AIR Classify FIRST, THEN SHRED

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ABSTRACT

Our five years experience in the shredding and processing of 800,000+ tons of solid waste, resulting in thirty (30) explosions, several of major consequence, dramatically illustrates a serious shortcoming of the conventional solid waste processing system of Shred First, then Classify. We found that the proposed system minimized danger of explosions, reduced wear in our shredders, and produced a classified waste fuel component having approximately 15 percent higher heating value and one third less ash.

INTRODUCTION

The Solid Waste Reclamation Industry has been growing rapidly in the past decade. Intensive efforts must continue to meet the increasing energy needs of a world that is fast depleting its natural resources and seeking new power and material resources. One new energy source already exists, solid waste, which has great potential in this dynamic field and might conceivably supply 3-6 percent of our total requirement of boiler fuel in the future, but will probably play a relatively lesser role due to the logistics of waste supply relative to energy-consuming facilities with waste-burning capability.

The use of shredders to process solid waste has increased remarkably during the past five years. According to the recent Waste Age Survey [1] (updated to late 1977) of shredding operations in the U.S. and Canada, the number of reported refuse shredding installations has multiplied approximately three-fold from 27 shredding plants reported in 1971 to approximately 80 in 1976. Many of these installations shred prior to land-filling, primarily because the Environmental Protection Agency [2] considers that landfilling of shredded refuse can be an environmentally acceptable disposal method that reduces the need for daily soil cover and increases site life. There are several other installations, with numerous others in the planning stage, that shred as a first step in order to obtain a relatively homogeneous waste stream said to be more amenable to automated material-handling and other processes associated with resource recovery, incineration, or the preparation of refuse-derived fuels.

It is hoped that the technique described in this paper will make a significant contribution to Solid Waste Processing and Resource Recovery Technology by minimizing existing potential dangers to equipment and operating personnel with concurrent reduction of operating expenses, and the production of higher quality recovered materials.

CONVENTIONAL CONCEPTS

The conventional process flow diagram for such systems is shown in simplified form in Fig. 1. The incoming waste from residential, commercial and industrial plants is delivered by trucks which dump their loads at a central receiving station where the
waste is loaded by mobile equipment on conveyors to the shredder operation. The shredded material is then classified by a separation device, usually providing an air stream, to produce a light fraction suitable for further processing and use as a fuel in boilers and kilns, and a heavy fraction containing the metals and the glass which then go through subsequent separation and beneficiation processes prior to marketing. The increased shredding activity has been accompanied by increased anxiety about an inherent hazard to municipal refuse shredding: The danger of explosions.

We designed and built the New Castle County, Delaware Solid Waste Processing and Resource Recovery Plant in 1971/1972 and have operated this plant under contract to the County for the past five years. We have had the unfortunate experience of thirty (30) explosions in the processing of approximately 800,000 tons of waste in this plant. We shred as a first step. One of these explosions cost more than one-quarter million dollars and the production line involved was out of service for 16 months, largely awaiting settlement by the County Insurance Carrier. Figure 2 is an “Exploded” View of the Plant. You will note that all of the metal siding and roof of the building was either blown off, or so severely damaged that it had to be removed. Portions of Feed Hoppers were blown approximately 200 ft (61 m) from their normal location — a mass of twisted steel.

The Factory Mutual Research Corporation recently conducted an assessment of the hazards of explosions from the shredding of solid municipal waste on a nation-wide basis for the U.S. Energy Research and Development Administration (E.R.D.A.) [3]. The summary of the Factory Mutual Explosion Survey indicates that 97 explosions, 69 causing significant damage, were reported for the shredding of 8,295,000 tons of solid waste. This is an average of one explosion
per 80,000 tons shredded nationally. Fortunately there were serious personnel injuries in only three of the explosions, and even more fortunately there had been no fatalities to the date of the survey.

In our relatively long-term operating experience with a conventional solid waste processing system that shreds as a first step, we have found certain disadvantages in this conventional system:

1. Explosions
2. Excessive shredder wear (Due mainly to glass)
3. Low heating value fuel
4. High ash in fuel

The most significant of these, of course, is explosions. Another great disadvantage is the excessive wear of the shredder internal parts caused by the severe abrasion of the glass contained in the waste. Figure 3 shows the typical wear on the rotor of a shredder. This same glass is pulverized during shredding into fine particles and part of the glass is embedded in the fibers of the paper, so that it is not removed during the subsequent air-classifying step to separate the light-fraction fuel-component. The glass that reports with the refuse-derived fuel results in lower heating value and much greater ash content, which has caused problems in boiler operation due to slagging of the tube banks. There have been certain steps taken by this emerging industry in its short experience to minimize the disadvantages of the conventional processing system. These are:

1. VENTING FOR EXPLOSION RELEASE. We consider it very important that any shredder for solid waste have a hood (vent) of heavy-steel construction, preferably 1 in. (2.54 cm), thick steel plates with ¼ in. x 6 in. (1.9 cm x 15 cm) external steel-bar reinforcement in a 12 in. (30 cm) waffle design, with greater cross-sectional vent area than the shredder inlet, extending straight up and vented through the roof.

At the discharge of this explosion vent there should be covers of light-weight construction and of such design as to prevent ballistic projectiles — spark plugs, etc. from flying out on the roof, but with minimum restraint, and with the covers designed so that they can readily open to relieve explosion pressures, but secured so that they cannot fly off the roof, thus creating a safety hazard.

2. MANUAL SCREENING AT PICKING STATIONS. The conveyor feeding solid waste to a shredder is normally a steel apron-type, approxi-
mately 6 to 8 ft (1.8 m to 2.4 m) wide. It is common practice to locate a Manual Inspection Station along this conveyor, so the Inspector may detect and remove unshreddable material, or material considered dangerous, such as gasoline cans, etc. Unfortunately, the burden of refuse on these conveyors in high tonnage plants is about 36 in. (90 cm) so that the Inspector is not able to detect harmful items buried therein. Experience has shown that many hazardous items, both explosives and massive pieces of steel, pass by an alert Inspector.

3. WATER FOG FOR EXPLOSION SUPPRESSION. We have conducted a considerable investigation of the design and installation of a fine-particle continuous water spray to create a concentrated micro-fog in the confining areas of the shredder to suppress explosions utilizing an energy absorption philosophy previously developed by the Factory Mutual Research Corporation. Since this installation in June, 1976, we have had nine explosions, all with rather heavy detonation, but only one caused any physical damage, which was minor, to the plant. We do not endorse this system as a safety guarantee, but the results are encouraging. It does not protect against dynamite and there have been objections to an increase in the moisture content of the fuel component. We question the validity of this argument, because the water added is a very limited quantity representing only 1 percent moisture in the waste. We use total water of approximately 4 gpm. (15 l/min) on two shredder columns (4 shredders) and adjacent auxiliary conveyor enclosures in the shredding of 100 tons of waste per hour.

