

PROCESSING OF MATERIAL MINED FROM LANDFILLS

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ABSTRACT

Collier County, Florida began mining one of their closed landfill cells in 1986. There were several motivations: recovery of recyclable materials, recovery of the landfill space for reuse and production of a humic material both for daily cover and possible use as soil augmentation off-site. Markets for recycled materials led to further consideration of processing the mined material to recover salable components that had not degraded. The development of a process train for mined material became an independent research effort. Various types of screening, ferrous and nonferrous metals recovery, and density separation were considered to various degrees. Some were rejected due to shortcomings immediately obvious from waste characteristics, and some were actually tried. Included have been: shaker screens, trommels, tail-rotor magnets, belt magnets, eddy-current separators, air classifiers, and air knives. As equipment was tried, its performance was assessed through material characterizations involving hand-sorting and screening. This paper presents a discussion of goals and the process of equipment evaluation. Data on material characteristics after various steps are presented and analyzed. Experience with equipment is discussed. Recommendations are formulated for processing of material mined from degraded fills, as well as for industry enhancement of this type of development.

INTRODUCTION

Florida has a preponderance of sandy soils that are not ideal for use as daily cover. Collier County, wherein is located Naples, Florida, is a heavily residential county with little industry. In 1986, Collier County began to mine a landfill with the primary intention of recovering the soil that had been used therein for daily cover, hoping that degradation in the intervening period had adequately stabilized the waste. It was found that, not only had the degradation stabilized the waste, but it had actually transformed most of the organic portion of the waste into more humic, or soil-like, material, with virtually no odor. It was then thought that, with full-scale mining of an old landfill, not only could adequate daily cover be provided for daily cover, but surplus humic material could be used off-site for soil emendation.

It has become increasingly recognized, largely through the work of Prof. William Rathje, an anthropologist at the University of Arizona, that dry, closed landfills do not degrade their contents in 20–40 years of closure. Anomalies attract him, and he studied the Collier County Landfill [1]. In consultation with this paper's writers, it was determined that this was an old-style Florida landfill: located above-ground, with minimally-impermeable cap, sides, and liner, in a wet, warm area. The landfill thus had significant moisture.

The region had far fewer persons when the landfill was begun in the 1950s; growth accelerated rapidly, as it continues to do. This indicates that early sections of the landfill were close to the surface for long periods. Later sections were, of course, closer to the surface after closure. This would give, in the Florida climate, extensive opportunity for aerobic degradation throughout the fill. Comparatively little odor was noticed in the mined material, although some pockets of anaerobic activity did assault the senses. On this basis, it was determined that most of the landfill was substantially stabilized. The nonodiferous nature, and the fact that a landfill closed only 10 years earlier was stabilized, led to the conclusion that substantial aerobic activity had occurred. It was foreseen that new cells being operated and built on the same site according to current standards would degrade much more slowly. Thus, one phase of this work involved altering the manner of operation of a landfill, turning it into an aerobic reactor. Current indications are that this concept is successful, and publications are being prepared. In addition to new landfill designs, this concept can also be applied as a retrofit to existing landfills, in much the same sense as gas extraction is currently fitted to old fills. With incorporation of this concept in landfill design and retrofit, the concept of mining a landfill would become applicable to all landfills.

Enhancing the recovery of desirable products from the landfill has been the other principal focus of this work. While the recovery of humic materials was the primary impetus to the work, it was recognized that significant portions of the waste were not degradable, and would not degrade during the time period required for stabilization of the organic fraction. As markets are being developed for recyclables recovered from solid waste, these materials could have markets that, if not actually generating revenue, could reduce the volume requiring redisposal.

Automated processing was considered for all phases of this recovery. As is detailed in the next paper in this volume, economic calculations with conservative assumptions repeatedly showed that automated processing was more cost-effective than manual sorting. This is not meant to imply that the current state of market-ready processing technology stands ready to replace all manual effort. Research and development are continuing; the concept calls for replacing any manual sorting with automation as technology evolves. Nevertheless, considerable equipment exists to process mined material. Evaluation of alternatives was conducted by considering the task required, the markets available, and the individual separation tasks required to reach these goals [2]. To the extent possible, equip-

ment was experimented upon. This paper discusses concepts, equipment, tests, data obtained, and the interpretations of these efforts.

MATERIALS AVAILABLE FOR RECOVERY

Following proper design procedure, the first step is to determine the materials that one desires to recover [2]. This requires both a preliminary assessment of markets and a characterization of the materials to be processed for sale.

It is difficult to develop separation systems for a new form of waste without being able to custom-design, test, and modify equipment: one is constrained by the separation capabilities of existing equipment. One does not know what that maximum product quality is until a unit operation is specifically designed for the application, often after evaluation of the feed by the manufacturer. In addition, recovered materials markets are in a state of tremendous flux, as industry gears up to meet this public demand.

Collier County is 150 miles from the nearest major industrial area (the Tampa Bay area). This gives a more realistic assessment of markets: consumers of recyclable materials must either be those industries that are viable in a relatively low-density area, or the value of the materials must justify a nontrivial transportation component.

The first effort, then, was to study composition. Following standard practice, a set of categories of waste materials was formulated, in conjunction with Prof. Rathje's Garbage Project. These categories are used throughout this paper; composition defines the makeup of waste material by reporting the mass percentage of each of those components. All are reported on the same type of bar graph, allowing easy cross-comparisons. Fines are defined by passage through a 1.27-cm (0.5-in.) screen. Further composition studies conducted by USF alone used the same techniques, although several of the categories were combined. Figure 1 shows the results. The tremendous number of fines is the most notable factor. The very few remaining identifiable organic materials made this young landfill interesting. Paper, one category of undegraded organic material, was only 10% of the total waste. Unidentifiable larger items were 18% of the waste. Wood was the one organic category that seemed to defy degradation. Notable also was the presence of nondegradable materials: ferrous metals, aluminum, plastic, and glass. Often, labels and glue had been removed from containers made of those materials by the degradation process. It was these four materials that became of interest to recycle.

