb ingots were produced from small induction furnace melts, as well as 50-, 400-, 750-lb ingots from 1-st electric arc furnace melts. A 50-lb ingot being poured during induction furnace tests is shown in figure 21. Ingots from both the induction furnace melts and the arc furnace melts were hot-rolled to provide material for mechanical and corrosion testing. Metal recoveries ranged from 64 wt pct for the highly oxidized incinerated ferrous fraction to 98 wt pct for the melt charged with 25 wt pct tin cans and 75 wt pct heavy melting scrap (*38*).

Results obtained in the study indicated that most steels rolled successfully and exhibited acceptable surface and edge conditions. Tensile strengths of the plain carbon steels were not significantly affected by tin content up to 0.16 wt pct. Yield strength increased while impact strength decreased with increasing tin content (*37*). In general, the mechanical properties of the steel exceeded minimum standards for plain carbon steel and were not measurably affected by charge composition (i.e., melting stock), melting practice, or method of scrap preparation. However, the ductility of certain combinations of scrap was notsatisfactory, indicating that additional research was needed (*41*).

Rolling studies included production of acceptable commercial reinforcing bar from the test steels, and these results indicated that acceptable mill shapes can be produced from ferrous fractions of urban refuse (*38*). Specimens of hot-rolled steel products, which underwent atmospheric weathering tests, exhibited properties comparable to those of commercial weathering steel alloys (*39*).

Figure 21.—Pouring a 50-lb steel ingot.

A fundamental study was conducted in which the magnetic fraction of urban refuse was used as melting stock in the preparation of high-strength, low-alloy, and carbon steels to determine the effect of residual elements on their atmospheric corrosion resistance in industrial, rural, and marine environments (*42-43*). The study, which extended over a period of almost 4 yr, showed that atmospheric corrosion properties of the prepared steels exposed to industrial, rural, and marine environments were not degraded by additions of the magnetic fraction of urban refuse. In fact, a marked improvement was noted in the atmospheric corrosion resistance of 1030 carbon steel when urban refuse scrap was used as melting stock. Copper and tin were the critical residual elements responsible for the improved corrosion resistance. The beneficial effect of tin appeared to be related to the accumulation of tin in the corrosion film near the film-metal interface. The presence of sulfur in the corrosion film is the most important factor affecting the corrosion resistance of steels. Because the copper and tin in the steels increased the concentration of sulfur in the corrosion film, the corrosion film became more protective.

In other Bureau research, raw refuse ferrous fractions were successfully used as a major portion of the feed for the production of gray iron (*44*). Tests were conducted in an 18-in-ID cupola furnace (fig. 22). Metallic charges consisting of up to 90 wt pct refuse scrap were blended with automobile scrap and evaluated. Typical charge material is shown in figure 23. Chemical analysis showed that chromium, molybdenum, and nickel levels were directly related to the ratio of refuse to automobile scrap in the charge. Residual levels of tin in the iron products increased in direct relation to quantity of refuse scrap in the furnace charge, while copper levels were scattered but decreased with increasing amounts of refuse scrap. Use of refuse scrap containing aluminum from bimetallic cans significantly reduced sulfur pickup in the iron product, from the normal 0.08 wt pct to 0.04 wt pct. Some carryover of aluminum from the refuse scrap was found; 0.03- to 0.06-wt-pct levels were typical in the iron. Ferrous metal yield was relatively stable considering the variation in charge materials; yield values consistently fell between 88 and 92 wt pct.

An extended series of cupola tests also was made using combinations of raw refuse magnetic scrap and shredded automobile scrap under basic and acid cupola slag practices (*45*). The level of refuse scrap ranged from 15 to 90 wt pct of the scrap charge. The study showed that refuse scrap in combination with shredded automobile scrap could be converted to gray iron. The study also showed that it was possible to utilize up to 60 wt pct refuse scrap in the charge under basic conditions. In acid slag practice, only 30 wt pct was permissible. The cupola operated smoothly with a basic practice because the slags were fluid. Using an acid practice caused the slags to become viscous with an addition of 45 wt pct refuse scrap in the charge.

The University of Wisconsin, under a grant from the Bureau, conducted research to determine the feasibility of using incinerator residue ferrous scrap in the production of ferrous castings (*46*). Results of this study indicated that scrap containing tin would not be suitable for cast steel production. However, the study did show that small amounts of tin would not be detrimental in gray iron. The grant also sponsored a fellowship research program that focused on beneficiating the incinerator residue scrap prior to its utilization as a charge material in melting operations (*47*). This work revealed that the removal or reduction of iron oxide scale from the incinerator residue scrap was the most important factor in increasing ferrous metal yield. Metallic yield was also increased by increasing the bulk density of the feedstock. The highest metallic yield obtained in the study (over 93 wt pct) was obtained by pretreating the scrap using a combination of compaction and pickling to remove iron oxide scale.

Tests with ferrous fractions from incinerator residues were conducted to determine the feasibility of using such scrap in commercial iron foundry operations. Foundry trials conducted using an 18-in-ID cupola capable of producing 3/4 st/h of hot metal (*48*). Results of these trials showed that the cupola could accept up to 50 wt pct residue scrap in the charge and still maintain favorable operating conditions for producing good gray iron.

NONFERROUS METALS

As shown in tables 3 and 5, in the sections "Compositional Studies," a small but significant portion of municipal refuse consists of nonferrous metals. This portion was separated into aluminum-rich fractions and copper-zinc rich fractions at both the incinerator residue and raw refuse pilot plants. When incinerated, aluminum cans melt and thus are not in a recognizable form in the residue. At the incinerator residue pilot plant, the plus 1/4-in nonferrous metal was separated into aluminum and heavier nonferrous metal concentrates either by jigging (*49*) or heavy media. These two concentrates were individually smelted into ingots and analyzed. The various fine aluminum products (plus 20-mesh and plus 1/8-in fractions) produced at the pilot plant were never recovered in sufficient quantities to smelt into ingots.