4. AUTOMATIC DETECTORS TRIGGERING RELEASE OF AN EXPLOSION SUPPRESSION AGENT. There are various types of Explosion Detection Devices (ultraviolet, infrared, thermal and pressure), that can be employed to actuate the suppression system, but the one found most suited for a shredding environment is a fast-response pressure-transducer. The Explosion Suppression Agents most commonly employed in the U.S. are the halogenated hydrocarbons (Halons). In Germany the Explosion Suppression Agents favored are the chemical extinguishing powders, ammonium phosphate and sodium bicarbonate.

Some rather severe explosions have occurred on refuse shredding equipment presumed to be protected with such devices.

5. SCREENING AS A FIRST STEP. THE USE OF TROMMEL SCREENS (ROTARY DRUM SCREENS). Trommel Screening prior to shredding has been advocated by the National Center for Resource Recovery (N.C.R.R.) based on testing in which we participated at New Castle County Plant and has been applied in one recent plant. Rotating Disc Screens may have similar applications. Such screens have the distinct advantage of eliminating most of the glass, but still permit explosive items such as gasoline cans, ordinance items, etc. to pass into the shredder.

6. SCREENING AFTER SHREDDING. This process procedure has the advantage of removing some of the glass from the fuel component prior to the air-classifying thereof — but the fine glass particles remain embedded in the paper fibers. The explosion hazard remains.

NEW CASTLE PLANT EXPERIENCE

When we first entered the solid waste business, our rationale was: “The Solid Waste Reclamation Business is relatively simple. First, one shreds the waste, which is easy, because at least 10 manufacturers offer suitable shredders. After shredding the material, it is easy to recover the ferrous scrap using a magnet and there is, of course, a good market for ferrous scrap. In the future, we can retrofit for cardboard and paper reclamation with an air classifier. This will enable us to produce dry fuel which the utilities just can’t wait to purchase. We will likely retrofit eddy-current magnets to pull the nonferrous scrap. This is a well-developed technology, because some 100,000,000 such devices are in daily use in the speedometers of America’s automobiles. We may even find a market for glass. But, of course, the first meaningful step is shredding — which is easy.” The New Castle plant was based on this rationale. How different was the real world from our dream world! Within four weeks of testing our new plant, we had broken all grate bars in one of our processing lines! It had become obvious that, although we had agreed to process only household solid waste, we were, in fact, being fed such interesting items as truck engines, truck drives, truck rear ends, manhole covers and the like. Needless to say, we had to redesign the shredders and retrofit heavy shredder parts in situ, so that by December, 1972, the shredder part of our plant was working well and has done so since then. We had, of course, considered the possibility of explosions, and installed quarter-inch steel vent hoods that would protect against about six sticks of dynamite, but we never
dreamed that we would ever ingest anything like that amount of explosives. How wrong we were!

In June 1973, we had the first major explosion. Fortunately, we were able to determine the cause, about 12 lb (5.45 kg) of smokeless powder. A trap-shooter who reloads his own shells had likely become concerned that his powder was damp, and threw it away. Our explosion vents worked perfectly, and we experienced only minor damage. We are rather certain of the cause of this explosion, because the Inspectors at the Picking Station had removed two such cans, and somehow, one was dumped back on the feed conveyor. During the following twelve months, we had three more explosions of about the same order of magnitude as the first, all caused by explosives that contained their own oxygen. We had only one explosion that was determined to be caused by an accumulation of vapors. This was a low order detonation caused by some 50 cases of discarded perfume, which was nearly 100 percent alcohol.

We congratulated ourselves on the excellence of our explosion venting systems. Then, on June 29, 1974, we had a granddaddy explosion. Its force, as estimated by U.S. Treasury Dept. Agents of the Bureau of Alcohol and Firearms, was equivalent to about 60 sticks of dynamite, and it did about $250,000 worth of damage. What a mess! Fortunately, because of personnel safety practices, there was only one injury. A man fleeing the scene fell and skinned his knee. Needless to say, we installed a completely new explosion venting system of heavier construction before returning this shredder to operation.

Two years ago, an Inspector happened to notice a strange object in the household waste. Luckily he pulled it from the waste stream. It was a World War Two anti-tank land mine with a Monroe Charge designed to penetrate about 12 in. (30.48 cm) of armor plate! Army ordnance experts detonated it about a half mile from the plant. How did such a device enter the waste stream? We were able to trace that one. An Army Colonel had kept it as a souvenir. He died, and his family put it in the garbage can. Such is the nature of “household” solid waste.

NEW CONCEPTS

In the light of the above problems, we asked ourselves: “Is there a technique or a device which before shredding would:
1. Separate the raw incoming waste into a light and a heavy fraction, with no explosives and very little glass in the light fraction.

2. Be highly unlikely to trigger a dust or gas explosion.

3. Produce a heavy fraction which is easy to inspect for landmines, gasoline cans, powder cans, etc., which due to the relatively low volume involved, can be readily detected and manually removed therefrom.

4. Remove most of the glass from the heavy fraction.

5. Drop most of the putrescibles into the heavy fraction.

6. Eliminate the need for a Primary Shredder. Unfortunately, we found no front-end separating devices available anywhere that would perform all or most of such functions. A patent owned by General Electric on a rotary drum separator was for sale, and after investigation, we purchased this patent which, with suitable modifications, we believed would accomplish all of our objectives. We then designed and built a full-scale prototype, 20 ft (6 m) diameter by 40 ft (12 m) long for testing performance and establishing capacities and other design criteria. This full-scale prototype is shown during construction in Figs. 4 and 5, and in operation in Fig. 6. The unit was tested over a 10 month period to accumulate performance data [4]. Fig. 7 illustrates a typical analysis reported by an independent testing laboratory on the light fraction (fuel component) produced by this system. Figure 8 similarly illustrates analysis of the heavy fraction (including glass).

### ANALYSIS OF LIGHT FRACTION OF SOLID WASTE AS PRODUCED BY

**AENCO ROTARY DRUM AIR CLASSIFIER/SEPARATOR**

**NOTE:** Testing performed and results reported by Research 900 Laboratory of Ralston Purina Company, Saint Louis, Missouri.