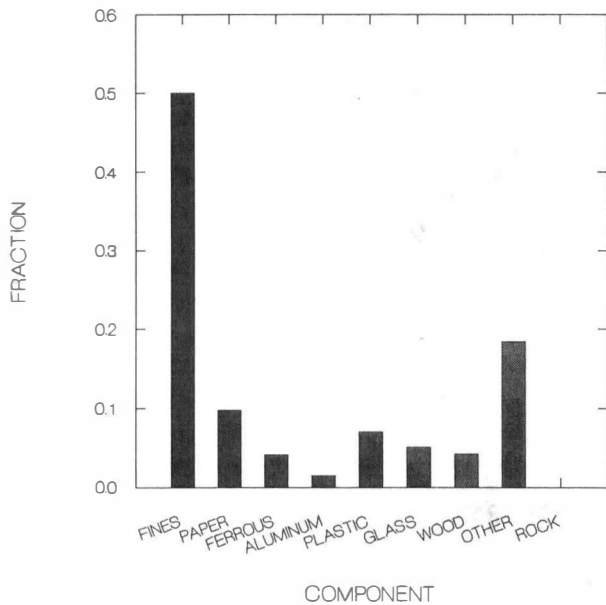


FIG. 1 COMPOSITION OF MINED MATERIAL BY MASS ("Rock" in "Other")

Glass was most often in cullet form. It had been collected in typical packer vehicles, driven over by landfill compaction equipment, and subject to mining and screening. Markets for mixed glass cullet are relatively poor. Combined with the transportation distances, it was decided not to pursue glass recycling from the mined material.

Aluminum and ferrous materials are desirable. Aluminum is somewhat more difficult to remove from the waste stream than steel, but aluminum is also more valuable. Recovery of both aluminum and ferrous materials were seen as desirable.

Plastics existed in considerable quantities. This is not surprising because, although the use of plastic containers has grown, the mass of each container has decreased as engineering and manufacturing technology improved. Nevertheless, many of the plastics that were readily identifiable were in sheet form. Technology does exist to clean and reuse such material, but it does not seem to have generated much interest in the United States [3]. Detect-and-route technology, which identifies polymers by spectral analysis of their response to various frequencies of electro-magnetic radiation and fires corresponding air jets to deflect the objects into appropriate bins, is available for purchase in Europe, but is only in the research and development stages in the United States [4]. Thus, particularly for film plastics, markets for mixed plastics were examined, and deemed likely to exist. These are also tolerant of more

contamination than more sophisticated recycling operations.

Thus, this study was undertaken to improve the recovery of plastics, ferrous material, aluminum, and fines.

At the start of USF's involvement, a mining and recovery system existed on the site. The objective was primarily that of a small-scale evaluation of the general concept of mining a degraded landfill, without system optimization.

Figure 2 shows the original configuration. The shaker screen was a wire screen with 7.6-cm (3-in.) openings, approximately 8-ft square. All conveyors were 3-ft belt conveyors; the overs stacking conveyor had a permanent magnet in the tailrotor. This held ferrous material to the belt so that it was ejected back under the conveyor, while nonferrous material projected away from the conveyor into a separate bin.

Examination of the material passing through the screen (unders) showed the extensive transformation of organic materials to a humic substance with a small particle size. Other materials that were present in the unders were clearly larger. It was immediately clear that a smaller screen-size was desirable. Looking at the materials not passing through the screen (overs), it was obvious to the eye that considerable fines were present. Further, screen jamming was frequently observed.

The tailrotor magnet was too weak (actual power unknown). Tailrotor magnets are generally acknowledged less efficacious than suspended magnets. There was considerable entrainment of sheet material in the ferrous material. There was much evident contamination in the nonferrous fraction. Even under the best of circumstances, further processing was required to separate aluminum and plastics.

Thus, without the need for further detailed analysis of the existing system, its enhancement was undertaken.

ALTERATIONS OF SCREENING PROCEDURES

Extraction of a well-defined fines fraction from a highly varied waste stream has been shown to be best achieved by a trommel [5]. A trommel was obtained for demonstration purposes. Data were gathered from its operation alone, and in combination with the shaker screen.

The trommel was a Powerscreen unit originally designed for removal of dirt from brush. It was equipped with a grizzly to remove large items (a grizzly is a set of parallel bars angled so that material not passing