The compositions of typical plus 1/4-in aluminum products recovered from incinerator residue are given in table 11. Metal yield during smelting was unusually high, averaging about 95.6 wt pct. Except for the excessive lead in sam-

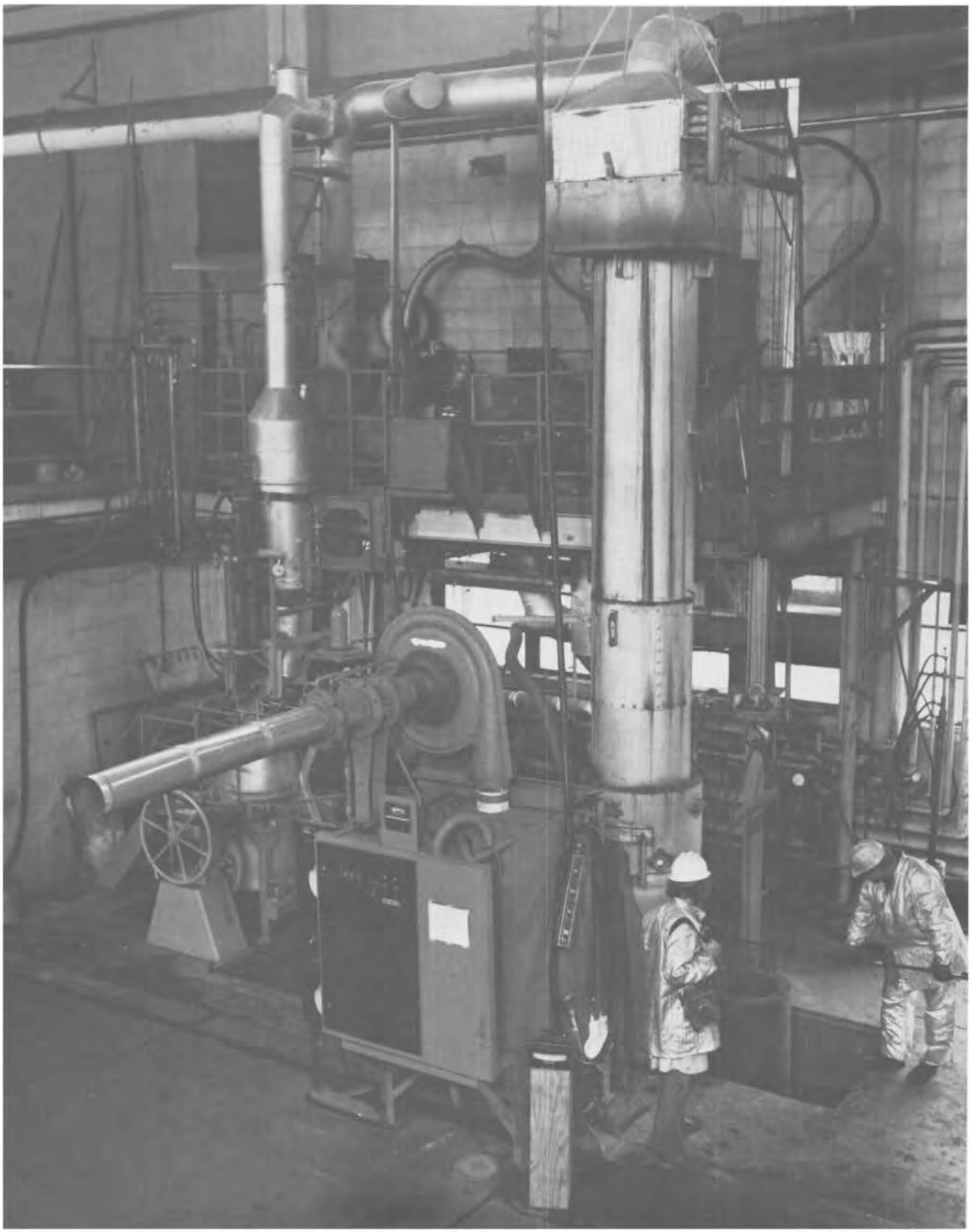


Figure 22.—Cupola furnace used to produce gray iron from refuse ferrous fractions.