**AENCO REFUSE SAMPLE NO. 14 - LIGHT FRACTION.**

**RESEARCH 900 LABORATORY NO. 115064 - 1/26/76.**

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Units</th>
<th>As Received</th>
<th>Dry-Matter-Basis</th>
<th>As-Assayed</th>
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<tbody>
<tr>
<td>Moisture</td>
<td>%</td>
<td>23.70</td>
<td>0.0</td>
<td>1.53</td>
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<tr>
<td>Aluminum Oxide</td>
<td>%</td>
<td>1.536</td>
<td>2.013</td>
<td>1.982</td>
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<tr>
<td>Ash</td>
<td>%</td>
<td>13.018</td>
<td>17.061</td>
<td>16.800</td>
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<tr>
<td>BTU/LB</td>
<td>%</td>
<td>5803.664</td>
<td>7606.371</td>
<td>7490.000</td>
</tr>
<tr>
<td>Calcium Oxide</td>
<td>%</td>
<td>1.679</td>
<td>2.201</td>
<td>2.167</td>
</tr>
<tr>
<td>Carbon</td>
<td>%</td>
<td>25.887</td>
<td>35.239</td>
<td>34.700</td>
</tr>
<tr>
<td>Chloride (Total)</td>
<td>%</td>
<td>0.477</td>
<td>0.625</td>
<td>0.615</td>
</tr>
<tr>
<td>Copper Oxide</td>
<td>%</td>
<td>0.032</td>
<td>0.041</td>
<td>0.041</td>
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<tr>
<td>Fixed Carbon</td>
<td>%</td>
<td>8.058</td>
<td>10.562</td>
<td>10.400</td>
</tr>
<tr>
<td>Ferric Oxide</td>
<td>%</td>
<td>0.596</td>
<td>0.781</td>
<td>0.769</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>%</td>
<td>4.742</td>
<td>6.215</td>
<td>6.120</td>
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<tr>
<td>Potassium Oxide</td>
<td>%</td>
<td>0.285</td>
<td>0.374</td>
<td>0.368</td>
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<tr>
<td>Nitrogen 0.02 N Sol</td>
<td>%</td>
<td>0.488</td>
<td>0.640</td>
<td>0.630</td>
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<tr>
<td>Magnesium Oxide</td>
<td>%</td>
<td>0.349</td>
<td>0.457</td>
<td>0.450</td>
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<tr>
<td>Sodium Oxide</td>
<td>%</td>
<td>0.604</td>
<td>0.792</td>
<td>0.780</td>
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<tr>
<td>Oxygen</td>
<td>%</td>
<td>30.994</td>
<td>40.621</td>
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<td>Lead Monoxide</td>
<td>%</td>
<td>0.018</td>
<td>0.024</td>
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<tr>
<td>Phos. Pentoxide</td>
<td>%</td>
<td>0.167</td>
<td>0.218</td>
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</tr>
<tr>
<td>Silica Dioxide</td>
<td>%</td>
<td>6.379</td>
<td>8.360</td>
<td>8.232</td>
</tr>
<tr>
<td>Sulfur</td>
<td>%</td>
<td>0.178</td>
<td>0.234</td>
<td>0.230</td>
</tr>
<tr>
<td>Sannic Oxide</td>
<td>%</td>
<td>0.002</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>Sulfite in Refuse</td>
<td>%</td>
<td>0.227</td>
<td>0.297</td>
<td>0.292</td>
</tr>
<tr>
<td>Titanium Dioxide</td>
<td>%</td>
<td>0.224</td>
<td>0.293</td>
<td>0.289</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>%</td>
<td>55.247</td>
<td>72.408</td>
<td>71.300</td>
</tr>
<tr>
<td>Zinc Oxide</td>
<td>%</td>
<td>0.032</td>
<td>0.042</td>
<td>0.042</td>
</tr>
</tbody>
</table>

**FIG. 7**
We anticipate the following applications and functions for this concept:
1. Retrofit to existing shredder plants.
   a. Shred only light fraction.
2. Retrofit to mass-burning and suspension-burning.
   a. Reduce ash.
   b. Reduce slagging.
   c. Reduce wear on moving grates.
   d. Reduce jamming of grates.
   e. Minimize excess air.
   f. Virtually eliminate the probability of explosions.
   g. Increase on-line availability.

We suggest that any system for resource recovery must be economically competitive with other environmentally-approved systems for waste disposal. This means in effect that the competition for resource recovery systems on a cost basis is the sanitary landfill, and if any resource recovery system is to be competitive, it must have a viable market for the fuel component, as the value of the remaining resources simply will not support the cost of such recovery system.

The principles under which the rotary drum separator works effectively for separation of a solid waste stream are:
1. As the drum rotates, the waste is repeatedly picked up and dropped through an air stream — for example, the heavy fraction is dropped approximately 20 times, which in effect makes a 20-stage air-classifying system for stripping the light fraction therefrom.

The air velocity up the drum exceeds the...
PARTICLE DYNAMICS

BY DEFINITION TERMINAL VELOCITY = $V_T$

$\left[ \frac{1}{2} \rho_C D_S \right] V_T^2 = W_p$  

(1)

IN A DRUM INCLINED AT AN ANGLE $\alpha$

$F_Y = \left[ \frac{1}{2} \rho_C D_S \right] V_A^2 - W_p \sin \alpha$

(2)

FOR A PARTICLE TO MOVE UP-DRUM:

$F_Y \geq 0$

OR $\left[ \frac{1}{2} \rho_C D_S \right] V_A^2 \geq W_p \sin \alpha$

(3)

SUBSTITUTE (1) INTO (4)

$\left[ \frac{1}{2} \rho_C D_S \right] V_A^2 \geq \left[ \frac{1}{2} \rho_C D_S \right] V_T^2 \sin \alpha$

(5)

OR $V_A \geq V_T \sqrt{\sin \alpha}$

(6)

FIG. 9

RECOMMENDED NEW PROCESS FLOW DIAGRAM

FIG. 10

INCOMING WASTE

CLASSIFYING

GLASS

BENEFICIATION

HEAVY FRACTION (METALS SEPARATION)

HEAVY FRACTION

R.D.F.

SHREDDING

LIGHT FRACTION (FUEL)

FIG. 11

Scale 1/550

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terminal velocity of the light fraction particles, such as paper, plastics, textiles, leaves, grass clippings, etc., causing them to flow with the air stream to the de-entrainment plenum.

2. The rotating drum is inclined at an angle with the horizontal, so that the heavy fraction is gradually screwed out the low end of the drum. The heavy fraction represents approximately 30 percent by weight, but only 10 percent by volume of the incoming waste. Where it is desired to reclaim the glass, the separator can be equipped with a trommel screen section having ¾ in. openings to produce a glass-rich aggregate for further beneficiation, as needed.

3. Much lower air velocity is required in a horizontally-inclined separator than in the conventional vertical air-separator, — a velocity only 30-40 percent as great. Figure 9 illustrates the principles of particle dynamics involved in this separator and applies to any particle located with the drum at a point defined by coordinates X and Y.

This principle of air classifying and separating the raw incoming waste prior to processing (shredding, etc.) will effectively minimize the dangers of explosion extant in existing waste processing technology. A recommended flow diagram is illustrated in Fig. 10. A layout of a typical rotary drum separator with its de-entrainment plenum, air-flow system, and feed and discharge conveyor system is illustrated in Fig. 11.

