PERFORMANCE CHARACTERISTICS OF A VERTICAL HAMMERMILL SHREDDER

P. AARNE VESILIND  
Department of Civil Engineering  
Duke University  
Durham, North Carolina

ALAN E. RIMER  
MICA  
Durham, North Carolina

WILLIAM A. WORRELL  
Brown and Caldwell, Engineers  
Atlanta, Georgia

ABSTRACT

This paper reviews the results of an acceptance test performed on a vertical shaft hammermill shredder installed at the Pompano Beach Solid Waste Reduction Facility, Pompano Beach, Florida. It was found that the shredder met the required acceptance condition, producing a refuse of at least 70 percent less than 3 in. (76 mm). The power requirements were low and the hammer wear was found to be linear with the amount of refuse processed.

DESCRIPTION OF PLANT AND PROCESS

The Pompano Beach Solid Waste processing facility consists of a shredder and landfill system, as well as an experimental refuse to methane facility (REFCOM). The overall processing facility layout is shown in Fig. 1.

The refuse trucks enter the solid waste reduction center and dump refuse on the tipping floor. The deposited refuse is stockpiled (the height may reach 20 ft (6 m) by a rubber-tired front-end loader until the refuse can be pushed onto the variable speed horizontal pit conveyor, which takes it to a variable speed inclined conveyor, which in turn feeds a 1000 hp (746 kW) motor vertical shaft hammer mill shredder (see Fig. 2). The shredded refuse is deposited onto a covered 5 ft (1.5 m) wide, troughed rubber belt conveyor and transported to the belt type magnetic separator which removes the ferrous from the waste stream. The nonferrous refuse (or all of the shredded refuse if the ferrous magnet is not operating) continues down the conveyor system and is either diverted to the methane production facility or the landfill loadout area. At the landfill loadout area, the conveyor dumps the shredded refuse through a bifurcated chute into the transfer trailers which are then driven the short distance to the landfill and dumped.

After an initial shakedown period, an acceptance test was conducted. The objectives of this test were:

1. To determine whether the shredder satisfied the specification that 70 percent (by dry weight) of the shredded refuse has a nominal size of less than 3 in. (76 mm).
   
2. To determine whether the solid waste shredding system would operate at a throughput of 60 tons/hr (54 t/h) for twelve consecutive days with an average minimum daily throughput of 850 tons (770 t).

In addition to these requirements, the following parameters were measured: 1. particle size distribution, wet and dry; 2. power consumption; 3. moisture content of refuse; and 4. hammer wear.

SAMPLING PROCEDURE AND SAMPLE ANALYSIS

The determination of the proper location and procedure for obtaining a sample of shredded refuse is dependent on several criteria. First, the most
FIG. 1 SITE PLAN FOR THE POMPANO BEACH SOLID WASTE REDUCTION FACILITY
important is that any sample obtained has to accurately represent the output of the shredder during steady-state operation. In addition, the sampling site and procedure must not interfere with the normal operation of the facility, and finally, the sampling site should be safe and conveniently located and the procedure as uncomplicated as possible.

SAMPLE COLLECTION

Based on the above constraints, it was decided that the best sampling site was the transfer point at the end of the conveyor exiting the ferrous separation building. Access to the conveyor head pulley area was gained through doors on either side of the conveyor (see Fig. 3). A canvas "stretcher" was placed through the doors and when a sample was required the stretcher was quickly opened into the freely falling waste.
stream, a sample collected, the two stretcher poles quickly closed, and the canvas stretcher containing the collected sample pulled out. Not only did this provide a representative sample under steady-state operating conditions, but it also captured the whole waste stream during the sampling, thus assuring that the sample was truly representative of the distribution of the shredded product across the conveyor belt. The contents of the stretcher, generally 5 ft³ (0.14 m³) of material were then placed into a 50 gal (190 l) can and carried to the storage and sieving building.

At the storage area the sample was either quartered or halved, depending on the amount of sample collected. The approximately 3 ft³ (0.1 m³) sample was then wet sieved through 8, 4, 3, and 2 in. (203, 102, 76 and 51 mm) sieves, weighed, divided into four ¾ ft³ (0.02 m³) pans and placed in a 217°F (103°C) oven to dry. After approximately 10 hr, the oven-dried samples were weighed on a single arm balance accurate to one tenth of a gram and then placed back in the oven. The weighing was repeated about every 45 min until the weight of the samples stabilized, which was considered to be the point at which all free water had evaporated, and was therefore the dry weight. The dry and wet weights were used to calculate the moisture content. The dry samples were again sieved through the same sieves and weighed. Finally the fines from the dry sample sieving were boxed and shipped to Duke University to be sieved through a set of standard engineering sieves. Figure 4 shows the four sieves used in analyzing coarse materials, and one of the tests in progress.