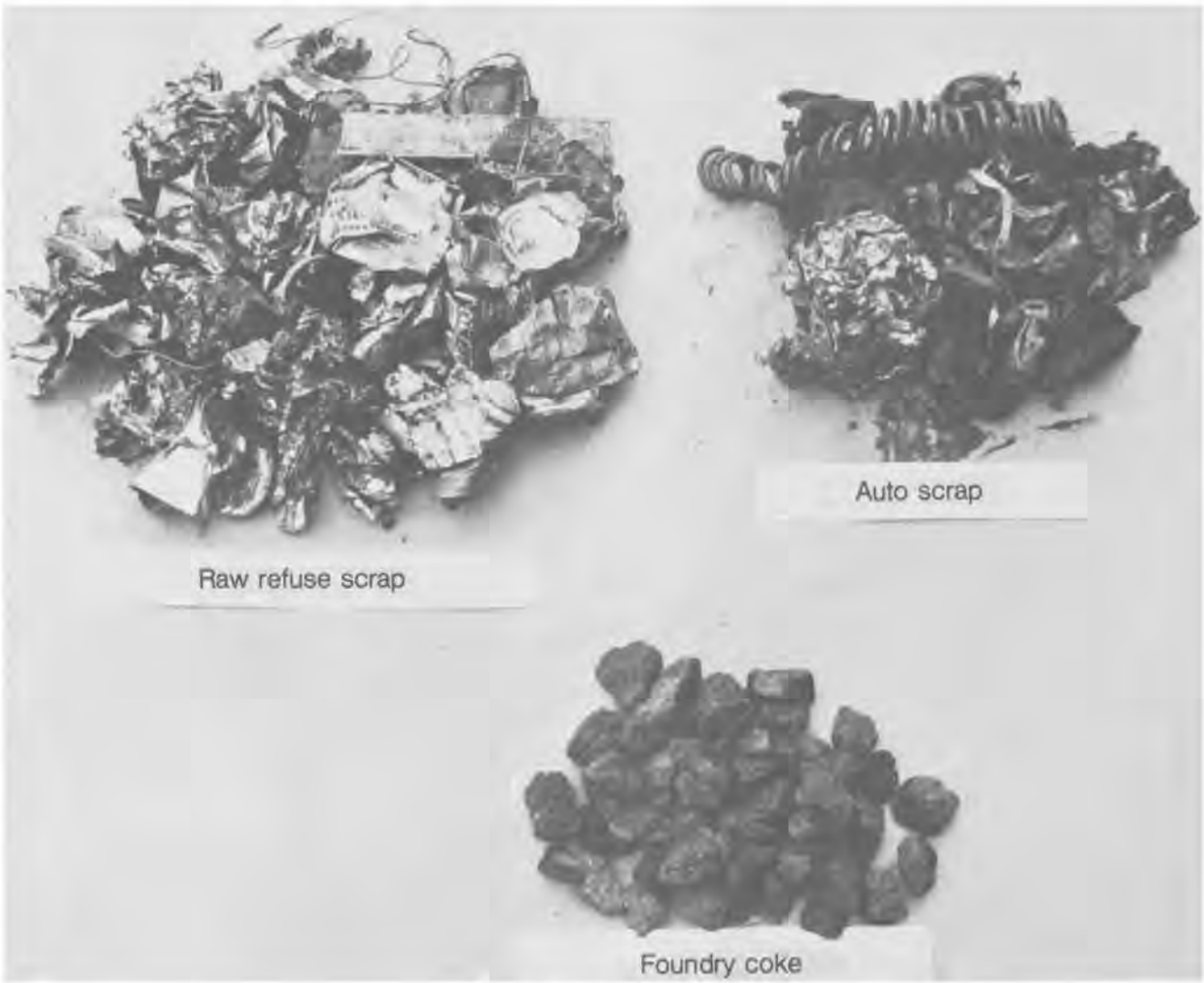


Figure 23.—Cupola charge.

Table 11.—Typical compositions of plus ¼-in aluminum product recovered from incinerator residue, weight percent

Sample	[1]Al	Cu	Fe	Mg	Mn	Pb	Si	Sn	Zn
1	97.55	0.16	1.3	0.38	0.30	0.12	0.15	0.012	0.03
2	97.31	.43	.83	.02	.41	.43	.30	.03	.24
3[2]	97.0	.2	.8	<.05	.05	.2	1.0	<.05	.2
4[2]	96.5	.5	.9	<.05	.1	.1	1.5	<.05	.3
5	96.5	.6	.8	.4	.6	.1	.7	<.05	.3
6[2]	94.1	1.10	.95	.10	.40	.10	2.80	NA	.35

NA Not available.
[1]Obtained by difference.
[2]Smelted, sampled, and analyzed by major aluminum producer.

ple 2, all of the products in table 11 appear suitable for producing 380 alloy, which is one of the main products of many secondary aluminum smelters. In fact, metal of this composition could probably be used for most of the alloys produced at secondary smelters. A major aluminum producing company evaluated samples of typical products and reported that the metal was a good commercial alloy of the 3105 type used in the construction industry (*50*).

The heavy nonferrous metal product, in both coarse and fine sizes, was composed of discrete nuggets of copper, brass, zinc die cast, solder, and an occasional piece of stainless steel. Ingots made from the smelted and blended metal had the compositions shown in table 12. No attempts were made to selectively sweat any of the low-melting metals from the as-recovered product. Even with the great number of copper-base alloys produced, it was impossible to match the chemistry of any of them with that reported in the table. However, this metal is suitable for blending with other types of scrap generally processed at secondary copper smelters.

In addition to using heavy media and jigging, the Bureau also devised and tested a novel magnetogravimetric separation method to fractionate mixtures of nonferrous metals recovered from municipal incinerator residues (*51*).

Table 12.—Typical compositions of plus ¼-in heavy nonferrous metal product recovered from incinerator residue, weight percent

Sample	Al	[1]Cu	Fe	Ni	Pb	Sn	Zn
1	0.25	59.3	0.10	NA	4.3	0.22	35.8
2	2.78	56.4	1.39	1.65	2.86	1.4	33.5
3	2.44	54.65	.30	NA	5.54	1.19	35.85
4	3.8	54.5	1.3	.8	3.3	.6	35.7
5	3.52	50.4	.84	1.48	4.93	.30	38.5

NA Not available.
[1]Obtained by difference.

By placing a magnetic fluid, a colloidal suspension of magnetite in kerosene, between the poles of a magnet, it is possible to vary the apparent specific gravity of the suspension and thereby separate metals according to their densities. A view of the apparatus used to separate the mixed nonferrous metal product is shown in figure 24. Chemical analysis of three metal fractions separated in one pass through the unit is shown in table 13. The average specific gravity of each fraction as well as the head sample is also given. The apparent mixing in the analyses of the zinc and copper fractions was undoubtedly related to the various compositions of brass found in municipal refuse. Brasses reported to both the middle- and heavy-density fractions.

As described in the section "Physical Benefication Flowsheet" for raw refuse, the nonferrous metals were concentrated in both the jig heavies product and the high-tension separator product.

The small but potentially important fraction of metals recovered from the bed of the jig consisted of minus 3/4-in metal such as ballpoint pen cartridges, broken castings, wire, and coins. Smelting of these metals in laboratory furnaces resulted in yields of 90 wt pct, with a typical range of compositions as shown in table 14 (*18*). The value of the coins in this product consistently amounted to between $0.15 and $0.20 per short ton of refuse fed to the pilot plant. Capitalizing on this fact, commercial plants processing 1,000 st/d minimum of municipal refuse have been able to recover as much as $1,000 per week in handpicked coins that are sent to the Philadelphia Mint for repayment. The majority of the minus 3/4-in aluminum recovered at the pilot plant reported in the glass fraction and was screened out when the glass was crushed prior to froth flotation. Trace amounts of aluminum also reported in the jig overflow product.

Figure 24.—Ferrofluid separator used in batch tests.