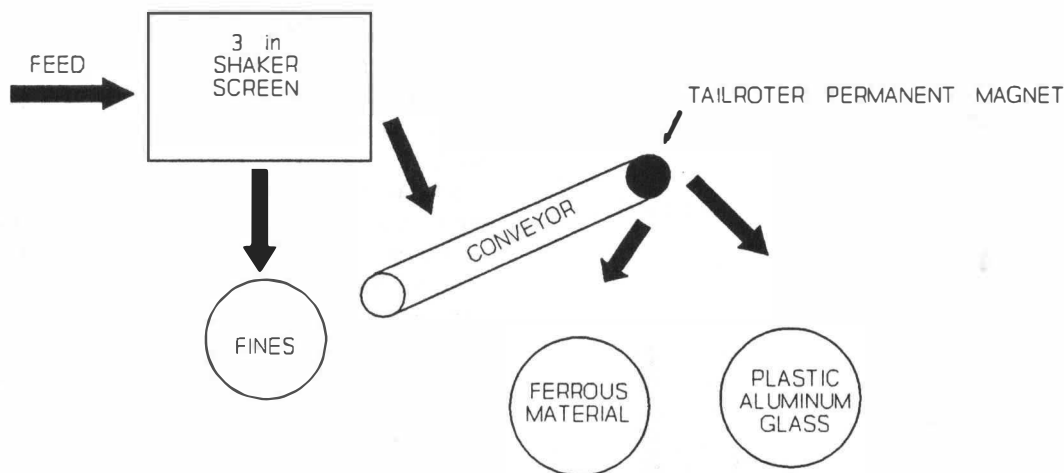


FIG. 2 ORIGINAL PROCESS TRAIN

between the bars falls to the side; the bar angle can often be adjusted, moving the bars). The trommel itself was 5.5 m (18 ft) long, with a 2.1-m (7-ft) diameter. There were small triangular flights of 7.5 cm (3 in.) in height. The hole diameter was 1.9 cm ($\frac{3}{4}$ in.). Throughput was approximately 70 tonnes per hour. Examination of trommel in operation gave the impression that it was close to an appropriately optimal design for this use. This was verified with design tools developed at USF [5], with only the need for additional length.

The trommel unders looked absolutely like soil. The 1.9-cm ($\frac{3}{4}$ -in.) holes were the correct size to prevent passage of non-humic materials. In a categorization, virtually all of the unders would be classified as fines. Thus, only the overs were actually sorted in the laboratory. These data are shown in Fig. 3. Excellent separation of fines is shown by the low fraction of fines in the overs. Eleven percent mass fraction of the overs is fines. Figure 1 shows that those fines were roughly half of the total mined material; therefore roughly 94% of the fines in the mined material were recovered to the unders. In examination of data in subsequent sections, this seemingly-satisfactory recovery is shown to be inadequate; more fines must be extracted to reduce contamination of other recovered fractions. The high percentage of plastics is also of considerable interest. Plastics were considered the most marginal of the materials considered for recovery. Such a large fraction made it desirable to further isolate plastics.

Just as with the original system, the trommel only segregates the humic material. Further effort would be required to recycle plastics, aluminum, and ferrous metals. Following current practice, an assumption was

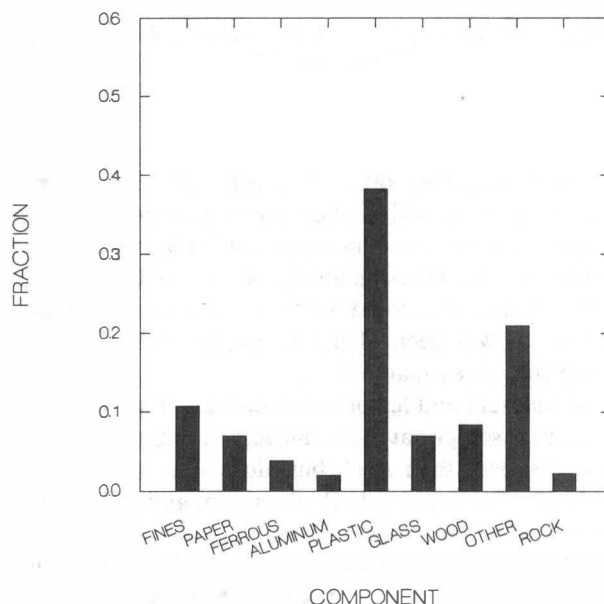


FIG. 3 MASS COMPOSITION OF TROMMEL OVERS

made that aluminum and ferrous materials would primarily be present in drink-container sizes. Therefore, a prior or further screening step was suggested to isolate cans. Just as with the glass, and, in distinction from curbside recycling, much compaction had occurred.

Combined with difficulty in obtaining unit operations for testing, it was decided to use the 7.6-cm (3-in.) screen. Two combinations were tried, as shown in Figs. 4 and 5. Sequencing the screen before the trommel would result in a combined fines and metals fraction reporting to the screen unders; this would have to be