The sieving was done by shaking the sieves vertically and horizontally until by visual inspection, no further particles would fall through. This method turned out to be simple and reproducible, and corroborates the results of other investigators [1,2].

POWER CONSUMPTION

The power consumption of the shredder was determined by a watt-hour meter. Due to the placement of the meter, the power was recorded only when the shredder ran in the forward direction (every other day). The variability of the amperage was recorded with an amp meter which produced a continuous strip chart at a speed of 3 in. (76 mm) per hour.

HAMMER WEAR

The hammer wear was determined by weighing all hammers and arm assemblies on a platform scale accurate to 1 lb (0.45 kg), at the beginning and end of the test period. One hammer from each level was also weighed after 3 days of testing and again after 10 days of testing.

THROUGHPUT

Three different types of throughput were calculated and used in this study:

1. Shredder throughput = tons of refuse shredded divided by the actual shredding time.
2. System throughput = tons of refuse shredded divided by the sum of the actual shredding time and any down time due to a system failure.
3. Total plant throughput = tons of refuse shredded divided by the sum of the actual shredding time, the system down time, and any other interruptions including break and lunch time.
FIG. 5 PARTICLE SIZE DISTRIBUTION IS TYPICAL OF SHREDDED REFUSE. (mm = in. x 25.4)
The different times were determined by using the daily shredder log maintained by the shredder operator, while the tons of refuse shredded were obtained by adding the weight of the refuse deposited on the tipping floor as recorded by the scale operator.

**PARTICLE SIZE**

Results of particle size analyses are commonly presented as semi-logarithmic plots such as the five representative samples shown in Fig. 5. These particle size curves are typical of the type of data commonly obtained for shredded municipal refuse [3, 4, 5, 6].

A major concern during the shredder evaluation procedure was the potential deterioration of performance, as measured by particle size distribution. This might occur when hammers wear excessively and thus allow progressively larger particles to leave as product.

Fig. 6 is a plot of the percent finer than several sizes as measured over the entire trial period. The refuse processed (tons) is the value at the end of the working day.

There seems to be no deterioration of particle size reduction during the trial period. In fact, the shredder performed well enough to have been able to meet a guarantee of 70 percent less than 2 in. (50.8 mm) in size if that was required.

One major drawback in the analysis of particle size distributions is that no single parameter can be used to describe a distribution. A solution to this problem is to plot the data in such a way as to obtain a straight line, which then allows for a complete description using only the slope and one point. The Rosin-Rammler equation [7] is such an empirical model, and is stated as

\[ Y = 1 - \exp \left[ -\frac{x}{x_0} \right]^n \]

where

- \( Y \) = cumulative fraction of particles by weight less than size \( x \)
- \( n \) = a constant
- \( x_0 \) = a constant, known as "characteristic size" defined as the size at which 63.2 percent of the particles are smaller

This equation can be linearized by noting that

\[ \ln \left( \frac{1}{1-Y} \right) = \left[ \frac{x}{x_0} \right]^n \]

and taking the log of both sides. A plot of
In (1/1-Y) vs x on log-log paper yields the slope n and the characteristic size \(x_0\) at \([\ln(1/1-Y)] = 1\), since the \(\log 1 = 0\), and hence \(x = x_0\).

Plots for all of the particle size analyses were constructed and \(n\) and \(x_0\) values determined. Figure 7 is a typical plot. It is noted that an acceptable straight line is defined, and that for this sample, the characteristic size is read as \(x_0 = 1.30\) in. (33.0 mm) and the slope as \(n = 0.62\). For the most part, all of the data plotted as straight lines, indicating good agreement with the Rosin-Rammler empirical particle size distribution equation.

Physically, as the characteristic size \(x_0\) increases, the particles increase in size. Further, if \(n\) increases, the particles sizes will tend to be most uniform (all of one size). A low value of \(n\) would denote a large size distribution, with many very small and very large particles.