It is planned to build this rotary drum separating system at minimum diameter of 20 ft (6 m). This is required for adequate clearances when classifying raw incoming waste without presorting the over-sized bulky wastes (O.B.W.). If the O.B.W. were presorted and removed from the feed-stream, the rotary drum classifier will operate satisfactorily at 14 ft (4.27 m) diameter.

Pertinent design and performance data for the 20 ft (6 m) diameter rotary drum separator, tested with unsorted raw mixed municipal solid waste:

1. Exhaust fan: 1000 hp (746 kW).
2. Air flow: 350,000 A.C.F.M. (165 m³/sec) @ 6 in. of water (15 × 10⁵ kg/cm²) static pressure.
3. Air velocity: 15 ft/sec (4.6 m/sec).
6. Angle of inclination of the drum: 7½ deg. (0.13 rad) to the horizontal.
7. Throughput Capacity: 150 tons per hour of mixed solid waste.
8. Lights/heavies, by weight: approximately 70 percent lights, 30 percent heavies.

CONCLUSION

Our tests indicate that front-end air classification of incoming Raw Mixed Solid Waste will result in:

1. Minimal explosion probability and severity.
2. Minimum maintenance and process operating costs.

REFERENCES


Key Words
Air
Btu
Classification
Process
Reclamation
Separator
System
Discussion by

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If suffering the experience of Refuse Shredder explosions is the criterion, no one is better qualified than the authors to discuss the necessity for minimizing the potential, – the precept of this paper.

Referring to subheadings in the paper:

Venting for Explosion Relief

As the authors indicate, adequate relief of explosion pressures, safely exhausted, can be considered axiomatic [1]. There could be considerable risk, however, in extending the shredder superstructure hood up through the building roof for venting without means (water fog, continuous purge, etc.) for mitigating the added propensity for a secondary explosive gas or dust mixture forming in the entire hood-vent enclosure.

Despite the favorable inverse relationship of vent-hood volume to deflagration pressure, along with a reduced recompression probability [1], the reliability of a more complex roof-top relief mechanism (louvers, doors, flaps, etc.) would be quite worrisome.

Water Fog for Explosion Suppression

This observer agrees that microfog spray looks quite promising if applied carefully and only to the “confining areas of the shredder” and its superstructure, mindful that highly humid air in pneumatic transport ducts, cyclone hoppers, rotary air locks and especially baghouses can be quite troublesome.

If the moisture added to an RDF product really can be limited to about 1 percent along with the foregoing constraints, then it is likely to be feasible. Missing from the text is an indication of fog nozzle header pressure (in the order of 200-300 psi).

New Concepts

The laboratory analyses for the light and heavy fractions seem excessive. Perhaps a simpler proximate analysis would suffice, especially if air classification of raw refuse is but the first in a series of process steps where a complete analysis of finished fractions would be more meaningful.

Missing from the text are two important criteria for each fraction:

- Screen Analysis
- Average Bulk Densities

Regarding the application of this concept to mass burning (assuming the author does not include the grate burning increment of spreader stoker firing), the following questions arise:

- Would the significantly reduced bulk density of the fuel mass have any unmanageable effect on its movement through the furnace (the stoker design would be important here, – travelling vs rocking vs reciprocating, etc.)?
- Conversely, would the reduced bulk density enhance the management of undergrate air?
- Would removal of the heat value of the heavy fraction be tolerable?

Particle Dynamics

A more thorough discussion of the equations, notation and rationale would be helpful. For example:

- An explicit definition of terminal velocity in this context.
- How do you optimize a? ... is the efficacy of heavies removal the dominant criterion?
- Is \( V_A \) calculated for the highest required particle fluidizing velocity considering the numerous aerodynamic mass-shapes encountered in raw refuse?

Future demonstration of this system should provide more design and performance detail for the drum, plenums, air circulation and dust collection subsystems, i. e.:

- An air flow profile for the drum and settling plenum including velocity and pressure gradients, turbulent and laminar flows, etc.
- Method and importance of seals at the numerous component interfaces, — drum, plenums and ducts, conveyors vis-a-vis air flow, fan power and dust control.
- A rationale for the air recirculation arrangement with determination of a reasonable rate of recirculation of dust laden air of increasing concentration vis-a-vis baghouse and fan size; fan, seals and duct wear; and creation of hazardous and/or nuisance ambient dust.
- What is “Critical Drum Speed”? If the stated “throughput capacity” of 150 ton/hr is raw infeed to the drum and the lights/heavies split is 70/30 by weight, then it is necessary to collect and convey unshredded as-received lights at a rate of 105 ton/hr.
In this loose, aerated state at say 5-7 lb/ft$^3$ \[2\], collecting and transporting such quantities could be a firm challenge for materials handling in its present state of the art (even 50-60 ton/hr might be tough).

**DISCUSSORS CONCLUSION**

This concept is an innovation which warrants further investigation. The foregoing observations are more in the spirit of curiosity rather than criticism, and with the hope that the authors will continue their pursuit of improvement in front-end processing systems.

**REFERENCES**


**Discussion by**

Marc L. Renard  
National Center for Resource Recovery  
Washington, D.C.

Much credit should be given to the authors of this paper for proposing and testing an innovative method of preprocessing municipal solid waste. The principle guiding the authors’ design philosophy is clearly stated in the title: “Air Classify, Then Shred”. On these premises, the other so-called “conventional concepts” are critiqued, and some drawbacks of shredding followed by air classification are underlined: for example, the generation of glass fines which ultimately are included with the combustibles.

There remains that, short of mass incinerating, some step of loosening the bulk waste and size classification is needed for further processing downstream: shredding is obviously one way to go. So is trommelling, flail milling, and wet pulping. Thus there are not one but many “conventional” processes to be compared to the one advocated in this paper.

The authors’ concern for the explosions is a most legitimate one. Resource recovery plants are handling the discards of society, and some low flash point or ordnance materials might be present. Although this has not always been the case in the past, it should be possible, however, to design new installations so as to direct, contain or control explosions even when shredding is taking place.

In the proposed scheme, air plays a double role: it should help loosen the packed and bundled light or combustible materials; it should classify the components.

Orders of magnitude calculations show that to achieve significant momentum or energy transfer, the products of the acting fluid mass by the first or second power of its velocity have to be large. Thus the low density of air (compared to liquids or solids) will have to be compensated for by large volumetric flow rates. A 200-lb hammer moving at 300 ft/sec will in any event have a much larger density of kinetic energy or momentum per unit volume available for the breaking process.

An air classifier is a device in which a particle of given shape, density and mean aerodynamic incidence has a probability to fly or drop in a given uniform air stream. Here the heterogeneity of the product being classified, sizes ranging from less than 1 mm to several meters, specific gravity from 0.05 to 8, shapes which are spherical, elongated, or flat, will very likely make a clean “split” a real challenge.