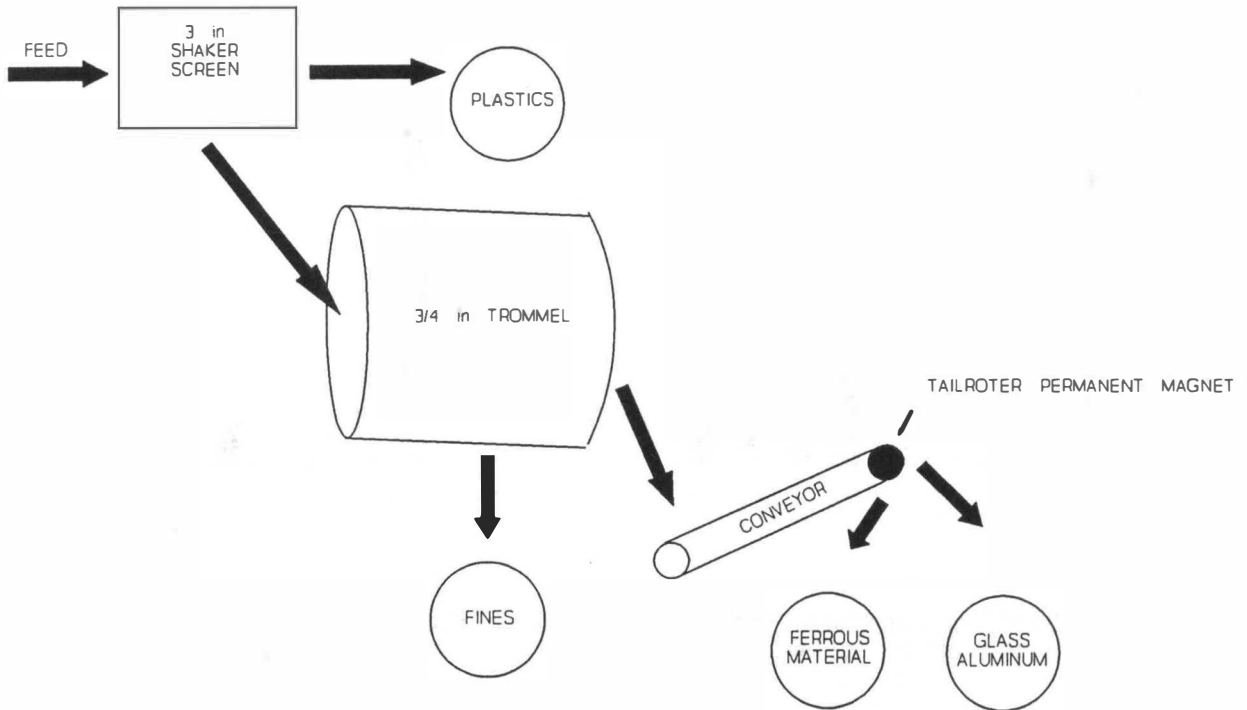


FIG. 4 SEQUENCED SCREENING: SHAKER SCREEN FOLLOWED BY TROMMEL

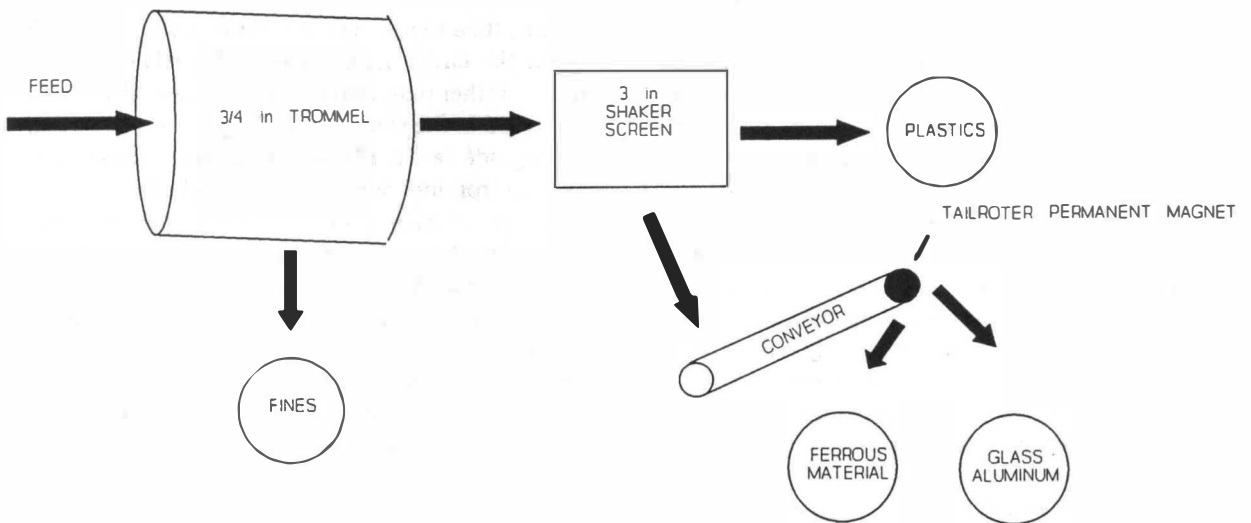


FIG. 5 SEQUENCED SCREENING: TROMMEL FOLLOWED BY SHAKER SCREEN

further sorted by the trommel to remove the fines. Plastics would report to the screen overs. Sequencing the trommel before the screen would first remove the fines, leaving the trommel overs to be sorted by the screen, with the metals reporting to the unders, and the plastics

to the overs. Because of the poor performance of the tailrotor magnet, it was decided to sample and sort the screen overs directly. This would also isolate the performance of the screen sequence from other operations.