Fig. 8 is a plot of both \(x_0\) and \(n\) over the test period. Although \(x_0\) varies from day to day, there seemed to be little if any overall change in \(x_0\) or \(n\) over the test period.

There was no correlation between characteristic size \((x_0)\) and \(n\) when plotted against the shredder throughput. This is partially explained by the fact that throughput is calculated on a daily basis, and the values are thus gross averages of the necessarily variable feed rates. Much more controlled test conditions, which would have violated the imposed acceptance test conditions, would be necessary to establish particle size variability with throughput.

**EFFECT OF REFUSE MOISTURE CONTENT**

The moisture concentration of the refuse did not change appreciably over the test period. Both wet and dry samples were analyzed for particle size distribution, and Fig. 9 shows the percent finer than 3 in. (76 mm) for wet and dry samples. There is no discernable difference between the wet and dry samples. This is interesting
FIG. 8 THE ROSIN-RAMMLER COEFFICIENTS DID NOT SEEM TO SHOW A TENDENCY DURING THE TEST PERIOD. (metric tons = 0.907 x tons)

FIG. 9 THERE WAS VERY LITTLE DIFFERENCE IN THE PARTICLE SIZE ANALYSIS FOR DRY AND WET SAMPLES. (mm = in. x 25.4)
TABLE 1 POMPANO BEACH PLANT THROUGHPUT AND DOWNTIME

<table>
<thead>
<tr>
<th>Date</th>
<th>1978</th>
<th>Plant</th>
<th>System</th>
<th>Shredder</th>
<th>Plant total tons/day</th>
<th>Plant Shredder tons/hr.</th>
<th>Shredder Breaks min. %</th>
<th>Electrical Breaks min. %</th>
<th>Conveyor Downtime min. %</th>
<th>Diverter Downtime min. %</th>
<th>Other Downtime min. %</th>
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<td>12:56</td>
<td>2530</td>
<td>76</td>
<td>119</td>
<td>132 13 150 14 32 2 55 3 67 4</td>
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</table>

Note: metric tons = 0.907 x tons
in terms of future shredder analyses, since dry samples may not be necessary, thus saving significant effort and perhaps allowing for a larger number of particle size analyses to be performed instead.

PLANT THROUGHPUT

During the twelve day test period, 14,133 tons (12,800 t) of waste were processed by the shredder. The total waste processing system was in operation for over 176 hr, and the shredder operated for more than 127 hr. The plant throughput was 80.3 tons/hr (73 t/h) but the shredder processed nearly 111.5 tons/hr (101 t/h) of waste. This significantly exceeds the contractual requirement to process at least 60 tons/hr (54 t/h) and for the discharge conveyor to handle 96 tons/hr (87 t/h). Table 1 summarizes the plant throughput and downtime.

About 25 percent of the plant operating time was devoted to dealing with problems or taking scheduled breaks (the latter was about 11 percent of the overall system operating time or 50 percent of the total downtime). Eight percent of the downtime was caused by conveyor or diverter problems. An additional five percent of the downtime was related to electrical problems or which the shredder manufacturer was not responsible.

During this test period, the plant was able to process 80 percent more waste than the design capacity. Following the acceptance test, the system throughput was further increased by making minor adjustments to the diverter and conveyor.

POWER CONSUMPTION

An analysis of power consumption was completed based on the throughput during the test period. For the entire plant operation time, an average of 5.33 kWh were consumed per ton of processed refuse (5.87 kWh/t). This figure must be reduced, however, since the shredder was not fed continuously, and consumed power during the time it was idling. Subtracting the total idling power consumption as determined from the log sheets, from the total recorded power use, total useful power consumption can be calculated (Table 2). The final net shredder power consumption is calculated as 5.25 kWh/ton (5.79 kWh/t).

Fig. 10 illustrates the impact of varying power costs on the power costs per ton of refuse shredded and can be used as a design tool to help indicate expected costs for other shredder installations.