In the formulae of Fig. 9, the authors might wish to consider the following:

- Large-size items will not reach their terminal velocity inside the drum, so that Eq. (2) would not apply.
- The drag co-efficient, $C_D$, is a function of the *instantaneous* relative velocity of the flow. Depending on the incidence, the same “$C_D$” might not always be used for the axial and transverse motions.
- The cross-section “S” in both directions is not necessarily the same.
- Aerodynamically profiled metallic objects might experience a lift force as well as a drag. Metal foils or flattened cans could fly “up-drum”.
- The maximum velocity of the air in the rotational motion is comparable to the axial velocity, and should appear in the calculations.

Regarding the power requirements of this process: at 1000 hp installed, is there any energy savings compared to a shredding process?

Forthcoming experimental results should answer many of the questions raised by Nollet and Sherwin’s paper.
The abstract claims reduced shredder wear, 15 percent higher heating value and 1/3 less ash in the subject process, but there are no data in the body of the paper to support these claims.

Nearly one half of the paper is introduction while the half devoted to subject matter is not perfectly clear or well organized.

Figures 7 and 8 give analytical data on the light and heavy fractions from the horizontal air classifier, but there are no analyses of comparable fractions by the more usual processing scheme of grinding first, followed by classification, for comparison. It is later stated that the division is approximately 70 percent weight light fraction and 30 percent by weight heavy fraction, but no comparable figures are given for conventional processing schemes.

The theoretical analysis in Fig. 9 is rather simplistic, the drag coefficient, $C_D$, is a function of Reynolds's number, and thus of velocity; and the terminal velocity is probably not attained.

A ten month test period is mentioned but no indication of how many hours of operation were obtained in that period. It would be interesting to know what was the longest continuous run and why it was stopped.

A size of 20 ft diameter is mentioned as being practical with 14 ft desirable. No indication is given as to the minimum height of the drop required to break up glass items or how bales or plastic bags are successfully broken.

An air flow of 350,000 acfm is given, along with an air velocity of 15 ft/sec. This air velocity and a 20 ft diameter classifier works out to about 283,000 acfm.

In the conclusions, the word minimum should be replaced by the word reduced and the word optimum replaced by the word improved. No data are offered to show that the conditions mentioned are indeed minimal and optimal.

An important gain of the scheme proposed in this paper is the removal of finely divided glass from the combustible fraction which is an important item in reducing downstream wear and preventing slagging problems in the burner. I feel the paper did not put enough emphasis upon this.

I found this paper to contain an innovative approach to processing solid waste. There are some comments and questions the article raised in my mind.

A major goal of such an approach is to minimize explosions and their severity. It seems questionable that effective separation of unshredded material can be made by rotating a large diameter drum while air passes through, particularly when moisture content can pass beyond the 23.7 percent value (on rainy collection days) and the drum has no perforations to let material exit. Explosives can possibly be entrapped in extremely wet paper and be passed into the "light" fractions where upon they would face RDF shredding with resultant explosions.

I question the reliability of such separation, then, with the resulting question on the degree to which explosions and their severity are reduced, using this method of waste processing.

Another major goal of the process is to minimize maintenance and process operating costs. If the testing using the prototype drum were done on a production basis with a constant infeed of raw refuse at the 150 ton/hr envisioned in this article were as effective as the test results listed in this paper, I would tend to agree that by obtaining a split of heavy materials from the waste stream, including the abrasive glass fraction, such a process would reduce shredder wear and probably require less horsepower for the shredder motor per infeed ton of raw refuse. I again question the effectiveness of separation on a production basis of this system.

The last major thrust or goal such a system discussed is to obtain optimum quality of recovered material. Again, if this system can actually perform, as described in production, separation would be excellent and the goal met. As I understand the design, cascading material constantly interrupts the air flow passing through the drum. Glass and grit entrapped in paper, etc. may not easily separate through the action of tumbling combined with air interruptions. I again question if the light fraction will end up without significant grit and glass, even if screen openings were introduced. In fact, I have been involved with trommel operations at Recovery 1 in New Orleans and I find we need larger holes than 3/4 in. diameter to allow easy removal of
from wet paper and corrugated.

Be aware that initial investment for such a large rotating drum and its air handling system is quite high, too, as compared with more conventional processing methods. The operating horsepower of 1000 for the fan motor and 350 hp for this drum presents high operating costs per ton that appear to approach those of more conventional shredding designs, particularly when compared with primary shredding.

For the basic idea of safety improvement the process described is noble in effort. I'm not confident of the results in production.

AUTHORS' REPLY

The authors are grateful to W. D. Robinson, Marc L. Renard, W. Y. Fischer and Irv Handler for their kind comments and searching appraisal of our paper. The allotted time and space are not adequate for in-depth analysis of all facets of air-classification by inclined rotary drums, but these areas will be covered in future papers.

To William D. Robinson

1. The purpose of this paper was not to discuss desirable design characteristics for shredder explosion vents, but to emphasize the need for new solid waste processing systems; and to introduce the new system of "Air-Classify First, Then Shred" as a means of alleviating the explosion hazards, and to produce higher quality products recovered from the solid waste stream.

2. However, we strongly recommend that all solid waste shredders be equipped not only with explosion vents, but with both microfog systems, and explosion detector and suppression systems.

The reader interested in further design aspects of such devices is referred to other papers [1, 2, 3, 4]. Generally we favor explosion vents of diverging cross-section up through the roof, for overall safety, unless the distance from feed inlet of the shredder to the roof is extremely great compared to the distance to adjacent walls.

3. On the microfog system the water pressure required for fine atomization is 600-800 psi with a flow rate of about 0.2 gpm per nozzle. In the AENCO New Castle installation we used 22 nozzles with a total flow rate of 4 gpm to the two shredding lines — this amounts to 1 percent moisture added to the total waste stream at our average shredding rate of 100 ton/hr.

4. We agree that proximate analysis of RDF and heavy fractions would suffice in most instances. We published complete analysis in this paper to permit comparison with the extensive test data compiled on the St. Louis/EPA/Union Electric installations.

Likewise we had all samples selected by the methods proposed by, and tested by the Research 900 Laboratories ofRalston-Purina Company who performed the testing work on St. Louis, in order to eliminate variables and questions regarding comparable test procedures.

5. Regarding the statement that the important criteria of screening analysis for each fraction is missing from the text, it is our opinion that screen analysis would have no significance in this instance, since the material being processed is raw solid waste as delivered by compactor and trailer trucks — there is no control over what the screen size might be on any given truck load.