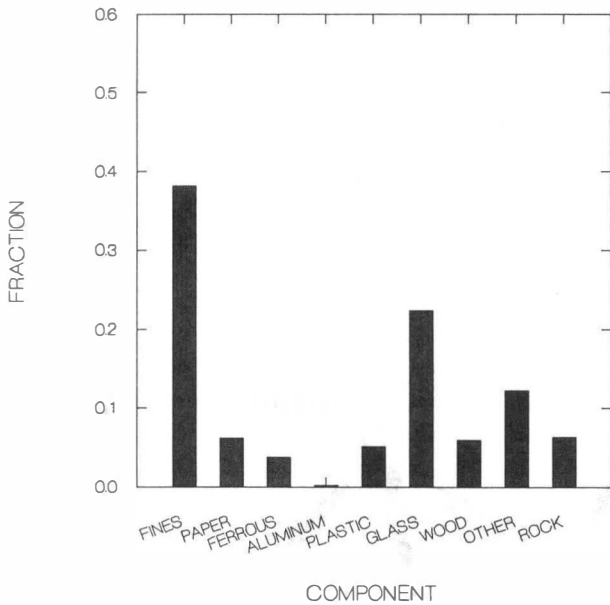


FIG. 6 MASS COMPOSITION OF SCREEN UNDERS; FEED WAS TROMMEL OVERS

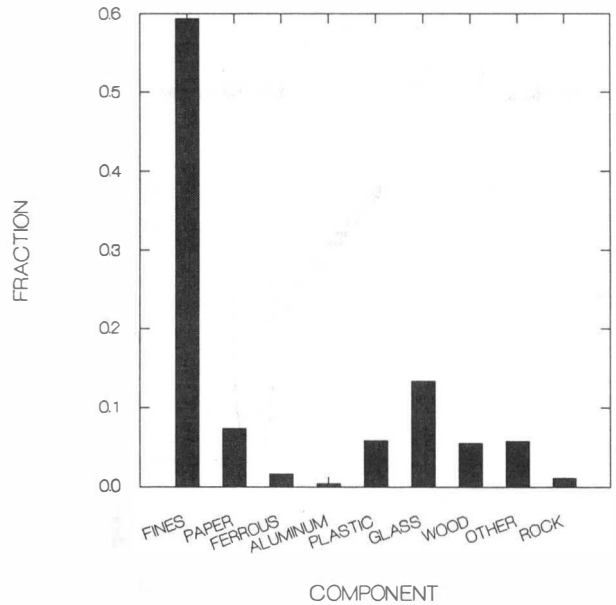


FIG. 7 MASS COMPOSITION OF SCREEN OVERS; FEED WAS TROMMEL OVERS

First are presented the results of the configuration in Fig. 4. Trommel unders are not reported here; they were 96% soil-like fines, as discussed above. There was a reduction in the amount of aluminum appearing in the trommel overs (see Fig. 3), meaning that aluminum was removed by the screen. However, there was no such concentration of ferrous material. It might be that older ferrous cans were stronger than their corresponding aluminum competitors: the rise of extruded steel cans is recent. This would imply that the compaction discussed above would occur primarily for aluminum cans. Glass and plastic also appeared in the trommel overs. That is not a good combination: glass contamination of the plastics fraction can damage extruders. Were glass largely of the single-serving bottle size, one might expect more to have been removed.

With the screen as the second unit operation (Fig. 5), taking trommel overs as feed, it was possible and useful to examine both the unders and overs from the screen. These are shown in Figs. 6 and 7. Glass showed an increase in the "drink-size," or screen under fraction. Trommels in solid waste management are often specified as at least the diameter of the test trommel to insure glass breakage. Thus, the increase in glass in the screen unders in this case may have been due to breakage in the trommel. Aluminum and ferrous were both significantly present in the screen overs, showing adequate recovery of neither. A possible explanation is that placing the trommel first significantly freed the plastics

of contaminants, allowing them to wrap around the plastic and aluminum and/or better occlude the shaker screen holes. If this applies to properly-specified screens, then the preferred order of screening would be to put the larger screen first, and further process the unders, rather than vice-versa. There was also considerable wood in the screen overs; large chunks of wood do not degrade easily. Plastics were somewhat segregated into the trommel overs, but the level of fines (remembering the efficiency of the trommel in its removal) shows that they were heavily contaminated. Comparison with Fig. 8 shows a cleaner product by having the trommel as the second unit operation; the screen removed the initial bulk of the fines, and the trommel served as a polishing operation.

The trommel was clearly the preferred screening device: its performance was better. Conversation with operating personnel and direct observation revealed that it gave far fewer problems: screen blinding was not a problem; there was negligible dust. Many waste processing trains use trommels for these reasons. It is likely that using a trommel with larger openings in place of the screen would have yielded much clearer results. Further, the size of the screen openings was too small, even for the substantially compressed nature of the feed.

The substantial prices paid for aluminum make it important to recover as much as possible, although the reduction in volume of material to be returned to the

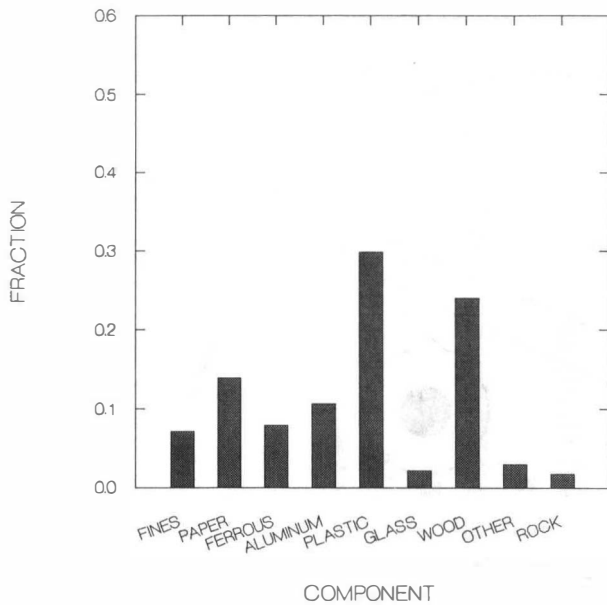


FIG. 8 MASS COMPOSITION OF TROMMEL OVERS; FEED WAS SCREEN OVERS

landfill may be insignificant. Neither of these systems could ever recover aluminum or ferrous material larger than drink container size. This would prevent the recovery of potentially considerable masses. If the recovered aluminum buyer could separate extruded from cast aluminum (easy to do with an air classifier), considerable revenue could be gained by collecting cast aluminum with a significantly higher bulk density. Also not recoverable by screening are aluminum bars and pipes, such as in lawn furniture. Similar arguments exist for steel. Thus, it was decided to evaluate systems that could recover metals by material, rather than secondary, properties.

ENHANCEMENT OF PLASTIC AND METALS RECOVERY

It was determined that the shaker screen did not provide appropriate segregation of aluminum and ferrous material. Therefore, further work was conducted on the mixed stream of plastic, nonferrous and ferrous materials that constitute the trommel overs.