<table>
<thead>
<tr>
<th>Table 2: Summary of Power Use</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Refuse Processed (tons)</th>
<th>Total Power Consumed (kWh)</th>
<th>Time Shredder was Idling (min)</th>
<th>Idling Power (kWh)</th>
<th>Net Power (kWh)</th>
<th>Shredder Efficiency (kWh/ton)</th>
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<td></td>
<td></td>
<td>5.25</td>
</tr>
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</table>

Note: metric tons = 0.907 x tons
kWh/metric ton = 1.1 x kWh/ton

Fig. 10: A range of shredder power costs may obtained for various power rates. (metric tons = 0.907 x tons)
The work performed by a shredder can be analyzed using several empirical relationships, the most useful of which is the Bond work index \( [8] \), defined as

\[
E = 10 E_i \left[ \frac{1}{L_P} - \frac{1}{L_F} \right]
\]

where

- \( E = \) work performed, kWh/ton, in reducing the size of a product from a feed with a size 80 percent finer than \( L_P \) (in microns) to a product 80 percent finer than \( L_F \) (in microns)
- \( E_i = \) work index, representative of the efficiency of a process, with a low number indicating high efficiency, and a high index indicating poor efficiency.

Using the data for the first day, where \( L_P = 2.18 \) in. (55.4 mm), and a reasonable value of \( L_F = 10 \) in. (254 mm), the \( E_i \) index can be calculated as equal to 230 kWh/ton (253 kWh/t).

This value can be compared to published work indexes by Stratton and Alter \([9]\), who calculated \( E_i \) values for a number of shredders, also using \( L_F = 10 \) in. (254 mm). On the average, the \( E_i \) for refuse shredding is reported by Stratton and Alter as about 400 kWh/ton (440 kWh/t), which is somewhat higher than that calculated above, indicating efficient operation of the vertical shaft shredder.

The value of \( L_F \) (80 percent finer size of feed) was not measured in this study. The value of \( L_P = 10 \) in. (254 mm) is not unrealistic, however, since most raw refuse has \( L_F \) in the range of 7 to 10 in. (178 to 254 mm) \([1,2,10,11]\) and the above calculations thus yield a conservative value of \( E_i \).

**HAMMER WEAR**

Table 3 shows the average weight loss at the hammer stations over the duration of the tests. The "vertical station" refers to the location of the hammers vertically, with station three being the uppermost hammers, and station nine being the lowermost set of hammers. At station seven, the shredder casing changes from conical to cylindrical. The hammers wear increasing as the station approaches the transition in the shredder.

Figure 11 illustrates the average weight loss of hammers at selected stations. These data demonstrate that the wear pattern for hammers is linear, at least up to about 14,000 tons (12,500 t) of refuse processed. In other words, the hammers seem to wear just as fast when they are new as when they are older.

Based on previous experience at other shredder installations, the hammers and arm assembly for this type of shredder are removed when they weigh between 140 and 150 lb (64 and 68 kg). The average weight of a new hammer and arm assembly is about 235 lb (107 kg). If it is assumed that this results in an average loss of about 90 lb (41 kg) per unit, a linear extrapolation of the wear data in Fig. 11 would indicate that the hammer units at station seven would last long enough to process about 16,000 tons (14,600 t) of waste while those at station 3 would be able to process nearly 52,000 tons (57,000 t) of waste.

If it is assumed that, on the average, the hammer...
mer units can process about 10.61 tons of refuse per pound of hammer weight loss (21.2 t/kg) (see Table 3) the total tons of refuse processed can be calculated as about 24,000 – 27,000 tons (21,800 – 24,500 t) per one complete set of hammer units. This value agrees with the results of the Charleston, South Carolina test, where it was estimated that the average life of replaceable hammer head is about 25,000 tons (22,700 t) of refuse [12].

**SUMMARY**

The primary acceptance criteria of the acceptance test were that the shredder produce a product with 70 percent finer (by dry weight) than 3 in. (76.2 mm) and that the shredder be able to operate at a throughput of 60 tons (54 t) per hour for twelve consecutive days at an average minimum daily throughput of 850 tons (770 t). In addition to particle size and throughput, the power consumption, the effect of moisture and hammer wear were also studied.

It was concluded that the shredder met the acceptance criteria. The following results over the duration of the test support this conclusion:

1. A product 86 percent less than 3 in. (76 mm) in size.
2. Operation at an average shredder throughput rate of 111.5 tons (101 t) per hour.
3. Operation for 12 consecutive days.
4. Average daily plant throughput of 1178 tons (1068 t) per day.

**REFERENCES**


**Key Words**

Economics  
Materials Handling  
Power  
Process  
Refuse  
Sampling Methods  
Shredding

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