6. Regarding the statement that the important criteria of average bulk densities is missing from the text, we did not make these determinations on all test runs — in fact the incoming material varies so much in size, shape, method of stacking, and individual densities that a great amount of work would be required to establish such data, and the results would have little application. Based on the testing we have done, we suggest an average bulk density for incoming solid waste as discharged on receiving conveyors to be about 15 lb/ft³, and at a 70/30 percent light fraction/heavy fraction split, the bulk density of the light fraction as classified varied in the range of 5-12 lb/ft³, and the heavy fraction in the range of 45-55 lb/ft³. The light fraction represents 90 percent of the volume of the incoming waste, and the heavy fraction about 10 percent.

7. The light fraction derived from this system can be burned either in mass-burning incinerators as generated, or might be more advantageously shredded to about 8 in. particle size and burned on spreader-stokers in order to maximize efficiency.

We do not believe that the significantly reduced bulk density of the fuel mass created by the light fraction will have an unmanageable effect on its movement through the furnace — mass-burning incinerators handling the complete waste stream are always called upon to burn concentrated loads of paper that might not have been mixed by the crane-operator.

We do believe, however, that manufacturers of mass-burning stoker equipment should give careful
design to an incinerator burning only light fraction, since much better performance in this instance can be expected. We do believe that the reduced bulk density and more uniform fuel would enhance the management of under-grate air.

The heat value of the heavy fraction amounts to about 500-800 Btu/lb of incoming waste — this would be lost from the incinerator and would go to landfill. However, the many advantages of burning only the light fraction produced when shredding is the first processing step far out-weight these relatively small fuel losses because:

- Stoker maintenance costs will be greatly reduced.
- Stoker size and resultant capital costs will be greatly reduced.
- The elimination of most of the glass from the light fraction reduces the ash by one third — in addition to reducing problems on the grate, the heat loss due to heating this glass and then removing it from the furnace as ash is eliminated.
- The ferrous recovered from the heavy fraction of this system has a relatively high market value compared to incinerated steel cans which are almost worthless.
- The evaporation loss due to the high moisture content of the putrescible material that reports to the heavy fraction by this system, is eliminated.

8. In air-classification, terminal velocity of a particle is defined \[5\] as that vertical upward air velocity that suspends a given particle in the air-stream — so that it moves neither upward or downward. The terminal velocity of any given particle is dependent upon its weight, its aerodynamic properties, and its surface area exposed normal to the air-stream.

In Fig. 9 of the paper, the writers inadvertently failed to state that \( V_A \) is the velocity of air-flow up the drum parallel to the longitudinal axis of the drum.

\( V_A \) was not calculated for the highest required particle fluidizing velocity considering the numerous aerodynamic mass-shapes encountered in raw refuse — it was, in fact, determined by experiment and experience at varying waste feed rates giving the desired light fraction/heavy fraction split.

9. The efficacy of heavy removal is not the dominant criterion for optimizing \( \alpha \), but it is one of the major parameters — other factors include drum diameter; number of drops desired for particles in each fraction; drum weight as it relates to cost; and total power requirements for driving the drum at different angles of inclination. These items are the subject of a current patent application and may be reported in future papers.

Referring again to Fig. 9, Eq. (2) is merely a summation of the forces acting in the axial direction along the drum upon a particle as it begins to drop in the drum. Dependent upon the terminal velocity of any particle as defined in paragraph 8 above, a particle will either move up the drum as light fraction, or down the drum as heavy fraction, or a quasi-heavy fraction. The angle of inclination of the drum with the horizontal determines the distance a heavy particle moves down the drum with each lifting and dropping; and for a given number of cycles of lifting and dropping thus determines the length of the drum required.

The inclined Rotary Drum Air-Classifier is obviously then a multistage separator. Material that would normally report as heavy fraction in a vertical air-classifier is in many instances a mixture of heavy and light material, which in the inclined rotary drum air-classifier is separated by the multiple drops, so that light materials report to the light fraction and heavy materials report to the heavy fraction.

10. We tested air-flow profiles with the drum at rest. Air-flow profiles with the drum rotating were not performed, nor were they deemed necessary — such profiles are very difficult and expensive to obtain.

We consider that the best test of any air-classifying system is its reproducibility on solid waste. We reran the light fraction through the Rotary Drum Air Classifier, and found that only 0.25 percent of the light fraction reported to the heavy fraction.

We may, however, find it desirable to do additional profile work as we apply this air-classifying system to other separating applications.

11. Seals at the component interfaces having relative motion — for example where the drum enters the light fraction settling plenum — will be a single-stage labyrinth design of rubber. Ducts will be of welded construction with flanged connections having gasket compound.

Seals are not an important item in-so-far as dust control is concerned, since the system operates under negative pressure.

Seals, however, are important to minimize leakage — we have designed the fan for providing the air flow through the drum with a 10 percent capacity allowance for system leakage. As a guide, the
air flow through a leakage path is approximately 30 cfm per sq. in. of leakage path at a pressure differential across seal of 1 in. of water.

12. Regarding air recirculation, we plan on recirculating 50 percent of the air-flow on the production unit.

On the full scale prototype unit tested, we did not have any dust removal equipment and discharged directly to atmosphere. Observations of the amount of dust generated together with measurements of dust concentration in the exhaust air led us to believe that we might recirculate the major portion — however, we think prudence dictates a maximum of 50 percent recirculation on account of the many unknown and variable constituents of solid waste.

13. On rotating drums “Critical Drum Speed” is defined [5] as the speed at which the centrifugal force on a particle in the drum is exactly equal to the weight of the particle.

This is the point where: 
\[ g = \omega^2 r \]

\[ g = \text{acceleration of gravity in ft/sec}^2 \]
\[ \omega = \text{rotational speed of the drum in radians per second} \]
\[ r = \text{radius of the rotating drum in feet} \]

14. The question is raised about the practicability of handling 150 ton/hr of loose, aerated light fraction at 5-7 lb/ft³ — in view of a statement that with the present state of the art in materials handling “even 50-60 ton/hr might be tough”.

We can but say that we had no problem moving this material with a 6 ft wide metal apron-type conveyor equipped with Z-Bar slats with 4 ft 6 in high skirts, the existing receiving conveyors being at New Castle County Delaware Plant where the tests were conducted.

For example, an 8 ft wide apron conveyor operating with 3 ft burden of material weighing 6 lb/ft³, when operating at 60 ft/min would have a theoretical capacity of 250 ton/hr. We would use one or two of these conveyors, dependent upon whether we had one or two shredding lines.

To Marc L. Renard

1. Mass incineration of solid waste results in explosions — in fact, there has been a major explosion in such a mass incinerator in the eastern United States within the past month. We advocate on such mass incinerators that the incoming solid waste be first separated into a light and heavy fraction to permit removal of explosives — or to avoid the explosion danger by incinerating only the light fraction from such separator.

Flail-milling as a first processing step is subject to the same danger from explosion as other type shredding. As the first processing step — air-classify first, then shred.

Wet-pulping is not subject to dust explosions, may not be subject to vapor explosions, but certainly is subject to explosions from dynamite, military ordnance, or any explosive containing its own internal oxidant. Recommend air-classify first, then wet-pulp only the light fraction from such a separator.