To maximize quality, it was decided to attempt separation by material characteristics. The most obvious was to remove ferrous materials by use of a magnet. The analogous process for nonferrous materials is the eddy-current separator. After a bit of a commercial hiatus, these are returning to American market avail-

ability. Either of these are well-understood. The predominance of film and sheet material could adversely affect the operation of either of these unit operations by being carried with the metals as they are forced from the stream. The flexibility, low bulk density, and large area of the plastic sheet material make them very prone to being carried with smaller, rigid objects being separated. Thus, removal of sheet material was seen as a prerequisite. As discussed above, material-property unit operations are not market-ready in the United States for plastics.

The characteristics of materials that cause difficulty in metals recovery make air separation the most appropriate technique. Large area and low density give a low aerodynamic weight. An air classifier is not appropriate because of the large sheets that could sweep the throat, carrying everything above the sheet with it into the light fraction. Thus, an air knife was selected. No commercial device was available for testing, so a crude version was built in the laboratory from a blower nozzle set under the tailrotor of a 1.8-m (6-ft) conveyor. The blower produced approximately 42 m³/min (1500 cfm) at approximately 7 m/s (23 ft/sec). Eddy current separation must be preceded by ferrous separation to guarantee that no ferrous material enters the eddy current separator. One of the newer units on the market, made by Eriez, takes this to heart by combining the two, with the sizing and component sequencing of the magnetic separator done in conjunction with that of the eddy current separator. One such was located at a nearby David J. Joseph Co. car shredding operation. They allowed it to be used for a trial. The resulting process train, were it assembled in one place, would look like Fig. 9.

Figures 10-13 show the mass compositions of the nonferrous, ferrous, reject, and plastic streams, respectively. Several features are of interest. The Eriez device left absolutely no ferrous metal in either the reject or nonferrous streams; similarly, no aluminum in the ferrous metal or reject streams. The light fraction of the air knife contains little aluminum or ferrous metal. This shows that the system performed well in recovering both materials. The biggest concern involved heavy contamination of the ferrous fraction with fines. This may be because of the design of the Eriez device in forcing ferrous materials to exit the stream first; if fines were to follow any given stream, they would preferentially follow the first to be removed. Rather than a problem with the Eriez device, this pointed out that more screening was necessary.

Plastics also heavily contaminated the aluminum fraction; there was a greater fraction of plastics in the aluminum fraction than in the plastics fraction. How-