Table 13.—Chemical analysis of nonferrous metal fractions recovered by magnetic fluid separation

Fraction	Sp gr, g/cm³	Chemical analysis, wt pct					
		Al	Cu	Fe	Pb	Sn	Zn
Head	3.5	54.5	19.7	1.9	2.1	<0.1	14.8
Light	2.7	83.8	2.1	1.3	.3	<.1	3.4
Middle	6.0	11.4	24.0	1.6	2.4	<.1	53.2
Heavier	8.2	1.6	56.3	2.4	11.1	.4	27.1

Table 14.—Compositional range of heavy nonferrous metal recovered from mineral jig at raw refuse pilot plant

Metal	wt pct
Ag	0 - 0.3
Al	1.3- 3.0
Cu	34 -43
Fe	.1- .5
Ni	.3- 1.1
Pb	14 -20
Sb	.2- .6
Sn	1.1- 2.3
Zn	36 -44

Smelting of the metals separated by the high-tension unit, together with a small amount of aluminum recovered at other points in the process, resulted in recovery of 75 to 80 wt pct of the aluminum in the furnace charge. Smelting tests on products accumulated from a large number of pilot plant operations produced ingots that consistently assayed 98 wt pct aluminum with small amounts of iron, magnesium, manganese, copper, and zinc.

As mentioned previously, material fed to the high-tension separator had to be thoroughly dry to recover a high-grade aluminum concentrate. In order to minimize drying costs, another separation scheme was tested that combined a commercially available eddy-current separator with the electrostatic device. Developed by the Raytheon Co. (*52-53*), this unique separator (shown schematically in figure 25) uses permanent magnets mounted in rows with alternating polarity on an inclined plane and covered with a thin sheet of nonmagnetic stainless steel. It works on the principal that when metal moves through a magnetic field, an

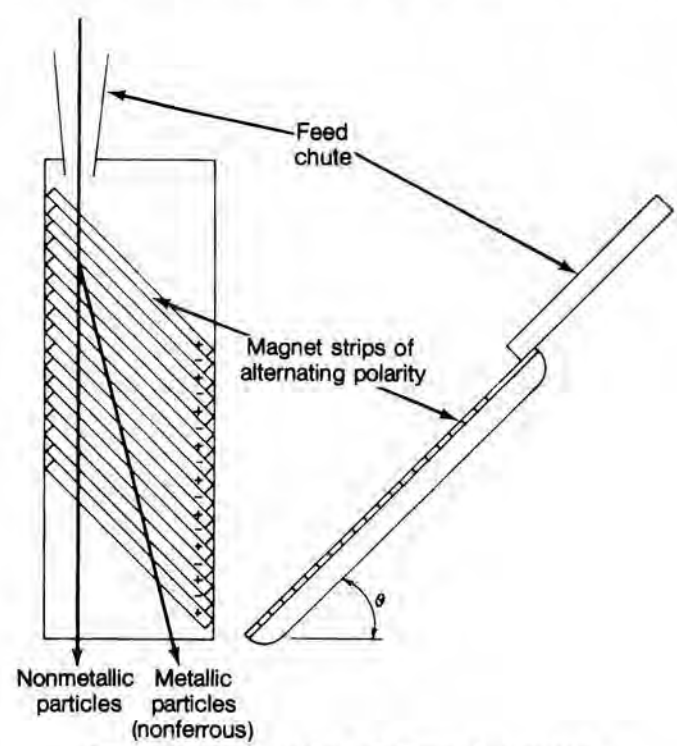


Figure 25.—Schematic of eddy-current separator.

electric eddy current is induced that is proportional to the electrical conductivity of the metal. The eddy current itself has a magnetic field that is repulsed by the magnetic field of the permanent magnets, causing the metal to be deflected to the side as it slides down the inclined plane over the alternating poles of the magnets. The separator was incorporated into a flowsheet developed under a Memorandum of Agreement between the Raytheon Service Co. (a subsidiary of Raytheon Co.) and the Bureau. This work showed that approximately 90 wt pct of the heavy combustibles could be rejected by the eddy-current unit without prior drying. The resulting aluminum concentrate after drying was then upgraded using a high-tension separator. As a result, over 96 wt pct of the aluminum was recovered in products containing as much as 92.3 wt pct aluminum metal.

An investigation also was made to determine the feasibility of recovering nonferrous metals from municipal refuse and auto scrap using a Bureau-developed elutriator (classification in a vertical water column) (*54*). Results of these studies showed auto scrap was more amenable to concentration than was municipal refuse because of the food waste present in the latter. Recovery of aluminum from samples of municipal waste was only about 39 wt pct.

GLASS

A concerted effort was undertaken by the Bureau to develop technology for recovering glass from incinerator residue and raw refuse for use as cullet in the production of new container glass. Initially, efforts concentrated on electronic color sorting using a sorting apparatus as shown in figure 26 (*55-56*). The machine was tested for recovering a colorless flint glass concentrate from a coarse fraction (minus 1-1/4 in plus 4 mesh) of incinerated residue as well as plus 1/4-in glass recovered from the jig products at the raw refuse pilot plant. Results of the study indicated that although concentration of the flint glass was achieved, the quality of the product would not be suitable for direct reuse as containers without further upgrading. In multiple-stage processing of a feed containing 45 wt pct flint glass, a concentrate containing almost 91 wt pct flint glass was achieved. Recovery of the flint glass, however, was only 60 wt pct, making the process uneconomical.

The feasibility of electronic color sorting for flint glass appeared in doubt, and the concurrent studies on glass flotation to produce mixed-color cullet showed greater promise; therefore, flotation was included in the flowsheets of both the incinerator residue and raw refuse pilot plants. Glass from both pilot plants was a sandlike product of mixed color, minus 20 plus 150 mesh in size. Glass container manufacturers contended that such material could be used in limited quantities for manufacturing either green or amber containers, provided the material consistently met their rigid specifications. The major criterion for determining if the product was acceptable was the number of refractory particles present. No more than two refractory particles were permitted in a 1-lb sample of minus 20- plus 40-mesh glass. In minus 40- plus 60-mesh particles, a 1-lb sample could not contain more than 20 refractory particles. These specifications were achieved regularly in Bureau bench-scale flotation tests (*13-14*). A typical batch glass flotation test is shown in fugire 27. In actual continuous pilot plant tests, mixed glass concentrate containing up to 99.9 wt pct glass with attended recoveries of 79 wt pct was consistently produced. The flotation cells used for the continuous tests are pictured in figure 7.