Trommelling the incoming solid waste as a first processing step has the following relative disadvantages compared to air-classifying as the first processing step:

- Large-scale trommelling has been reported by the National Center for Resource Recovery as giving about a 50 percent/50 percent light fraction/heavy fraction split.

By contrast, when air-classification of the incoming solid waste is the first processing step, the split may be adjusted from 60 percent/40 percent to 85 percent/15 percent light fraction/heavy fraction — dependent upon the constituency of the waste — thus maximizing the energy recovery therefrom.

The energy recovery where trommelling is the first processing step, however, may be improved by multiple subsequent trommelling, shredding and/or air-classification operations — but at a sacrifice of considerable extra capital investment and operating and maintenance expense relative to the system where air-classifying is the first processing step.

- Trommelling as the first processing step does not provide protection against explosion. Most explosives will report to the over-size, which is then shredded under the system suggested by the National Center for Resource Recovery — then explosions occur in the shredder.

2. Mr. Renard states that “it should be possible, however, to design new installations so as to direct, contain or control explosions even when shredding is taking place.”

We welcome information on techniques on how this might be accomplished — how can dynamite, military ordnance, other explosives containing their own oxidant, cans of gasoline or solvents be detected and removed prior to shredding — it
might be done by spreading out all the waste in a 3 in. layer on a concrete slab for visual inspection and removal of any suspicious materials therefrom — this would be tremendously expensive. Air-classify first, then shred.

We have operated the New Castle County Delaware Plant over a six year period and have shredded more than 800,000 tons of solid waste with a system where shredding is the first processing operation. Our search for a system to remove potentially explosive materials has been unfruitful — in the interim explosions in our shredders in this system — employing shredding as a first processing step — continue with the latest explosion doing significant damage to the plant occurring in June 1978.

If the way is known to get out of this dilemma, please help us!

3. We do not believe there is any correlation between the energy requirements for comminution of solid waste as compared to separation. The AENCO Rotary Drum Air-Classifier opens the bags and bales of solid waste by lifting and dropping on bag-breakers in a steel drum, and then separating the materials by air-classification in relation to particle terminal velocities. The AENCO device performs very little reduction in particle size of the incoming waste stream — merely breaks friable items, such as glass bottles, etc.

4. Mr. Renard is certainly correct — heterogeneity of incoming solid waste did in fact present us a real challenge in our development of this equipment.

5. Mr. Renard is quite right in his analysis of the drag co-efficient, \( C_D \). This theory explains the disadvantage of the vertical and zig-zag air-classifier and substantiates the need for multiple-stage air-classification — the AENCO Rotary Drum Separator is such a device in that it repeatedly lifts and drops quasi-heavy particles permitting the light fraction to be stripped therefrom by the air flow and carried to the light fraction settling plenum at the upper end of the drum.

Mr. Renard is correct that metal foil and flattened cans will fly up the drum. Likewise, large pieces of paper and large pieces of cardboard do move up the drum at a rate faster than small objects — the effect is to increase the relative throughput tonnage of the drum versus the same drum when classifying shredded material.

Mr. Renard is correct that in the full-scale prototype drum utilized for test performance, the velocity of air in the rotational direction due to the lifters happens to approach as a maximum the axial velocity of the air. We think the effect thereof is to create a slightly spinning motion in the particles, tending to make their separation into light and heavy fraction more effective. The equations required for the analytical handling thereof for precise predictions of effects are beyond our in-house capabilities.

6. The power requirements for the AENCO Rotary Drum Air-Classifier to separate the incoming waste as the first processing step is very comparable to the power requirements for rough shredding or flail-milling to particle size in the range of 3 in. to 8 in. — about 6-8 hP/hr/ton.

To William H. Fischer

1. The values reported in Fig. 7 of the paper of 7600 Btu/lb (dry-matter basis) for the light fraction and 17 percent ash (dry-matter basis) compare with similar average results for the St. Louis pilot plant of 6300 Btu/lb and 25 percent ash. The sampling methods were designed by and the tests were conducted by Research 900 Laboratories of Ralston-Purina in each instance.

2. Regarding reduction in shredder wear, we have not substantiated this, because we did not run enough tonnage through the AENCO Rotary Drum Air Classifier to make adequate evaluation of relative shredder wear. We did show you a good picture in Fig. 3, Worn Rotor of Shredder, wherein you will note:

- The rotor discs which were originally 1-5/8 in. thick are worn to a knife edge — the rotor was removed from service because there was evidence of cracking from the hammer pin holes to the outer periphery of the rotor disc and we feared the throw-out of an entire row of hammers.

- Figure 3 also shows a new hammer weighing 135 lb as compared to a worn hammer weighing 97 lb that has shredded a total of 4000 tons — 2000 tons on one side, then turned over on the pin with 2000 tons on the other side.

It is our belief that glass is a major factor in the severe wear of shredders that are fed incoming solid waste as the first processing step. It was gratifying to note that Irv Handler concurs that the removal of the “abrasive glass fraction . . . would reduce shredder wear and probably require less horsepower for the shredder motor per infeed ton of raw refuse”.

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3. William Fischer is correct that we failed to furnish the comparable analysis of the light fraction and heavy fraction by the usual process of grinding first followed by classification for comparison. These have been fully covered in various summary reports of the St. Louis/EPA/Union Electric project. Salient data is presented in paragraph 1 above. The test data was copied precisely from the test reports submitted by Research 900 and are clear to us — Sol. is an abbreviation for solution; and NR usually means “Not Reported,” although we do not see such reference in either Fig. 7 or Fig. 8. We suggest that William Fischer address his critique on method of test reporting to Ralston-Purina, on this subject.

4. In the paper we stated that “We suggest that any system for resource recovery must be economically competitive with other environmentally-approved systems for waste disposal.”

Our philosophy is predicated on six years operating experience processing more than 800,000 tons of solid waste for resource recovery. We thought our opinion might be of general interest to the industry.

5. We agree with William Fischer that half of the paper is introduction and half is our new concept. It was felt by the authors and emphasized by the Official Reviews that the stage should be properly set to establish the impracticability of shredding as a first processing step as evidenced by the Factory Mutual Research Corporation report of Survey of the Industry, and our own operating experience processing more than 800,000 tons of solid waste for resource recovery. We thought our opinion might be of general interest to the industry.

6. We agree that our theoretical analysis presented in Fig. 9 “is rather simplistic” — we agree that a more esoteric analysis might be interesting, but we doubt that it would prove productive in the performance of this separator on heterogeneous matter, such as solid waste.