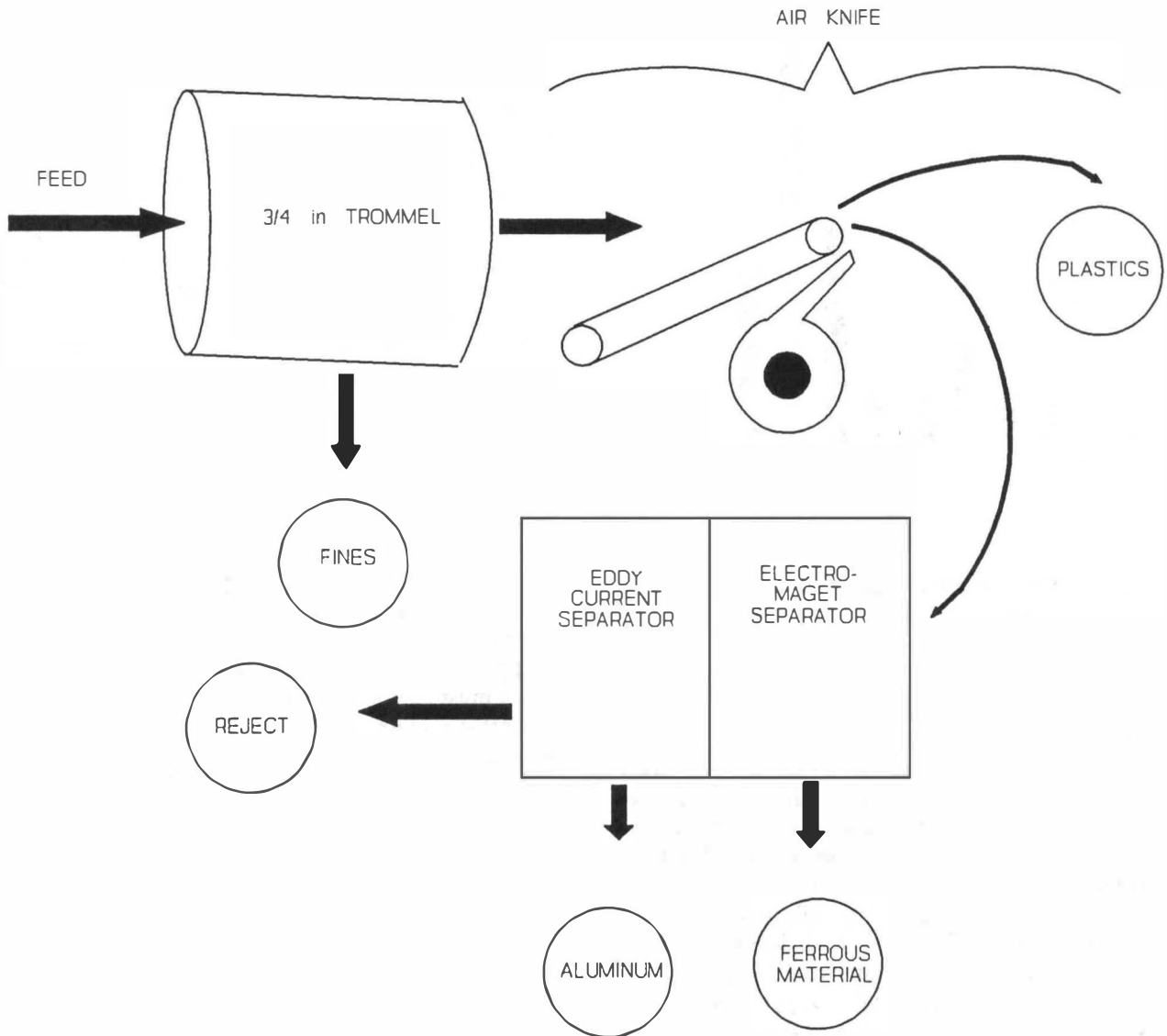


FIG. 9 TROMMEL, MAGNETIC, AND EDDY-CURRENT TRAIN

ever, it must be remembered that these are mass fractions: with the high presence of fines in the ferrous fraction and the greater bulk density of ferrous materials, calculation showed that there were approximately equal contaminations by plastic. Wood and rock were a significant contamination problem in both metal streams; both have higher specific gravities than the predominantly can-type metals, and so would have been present in the air knife heavy fraction along with the metals. All together, the system managed only to concentrate plastics by a factor of 10. As a measure of contamination, a ratio was taken of fraction by mass to fraction by volume. The low specific gravity of plastics

makes the lower number indicative of a cleaner product. In the trommel overs, the ratio was 0.71. The sequence of trommel followed by screen, giving the best result of that series of tests, showed a ratio of 0.67. However, the air knifed plastics were the cleanest, at 0.35. Clearly, though, the air knife was the weak link. Some commercial air knives are available with three streams. Because of a clearly-defined, very dense fraction consisting of rock and chunks of wood, it is valid to seek a "heavy heavies" reject fraction. The middlings would concentrate the metals. With a more carefully constrained airstream, again available in commercial devices, more plastics removal could be expected.