Prior to commencing froth flotation studies, the Bureau provided an industrial glass container manufacturer with 5 st of minus 20-mesh "glass product" recovered from incinerator reside after being processed through the wet, high-intensity, magnetic separator. The company diluted the recovered glass with approximately 95 wt pct cullet and used the mix successfully in manufacturing approximately 100,000 amber-colored beer bottles. Although the test indicated that producing bottles by this process was possible, a number of bottles also were produced with defects due to stones, ceramics, etc. in the feed material. Consequently, the glass produced by froth flotation was much preferred by

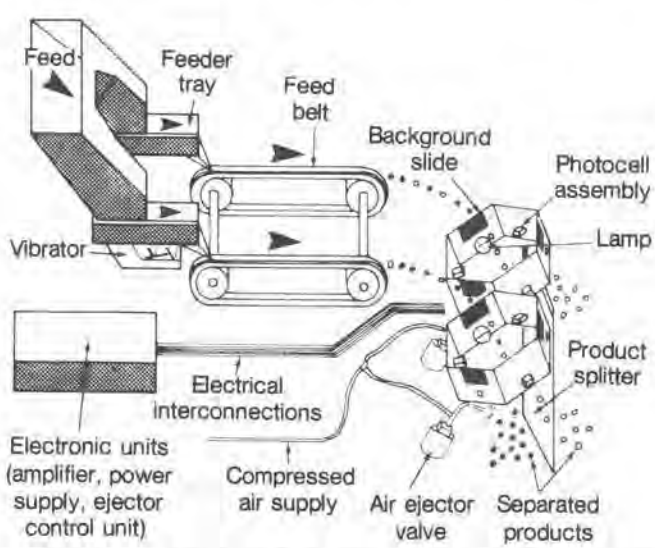


Figure 26.—Schematic of electronic optical sorter used to recover flint glass.

Figure 27.—Batch flotation of glass.

glass container manufacturers to the glass produced for this early test.

The Bureau also conducted research on a variety of methods to utilize waste glass that did not require the quality needed for new containers. Methods for producing brick and glass wool insulation from incinerator residues were developed (*57-62*); typical products are shown in figures 28 and 29. In using waste glass as a flux for clay bricks, the Bureau found that the bricks were suitable for facing brick and that the maturing temperature of glass-brick was from 400° to 500° F below conventional clay-brick maturing temperatures, thus reducing energy requirements and increasing kiln capacity. Demonstration brick has been successfuly in use for over 10 yr as the entranceway to the Bureau's Tuscaloosa Research Center (fig. 30). Research in producing glass wool from incinerator residues showed that physical characteristics of the wool could be controlled by varying the composition of the melt. Fine fiber wool was found suitable for loose fill insulation in attics or acoustic ceiling tile, while coarse fiber wool was acceptable for blanket insulation in building walls.

Methods were also developed for utilizing waste glass from incinerator residues in floor tile and glass reflecting beads. Cost evaluations of the processes studied indicated favorable economics (*63-64*). For over 7 yr, demonstration tile made from 40 wt pct ground glass recovered from refuse and 60 wt pct clay waste from a Florida sand operation have been in use on the entryway of the Duncan Fletcher State Office Building in Tallahassee, FL. Individual tiles used in this application are 9 in long, 4-1/2 in wide, and 1/2 in thick.

Figure 30.—Glass brick used on entranceway and planters at Bureau of Mines Tuscaloosa Research Center.

The Bureau also provided approximately 3-1/2 st of glass recovered from the raw refuse pilot plant to Brookhaven National Laboratory for use in tests on forming a glass polymer composite (GPC) made into pipe for storm drains and sanitary sewers. The GPC pipe retained its strength better than did pipe made from vitrified clay, asbestos cement, or reinforced concrete, especially when tested under acid conditions (*65*). A 10-ft section of 12-in-diam pipe was installed in an industrial sewer in Newark, NJ, in 1975, and two additional sections were installed in 1978, all with excellent results.

Under contract to the Bureau, the University of Alabama initiated an investigation on the possibility of using

Figure 29.—Glass wool made from incinerator residue glass fractions.

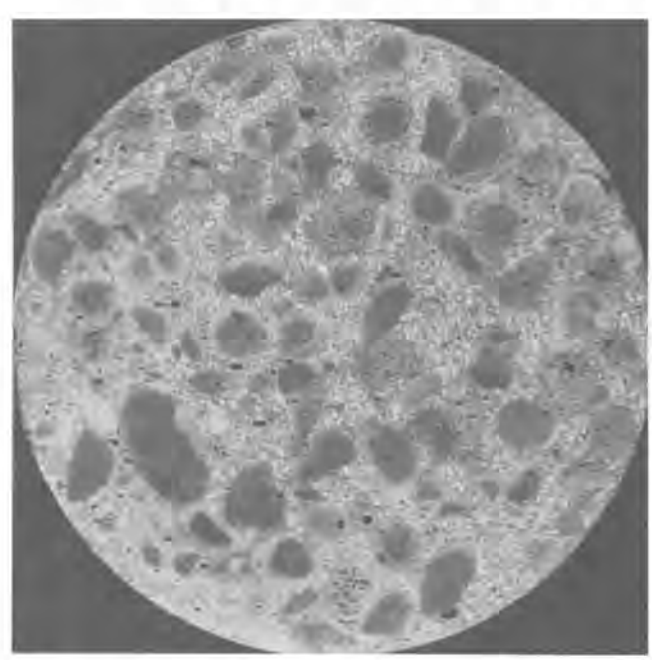


Figure 31.—Lightweight concrete made from incinerator residue glass fractions.

incinerated waste glass as an ingredient in lightweight aggregate (*66*). Acknowledging the potential of this initial study, the Bureau continued the research (*67-68*) and found that a mixture of 78 wt pct waste glass, 20 wt pct clay, and 2 wt pct dry sodium silicate, when fired at 1,550° F for 15 min, produced aggregate having a bulk density of 38 lb/ft³. Glass aggregate concrete (fig. 31) has an average unit weight of 102 lb/ft³ and a compressive strength of up to 3,025 psig. To meet American Society for Testing and Materials specifications, concrete having a unit weight of 105 lb/ft³ must have a minimum compressive strength of 2,500 psig.