In any type of air classifier, be it vertical, zig-zag, rotary drum (inclined) or other, the particles never attain their terminal velocity. Terminal velocity — as explained under response to Robinson Item 8 — of a particle is defined [5] as that vertical upward air velocity that suspends a given particle in the air stream — so that it moves neither upward or downward. This means that if you want the particle to travel in the direction of the air stream, the velocity of the air stream must be slightly greater than the terminal velocity of the particle — then the particle will move at a velocity somewhat less than the difference between the actual air velocity and the particle terminal velocity.

As presented in Fig. 9 of the paper on an inclined rotary drum separator, the air velocity required (critical velocity) to move the particle in the direction of air flow must be greater than the terminal velocity of the particle (in a vertical column) times the square root of the sine of the angle of inclination of the longitudinal axis of the drum with reference to the horizontal — refer to Eq. (6) Fig. 9.

7. When we started construction of the full-scale prototype air-classifier, our test objectives were limited to the following:

- We had procured from General Electric Company their patent on rotary drum separation together with their 5 ft and 3 ft diameter rotary drum which had been tested on shredded solid waste for an extended period of time to establish performance and throughput capacity.

- Our objective in building the full-scale unit was to confirm scale-up predictions.

- To establish ability to open paper and plastic bags of garbage in order to expose the individual pieces therein to air separation.

- To test a number of different drum internal configurations and study different designs of lifters.

Our ability to feed the machine at high rates for protracted periods was limited by the amount of material that could be prepositioned on the feed conveying system. We tried to extend the time by loading the outboard end of the conveyor while in operation with a large front end loader, but the maximum continuous rating obtainable with the front end loader was only 30 ton/hr. Our longest
run at high feed rate (134 ton/hr) lasted 253 sec. We made numerous other high capacity runs up to a maximum of 360 ton/hr for 40 sec.

8. William Fischer is basically correct — on rotating drums “critical drum speed” is defined [5] as the speed at which the centrifugal force on a particle in the drum is exactly equal to the weight of the particle — in other words, the speed at which the particles hang on the outer periphery of the drum and do not drop therein. The technical aspects of critical drum speed are further discussed under the response to Robinson Item 13.

9. William Fischer has misquoted our statements regarding drum diameter — on the last page of the paper we state — “It is planned to build this rotary drum separating system at a minimum diameter of 20 ft (6 m). This is required for adequate clearances when classifying raw incoming waste without presorting the over-sized bulky wastes (O.B.W.). If the O.B.W. were presorted and removed from the feed-stream, the rotary drum classifier will operate satisfactorily at 14 ft (4.26 m) diameter.”

10. The minimum height to break bottles dropping in a steel drum is about 8 ft; however, in the instance of the AENCO Rotary Drum Air Classifier, the bottle has a striking velocity due to the vector summation of the velocity from dropping and the rotational velocity of about 26 ft/sec as the bottle strikes the steel.

Bales and plastic bags are opened by being repeatedly lifted and dropped on serrated bag openers — this proved very effective on the prototype as shown on our slides and movies, and illustrated in Fig. 6 of the paper.

11. As William Fischer stated, the air flow used was 350,000 acfm versus the indicated air flow in the drum of 283,000 acfm. The difference is accounted for by air supplied through by-pass dampers for control of flow up the drum together with providing for air leakage through the seals. See response to Robinson Item 11 for further evaluation of air flow supplemental requirements to provide for leakage around seals.

The air flow must have variable capacity adjustable so as to provide for splits from 60 percent/40 percent to 85 percent/15 percent. The percentage of combustible desired for reporting to the light fraction will vary from site to site, and season to season.

- Some bales and heavy plastic bags may not break open — however, we found by test that an insignificant number failed to open.

12. We believe that the terms used in our conclusion of the paper are proper based on known technology today. However, in view of continuing improvements in the state of the art, we agree with William Fischer that the word “minimum” in conclusion 1 should be replaced by the word “reduced,” and the word “optimum” in conclusion 3 should be replaced by the word “improved”.

13. We believe we emphasized throughout the paper that one important gain of this new processing equipment is the removal of finely divided glass from the combustion fraction. However, we concur with William Fischer that greater emphasis should have been placed upon down-stream wear reduction and minimizing slagging problems in the boiler — these are two highly desirable advantages of the AENCO system of Classify First, Then Shred.

To Irv Handler

1. We can envision scenarios in which a person desiring to sabotage the down stream equipment could package explosives so that they could conceivably report to the light fraction.

Our observation of our light fraction, however, shows that such action is extremely unlikely except for explosive charges of very small weight, that would be apt to cause relatively little damage.

2. The theme of Mr. Handler’s comments is that he does not think the AENCO Rotary Drum Classifier will work but that it would be a great device if it did work.

We compiled extensive test data during 59 runs with 18 different configurations of which some worked better than others. A great amount of this data was utilized in support of U. S. Patent No. 4,070,202 issued January 24, 1978 and is available at our office for review of interested parties. Certain test data cannot be submitted for review at this time pending approval of other outstanding patent claims.

We assure Mr. Handler that the system will in fact work as stated, and AENCO (Cargill) stands ready to guarantee the performance and capacity of this separating system when handling incoming solid waste as the first processing step.

3. The initial capital investment and the operating cost for electrical power alone for this system are comparable with conventional shredding system design.

However, the total capital cost of the AENCO system is about 20 percent less than conventional
grit and glass shards, after which air classification is still required to cleanse or separate the material systems designed to produce refuse-derived fuel (RDF) in each instance; and the operating and maintenance costs are about 35 percent less for AENCO systems than for conventional systems on plants having a solid waste input capacity of 1000 ton/day of solid waste and producing RDF in each instance.

During our presentation of this paper at ASME we presented the following cost information and comparison by slides:

<table>
<thead>
<tr>
<th>System Description</th>
<th>Total Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Plant — Shred First, Then Air-Classify</td>
<td>$11,500,000.</td>
</tr>
<tr>
<td>AENCO New Plant — Air Classify First, Then Shred</td>
<td>$9,400,000.</td>
</tr>
</tbody>
</table>

**ESTIMATED OPERATING & MAINTENANCE COSTS PER TON FOR 1,000 TON/DAY PLANT TO PRODUCE RDF**

<table>
<thead>
<tr>
<th>System</th>
<th>Utilities Cost</th>
<th>Parts &amp; Materials</th>
<th>Labor</th>
<th>Process Labor</th>
<th>Overhead</th>
<th>Repairs to Explosions</th>
<th>Total Cost Per Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shred First</td>
<td>$1.90</td>
<td>$1.67</td>
<td>$1.50</td>
<td>$1.29</td>
<td>$2.26**</td>
<td>$0.62</td>
<td>$9.24*</td>
</tr>
<tr>
<td>Classify First</td>
<td>$1.95</td>
<td>$0.80</td>
<td>$0.70</td>
<td>$0.43</td>
<td>$2.26**</td>
<td>$-</td>
<td>$6.14</td>
</tr>
</tbody>
</table>

**REFERENCES**