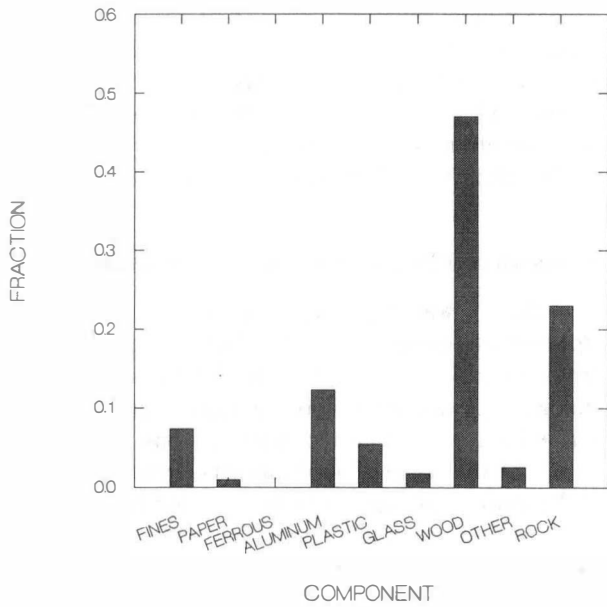


FIG. 10 MASS COMPOSITION OF THE NONFERROUS STREAM FROM THE AIR KNIFE TRAIN

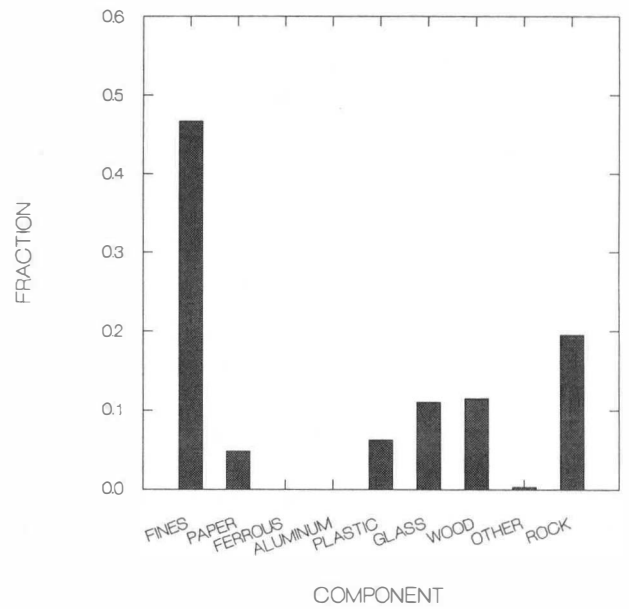


FIG. 12 MASS COMPOSITION OF THE REJECT STREAM FROM THE AIR KNIFE TRAIN

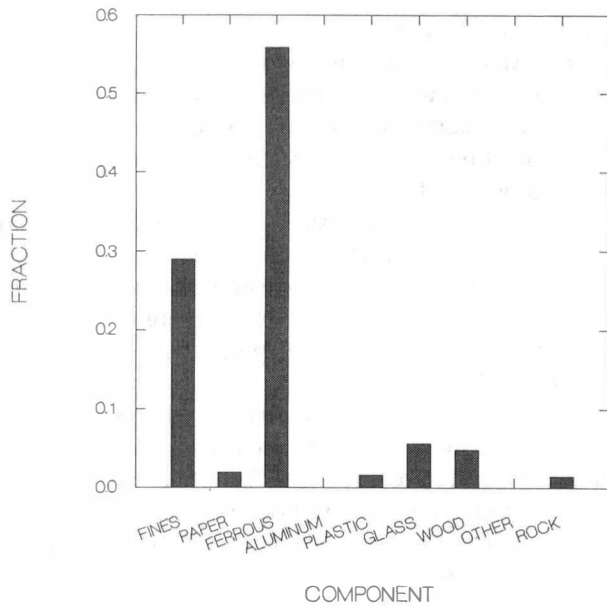


FIG. 11 MASS COMPOSITION OF THE FERROUS STREAM FROM THE AIR KNIFE TRAIN

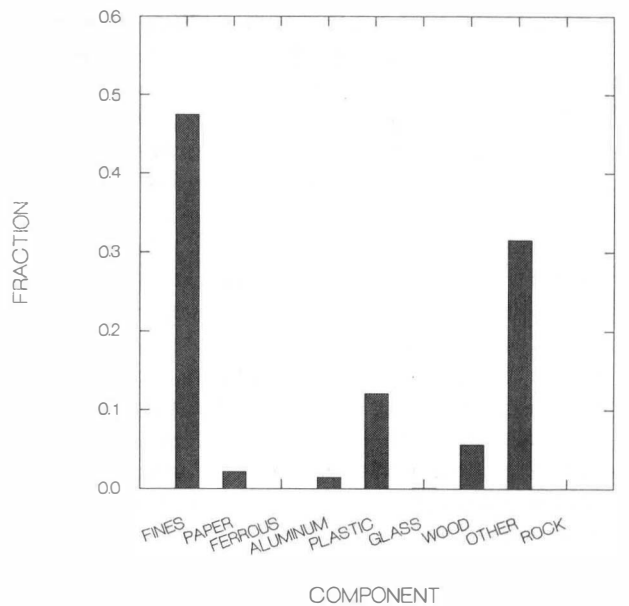


FIG. 13 MASS COMPOSITION OF THE PLASTICS STREAM FROM THE AIR KNIFE TRAIN

None of these materials streams met typical criteria for purity. However, most of this could be attributed to difficulties in screening or in the air knife. Further, it is not clear if changes in the operating parameters of the eddy current separator would have reduced con-

tamination while costing little to the perfect metals recovery shown in Fig. 12. Nevertheless, significant concentration of ferrous metals, aluminum, and plastics were achieved.

CONCLUSIONS AND RECOMMENDATIONS

One can draw two categories of lessons from this work: one stems from indications of the best process train revealed by these nonideal efforts; the second concerns difficulty in conducting definitive work of this type.

Process Train Recommendations

Despite difficulty in achieving marketable quality, several conclusions can be drawn and recommendations made:

(a) The recovery of materials from mined material made the removal of fines very critical to acceptable quality of the other materials. This required removal in considerable excess of that needed simply to achieve satisfactory recovery of humic material.

(b) Trommels are clearly preferable to shaker screens.

(c) The trommel design was close to that necessary. However, the need for additional screening to reduce contamination of other recyclables required that the trommel should be longer: approximately 9 m (30 ft). Alternatively, feed rate could have been reduced by roughly 35%. In all cases, feed rate must be carefully controlled to assure adequate fines removal.

(d) It was not possible to determine whether two screening operations would be a worthwhile investment. Given the priority on fines removal, further removal might be affected with the additional agitation. In that case, the balance of fines contamination of the plastics fraction, and the metals fractions would determine whether the larger trommel would precede the smaller or vice versa. Current practice seems to indicate that the trommels should be in order of increasing holes size; this may simply be a remnant of the days of the dominance of the multi-segment trommels. These results suggest the use of a smaller-hole trommel to process the unders of a larger-hole trommel. In any case, the trommel hole size should be greater than that used: a minimum of 13 cm (5 in).

(e) Magnetic and eddy-current separators are both very effective for recovery. They depend upon good preprocessing for adequate purity, however.

(f) There was good indication that the air knife would work. A three-way split would be required: a heavy reject fraction for stones and wood blocks, a middlings fraction for metals, and a light fraction for plastics. The airflow should be sufficiently contained to allow good residence time with sufficient agitation.

(g) The issue of automation versus hand-picking keeps recurring. In the case of a magnetic separator,

an example calculation was carried out. Assuming an equipment cost of \$20,000, a life of 10 years, no salvage value, an interest rate of 8%, electricity costs of \$0.08/kWh, a 5-kW magnet, the annualized cost of owning and operation is slightly less than \$4000/year. This is far less than half of the minimum possible labor costs.

Research and Development Recommendations

Difficulty was experienced in obtaining equipment upon which to experiment. Further, perusal of international journals indicates that all the options that technology provides are not being made available in the United States. Certain recommendations follow:

(a) As the range of applications of waste processing technology continues to broaden, engineers will continue to find new applications that will require testing before a financial commitment can be made. It would perhaps be wise to have one or more units constructed simply for demonstration purposes.

(b) In many cases, a new application may require modifications unforeseen when a trial begins. The demonstration units should be more flexible than production units: variable speed motors, interchangeable plates, etc. should be incorporated.

(c) An independent test and evaluation organization is needed. It could house both solid waste testing equipment and some permanent equipment, with other equipment on extended loan, and still more equipment loaned on an ad-hoc basis.

(d) The American waste processing industry should act to replace discontinued government research so that the United States can continue broad-based, significant innovation. This would require a structure to conduct long-term research and development, and a willingness to use its findings.

Landfill mining is an increasingly relevant option as siting of waste management facilities becomes increasingly difficult. Provided that fortuitous circumstance or new design provides well-degraded fill, considerable reusable materials are obtainable with efficient, automated processing. Opportunities for further refinement with new technology remain exciting.

ACKNOWLEDGMENTS

This work was funded by Collier County, Florida, and the Florida Center for Solid and Hazardous Waste Management. In addition, the authors would like to express appreciation for the extensive aid furnished by Powerscreen of Florida, Inc., who loaned screening equipment for evaluation, and David J. Joseph Com-

pany, who allowed use of their Eriez magnetic and eddy current separator.

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