COMBUSTIBLE PRODUCTS

Plastics

The composition of the three cyclone products from raw refuse processing (flowsheet, figure 8) was primarily paper, plastic film, light fabric, and, during the fall season, significant quantities of leaves. One important phase of the research on unburned urban refuse was aimed at producing a paper-free plastic concentrate. The method investigated utilized a high-tension (electrodynamic) separator, shown in figure 32 (*69*). Separation of plastics from paper is based on the fact that paper is a partial conductor and plastic is a nonconductor. When water is added to a mixture of plastic and paper, the paper absorbs the bulk of the water and becomes more conductive. The plastics, which do not absorb moisture, remain nonconductive. This difference in conductivity enables a clean separation to be made on a mixed paper-plastic product, with the paper fraction falling on the front side of the diverter plate shown in the figure. Results of tests to establish the effect of moisture content on the separation of plastics from paper are given in table 15. The data show that the moisture content of the feed material has a pronounced effect on separation efficiency. At 0 wt pct moisture, all material reported to the plastic concentrate. All other moisture content levels resulted in a paper fraction free of plastic. However, 55 wt pct moisture was required to obtain a plastic fraction free of paper in one pass through the high-tension separator.

Table 15.—Effect of percent moisture on separation efficiency of plastics from paper, weight percent

Moisture, wt pct	Plastic concentrate		Paper concentrate	
	Plastic	Paper	Plastic	Paper
0	12.0	88.0	0	0.0
10	68.3	31.7	0	100.0
15	72.4	27.6	0	100.0
20	88.1	11.9	0	100.0
25	90.8	9.2	0	100.0
30	94.1	5.9	0	100.0
35	96.5	3.5	0	100.0
40	98.7	1.3	0	100.0
45	99.4	.6	0	100.0
50	99.8	.2	0	100.0
55	100.0	.0	0	100.0

A method for separating and reusing the various plastics discarded in municipal refuse also was investigated (*70-74*). The plastics were separated into three major thermoplastic families—polyolefins, styrenes, and vinyls—based on differences in density using a sink-float-elutriation hydraulic separator (fig. 33). Results of a typical separation made in the unit, given in table 16, show that separation efficiency was extremely good. The polyolefin product with a density of less than 1, which was the bulk of the plastic type in this particular sample, was essentially a

Figure 32.—High-tension (electrodynamic) separator used to separate paper from plastic.

Figure 33.—Sink-float plastic separator.

Table 16.—Results of hydraulic separation of waste plastics from municipal refuse, weight percent

	Polyolefin	Polystyrene	Polyvinyl chloride
Distribution in feed	95.2	2.2	2.6
Sink-float analysis of fraction by density specified:			
<1.0 g/cm³	99.9	12.0	0
1.0-1.2 g/cm³	.1	86.6	2.5
>1.2 g/cm³	0	1.0	97.5

pure product. The second product, which had a density of between 1.0 and 1.2, analyzed better than 92 wt pct polystyrene. The polyvinyl chloride product, which had a density greater than 1.2, analyzed over 99 wt pct polyvinyl chloride.

Fiber Recovery

Samples of raw refuse pilot plant cyclone products also were submitted to various private companies for evaluation as potential sources of secondary fiber. Definite commitments were not obtained as to the utility of the materials in making new fiber products. However, some verbal reports were encouraging to the extent that it was suggested that the products from cyclones 1 and 2 (flowsheet, figure 8), with proper cleaning and sterilization procedures, could be used to make lower grade fiber products such as boxboard.

Refuse-Derived Fuel

Prior to its transfer to the Department of Energy in 1977, the Bureau's Pittsburgh Energy Research Center investigated the conversion of municipal refuse into gas, liquid, and solid fuels by pyrolysis (*75-77*). Pyrolysis was conducted by heating combustibles at atmospheric pressure in the absence of air and, as applied, is almost the same process as that used for the manufacture of coke and charcoal. Results of the pyrolysis at 900° C of a typical municipal refuse sample is given in table 17.

Major combustibles constituents in the gas were found to be hydrogen, carbon monoxide, methane, and a small amount of higher hydrocarbons. The mixture has a heating value of 447 Btu/ft³ and represents 7.93 million Btu/ton of feed, or a heat recovery in the gas alone of 82 pct. The aqueous product was mostly water, and the residue was a lightweight flaky char that had a heating value of over 5,000 Btu/lb.

The Pittsburgh Energy Research Center also investigated and patented a process to convert the organic fraction of municipal refuse to oil using carbon monoxide and steam under pressure (*78-82*). Typical results of the investigation, with the conditions of trial, are given in table 18. The studies concluded that an oil yield of 23 wt pct from refuse was fairly good because the ultimate theoretical yield from these materials is about 50 wt pct (*80*).

Table 17.—Products from pyrolysis of municipal refuse

Product	*Yield per ton of feed*
Gas, ft³	17,741
Oil, gal	0.5
Ammonium sulfate, lb	25.1
Aqueous, gal	113.9
Residue, lb	154

Table 18.—Results of continuous bench-scale test to convert municipal refuse to oil

Test conditions and results	*Value used or obtained*
Conditions:	
Feed—pulped refuse slurry, wt pct H_2O	85
Gas	CO
Temperature, °C	350
Pressure (CO + steam), psig	4,000
Residence time, h	2
Results:	
Oil yield, wt pct of charge	23
Oil properties:	
Viscosity, cP at 150 °C	200
Approximate formula	$(C_{11}H_{19}O)_n$
Heating value, Btu/lb	15,000

Inasmuch as the combustible fraction of municipal refuse had been extensively considered as a fuel supplement for coal in the generation of heat and power, the Pittsburgh Energy Research Center again cooperated to determine the heating value of the combustible products recovered at the raw refuse pilot plant (*83*). The study concluded that the calorimetry methods used to evaluate the fuel values of coal were suitable for use on refuse and that municipal refuse contained approximately half the heating value of high-quality coal. Samples of all the combustible products recovered at the pilot plant during tests on refuse from various municipalities were sent to the Pittsburgh facility for fuel evaluation. Duplicate samples from several communities were also sent to the calorimetry laboratory at the National Bureau of Standards (NBS), where a study to evaluate refuse-derived fuel (RDF) was commencing. The fuel values received from NBS agreed with the values obtained from the Pittsburgh Energy Research Center.

Table 19 shows the range in total fuel values obtained from analyzing the combustibles recovered from these tests (*18*).

The Bureau recognized that an important concern in using the combustible fraction of municipal refuse as a fuel supplement was the possible environmental impact from trace elements released to the atmosphere during the combustion process (*84*). In addition, it recognized problems associated with characterizing highly variable municipal waste and conducted studies to develop reliable and accurate analytical methods for determining the amounts of trace elements contained in the refuse (*85*).

As a result of this concern, an extensive investigation was made to determine the concentration of major, minor, and trace elements in the combustible fractions collected following various processing steps in the Bureau's raw refuse pilot plant (*86-89*). Twenty-five elements were determined in samples from six geographic areas and were compared with element concentrations found in typical coal samples. The studies found that, in general, the concentra-

Table 19.—Fuel evaluation of total combustible products recovered at raw refuse pilot plant

Total combustible products without fines[1]	*Calculated values*
Higher heating value[2], Btu/lb	8,107-9,065
Moisture, wt pct	14.5- 34.9
Ash[3], wt pct	6.2- 10.0
Sulfur[3], wt pct	0.1- 0.3
Chlorine[3], wt pct	0.2- 0.7
Percent of combustible products[2]	81.0- 91.4

[1]When fines (primarily glass and dirt) were not removed from the combustible products, fuel evaluations were 100 to 400 Btu/lb lower and ash content was 1 to 3 pct higher.
[2]Moisture-free basis.
[3]As-recovered basis.

tions of several trace and minor elements such as cadmium, copper, lead, mercury, silver, and zinc were one or two orders of magnitude higher in the combustible fraction of municipal refuse than in coals. Titanium was also higher in refuse by about a factor of 4. The chlorine content, probably in the form of chloride salts and in some plastics, was also an order of magnitude higher in the refuse than in coal. The sulfur content of the refuse fraction, on the other hand, was one order of magnitude less than in the coals evaluated. Mixing RDF at a 5- to 20-wt-pct ratio with coal had the advantage of slightly lowering the total sulfur content of the fuel as well as diluting the elements of high concentration in the refuse combustibles.

Metal concentrations in raw refuse and incinerator residues also were determined to ascertain whether the metals that appeared in the residues came from the combustible or noncombustible portion of municipal refuse (*90-94*). These studies indicated that cadmium, chromium, lead, manganese, silver, tin, and zinc apparently came from both the noncombustible and combustible components of refuse. Removal of the noncombustibles from municipal refuse prior to use of the combustible components for fuel showed a reduction in the concentrations of these seven metals. In addition, concentrations of antimony, cobalt, mercury, nickel, and possibly other metals would be reduced in the residues by removing the noncombustibles prior to burning. By not including the heavy combustibles, especially the heavy gauge plastics, the concentration of cadmium and copper was further reduced. The light combustibles were found to be the RDF source containing the lowest concentrations of trace and minor elements.

Because of the interest in using the combustible fraction as a fuel supplement, the Bureau prepared RDF samples as proposed reference material for use by other research organizations to evaluate analytical procedures (*95*). The reference material was prepared by shredding, milling, and blending the light combustibles recovered from pilot plant samples obtained from several municipalities. The study concluded that an RDF reference material could be prepared. Homogeneity was verified by comparing analytical values for replicate samples. A comparison of results from three cooperating analytical laboratories found no significant differences in terms of evaluating potential environmental impact.

Composted Refuse

Although the Bureau did not conduct any research to convert municipal refuse into compost, it did cooperate with other government and private research organizations in the country that were using municipal refuse or fractions of municipal refuse for compost production. The Bureau's primary research effort involving composted refuse was in its mine tailings stabilization work, which used compost produced by one of these other research organizations. Generally speaking, tailings discarded by mineral processing operations create environmental problems because tailings are sterile and lack the essential nutrients as well as the physical nature required for sustaining vegetative growth. The Bureau conducted some tests using combinations of chemical-vegetative procedures that prevent wind and water erosion of fine-sized tailings products. Laboratory experiments showed that composted municipal refuse was a useful supplement to chemical additives in promoting germination and plant growth on typical mill tailings (*96-97*). The studies indicated that microbial populations at the surface increased dramatically when an acre of tailings was mixed with the equivalent of 15 st of composted municipal refuse. Pelletizing the tailings with additions of compost and placing a 1-1/2-in layer of the pellets over tailings that contained a layer of compost 3 in below the tailings surface improved plant growth by providing a better root environment. In essence, an artificial soil was created.

Other Bureau cooperative efforts included providing samples of raw refuse pilot plant products to the U.S. Department of Agriculture (DOA) for use in studies being conducted on windrow composting at its Beltsville, MD, research facility. Quantities of heavy organics remaining after the aluminum recovery circuit, dewatered organic wastes discharged by the mineral jig in the glass recovery circuit, and light paper and plastic discharged from the cyclones were used successfully in DOA tests. Plastics contained in the pilot plant products were not biodegradable and, hence, adversely affected the appearance (but not the nutrient value) of the compost produced.

OTHER PRODUCTS FROM PROCESSING INCINERATOR RESIDUES

Generally speaking, the residues processed from newer incinerators with higher operating temperatures contained virtually no unburned organic material. The flotation tailings, slag, and waste sands were inert and, providing they could pass the Environmental Protection Agency's toxicity test, would be suitable for almost any type of fill. The finest size waste product produced in the pilot plant was the carbonaceous ash fraction reporting to the filter cake. This material normally contained 1 to 3 wt pct each potash and phosphorous, and conceivably could be used as a soil conditioner for highway embankments or grassy median strips.

To provide a comprehensive study of the various products associated with incinerator residues, the Bureau funded a grant to the University of West Virginia to characterize and analyze the fly ash fraction recovered at a number of municipal incinerators (*98*). In summation the study showed

1. Fly ash was uniformly distributed by size.
2. In a number of the samples certain metals were found to be present in amounts that appeared to be near ore concentrations currently considered minable. For example,
   A. Aluminum: present in amounts up to 15 wt pct.
   B. Silver: in one sample amounted to 19 oz/ton, which exceeds some current silver ore assays.
   C. Copper: in some cases approached 0.2 wt pct, which exceeds the grade of some copper wastes currently being leached.
   D. Other elements of interest: lead, 0.7 wt pct; tin, 0.09 wt pct; zinc, 0.9 wt pct.

The Bureau also conducted its own characterization studies of various aqueous emissions from typical municipal incinerators to determine the concentration of dissolved metals (*99-102*). The studies indicated that cadmium, chromium, lead, manganese, silver, tin, and zinc found in the aqueous discharges were actually derived from the noncombustible sources of the refuse. The studies recommended that removal of the noncombustible components of municipal waste prior to burning would no doubt reduce the emissions of these seven metals.

FURNACE TREATMENT TESTS ON INCINERATOR RESIDUE

The American Society of Mechanical Engineers' Research Committee on Industrial and Municipal Wastes has expressed concern regarding the suitability of using incinerator residue as landfill material. In response, the Bureau proposed a method for converting the waste into a desirable fill, and test heats were made on incinerator residue in an electric arc furnace to determine if a glassy slag could be produced that would pass Environmental Protection Agency (EPA) ground water leaching tests for drinking water standards. Successful trials were conducted in a 300-lb electric arc furnace, and both the metal and slags produced were subjected to standard extraction procedure (EP) toxicity tests and passed without problem. A control sample of "as-received" incinerator residue, however, did not pass the toxicity test. The leached lead content, while high at 2.0 ppm, was within the 5.0 ppm EPA limit, but the cadmium in solution was 1.5 ppm versus the EPA limit of 1.0. These two metals are of major concern when incinerator residue is landfilled. These tests determined that the slagmaking procedure is technically viable.

COMMERCIAL APPLICATIONS OF BUREAU TECHNOLOGY

Ferrous and nonferrous metals have been recovered from incinerator residue at the Pinellas County, FL, Energy Recovery Plant. This plant incinerates 2,000 st/d of refuse and is operated by Signal-Resco, Inc. Following incineration, the residue is conveyed to the materials recovery section of the plant where the metals are separated for recycling by shredding, screening, and magnetic and heavy-medium separation. A number of other incinerators operating in the United States are screening the residue and magnetically separating a ferrous fraction for recycling.

A number of facilities throughout the country that are designed to process raw refuse have developed a considerable number of operating problems; however, some of the commercial firms that have applied technology developed at the Bureau's raw refuse pilot plant have met with success. As shown in table 5, raw refuse consists of 63 to 83 pct combustibles; hence the economic viability of raw refuse processing is dependent upon the successful marketing of the combustible products. The Monroe County, NY, refuse processing facility, operated by Raytheon Service Co., had for 4 yr recovered and marketed ferrous, nonferrous, and cullet-grade glass products; however, when the combustible product recovered at the facility was determined to be an unsuitable fuel by the Rochester Gas and Electric Power Plant, lack of another market for the combustibles led to the closure of the 2,000-ton/d facility in July 1984. Equipment installed at the second plant built by Raytheon in New Castle County, DE, includes steam-generating and turboelectric machinery to convert the combustibles into electric power that is sold to the Delmarva Power and Light Co. Additional revenue is generated at this facility by the successful recovery and marketing of ferrous, aluminum, and glass products. Figure 34 shows the glass flotation circuit at the 1,000-st/d Delaware Solid Waste Processing Plant. Glass from this plant is being used by a fiberglass producer to make building insulation. National Ecology (formerly Teledyne National) conducted cooperative studies with the Bureau's researchers at the raw refuse pilot plant and built a facility in Baltimore County, MD, that has processed 600 to 900 st/d of refuse since 1976.

Figure 34.—Froth flotation cells for recovering glass at the Delaware Solid Waste Authority Reclamation Plant.

Various types of ferrous, nonferrous, and glass recovery equipment have been demonstrated at this facility. The combustibles are prepared as RDF for the Baltimore Gas and Electric Co., glass is used to make fiberglass, and nonferrous metals are handled by a commercial secondary processor.

Plants located overseas have also benefitted from Bureau technology. The Clean Japan Center in Tokyo (*103*) recovers nonferrous metals from refuse by eddy-current separators pioneered at the Bureau pilot plant. Cooperative agreements between the Bureau and Empresa Nacional Adaro de Investigaciones Mineras S.A. (Adaro) led to Adaro's construction of six resource recovery facilities located in four European countries. In Spain, Adaro does not burn the combustibles in refuse; instead paper, plastics, and compost are individually separated for recycling, and the residue is landfilled.

SUMMARY

This report has described the operation of the Bureau's pilot plants for treating both incinerator residue and raw refuse, technology developed for using the magnetic products recovered from resource recovery plants, and methods devised for recovering usable nonferrous metals and glass from refuse. These pioneering studies were conducted by the Bureau primarily between 1966 and 1979 and provided much of the technology and encouragement municipal officials needed to implement resource recovery in their jurisdictions. The Bureau concentrated its research on recovering mineral values in the noncombustible fraction of muncipal refuse, for in many municipalities the combustible fraction is used for its heat value. Since some of these municipalities have heat-recovery incinerators and others have processing facilities producing RDF for a dedicated boiler, techniques developed at both of the Bureau's pilot plants have application. In areas where markets can provide an economic incentive, unit operations pioneered by the Bureau have been successfully adopted for the recovery of metals and glass from the wastes.

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