**Proceedings of the 17th Annual North American Waste-to-Energy Conference**
**NAWTEC17**
**May 18-20, 2009, Chantilly, Virginia, USA**

# NAWTEC17-2358

# TECHANICAL AND ECONOMIC IMPACTS OF PRE-SHREDDING THE MSW FEED TO MOVING GRATE WTE BOILERS

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## ABSTRACT

Chemical rate and heat transfer theory indicates that the combustion performance and productivity of a moving grate waste-to-energy boiler should be enhanced by means of pre-shredding of the MSW, thus reducing the average particle size, homogenizing the feed, and increasing its bulk density by an estimated 30%. However, the capital, operating and maintenance costs of the shredding equipment should be low enough so that existing or new WTE facilities consider pre-shredding of the MSW. In cases where MSW is transported to a central WTE from a number of Waste Transfer Stations (WTS), pre-shredding may take place at the WTS, thus increasing density and decreasing transportation costs. This is a mechanical engineering study that examined the evolution and present state of shredding equipment since 1994 when the last WTE shredder in the U.S. was installed at the SEMASS facility. The quantitative benefits realized through the pre-processing of MSW by means of modern shredding equipment are evaluated both for the traditional high speed hammermills and the new generation of low-rpm, high-torque shredders. The combustion characteristics of shredded MSW were analyzed and compared to those of the "as-received" material that is presently combusted in mass burn WTEs. The emphasis of the project has been on equipment that can be integrated in the traditional flowsheet of a WTE and serviced readily. The most important criterion in the final design will be that the economic and energy benefits of pre-shredding be clearly greater than the conventional operation of combusting as received MSW.

## INTRODUCTION

Municipal solid waste is a mixed stream of widely varying composition and particle size that is continuously generated by our society. Its management and disposal in an environmentally sound manner is a difficult task and has seen large improvements over the past decades. Incineration of MSW as a means of reducing its volume and facilitating disposal has been a common waste management technique for centuries, yet the majority of incinerators in the U.S. did not recover the heat of combustion generated via MSW incineration, until the mid seventies. At this time, 88 Waste to Energy plants in the U.S. and over 600 worldwide are a clean and safe way of disposing MSW and also recovering energy, in the form of electricity and heat, and metals.

One of the reasons that there have not been WTE facilities in the U.S. for several years is the very high capital cost of new plants. It is believed that one way of increasing the specific productivity of such plants, and thus reducing their size and capital cost, may be by pre-shredding of the MSW, thus homogenizing and increasing the density of the feed to the grate. This study evaluates the potential benefits that pre-shredding may have on MSW management, both by means of combustion with energy recovery and of landfilling in regulation landfills.

Most of the present WTE facilities are based on the combustion of "as received" MSW, commonly referred to as "mass burn" or "stoker" combustion. Refuse Derived Fuel (RDF) is a less widely used form of MSW in WTE facilities. In the U.S., an estimated 6 million tons of MSW are used as the fuel of RDF WTE facilities, i.e. 23% of the total MSW combusted in the U.S. The RDF fuel is MSW that has undergone treatment to remove non-combustibles, with shredding being the first step in the pre-processing of MSW to RDF. In RDF plants, shredding is followed by some sorting and recovery of non-combustible materials such as glass, ferrous and non-ferrous metals. However, the recovery of non-ferrous and ferrous materials can also be carried out at the back end of incineration process, via separation from the bottom ash by-product. This leads one to believe that shredding of MSW is not only viable for RDF burning facilities but also for the mass burn plants. The major concern with shredding MSW for mass burn facilities is that the capital and operating costs required for shredding MSW may not be recovered by the improved efficiency. This perception is reinforced by the fact that RDF facilities are as costly to build as mass burn plants and also require about twice the personnel complement of mass burn facilities of the same capacity. Therefore, the question arises: Has shredding technology progressed sufficiently in the last fifteen years –since the design of the last WTEs in the U.S. to the point that shredding can be now implemented much more economically than in the past?

## POTENTIAL BENEFITS OF SHREDDING IN MASS-BURN WTE FACILITIES

The particle size of raw MSW ranges from 1 to 900 mm while shredded ranges from less than 0.1 mm up to a maximum of 150 mm. The reason for this decrease in particle range is due to the shredding of soft materials and the shattering of brittle materials such as glass and ceramics. Shredding is required in RDF type WTE facilities because different materials tend to break in to distinctive size ranges allowing for easier sorting and recovery. The overall effect of shredding tends to reduce particle size between 3 to 4 times and with an average size of 150 mm minus, depending on feed composition. Of course, decreasing the particle size of combustible materials increase the surface to volume ratio, thus allowing for quicker heat and mass transfer and combustion rates; therefore, the feed rate of shredded material per unit surface area of the grate should be greater than that with "as received" MSW.

Also, MSW streams are inherently non-homogeneous leading to varying ranges of heating values. The effectiveness of combustion and pollution control can be improved if the heating value of a fuel is more uniform and known more precisely. Finally, the passage of primary air through a packed bed of shredded MSW should encounter a greater pressure drop, on the average, and thus the drying, volatilization, and combustion phenomena through the bed should be more intense and evenly distributed.

Shin et al. [6] investigated both experimentally and theoretically the effect of particle size on combustion characteristics via the study of wood particles. They showed that increasing the mean particle size from 10 to 30 mm resulted in a decrease in the flame propagation speed from 0.8 cm/min to 0.6 cm/min indicating a combustion rate dependence on particle size. Figure 1 shows their results relating particle size to flame propagation speed; as the particle size increases, the air supply for stable combustion also increases due to the decrease in total surface area via larger particles, allowing for less convective heat loss. The dependence of the required air supply rate on particle size becomes more sensitive for smaller particle sizes due to the ability for convective cooling to quench the flame more easily. It should be further investigated as to the extent of this phenomena and how it would affect the ability to control combustion in a MSW grate. The same beneficial effect of smaller particle size should occur for radiant heat transfer which also depends on particle surface area.

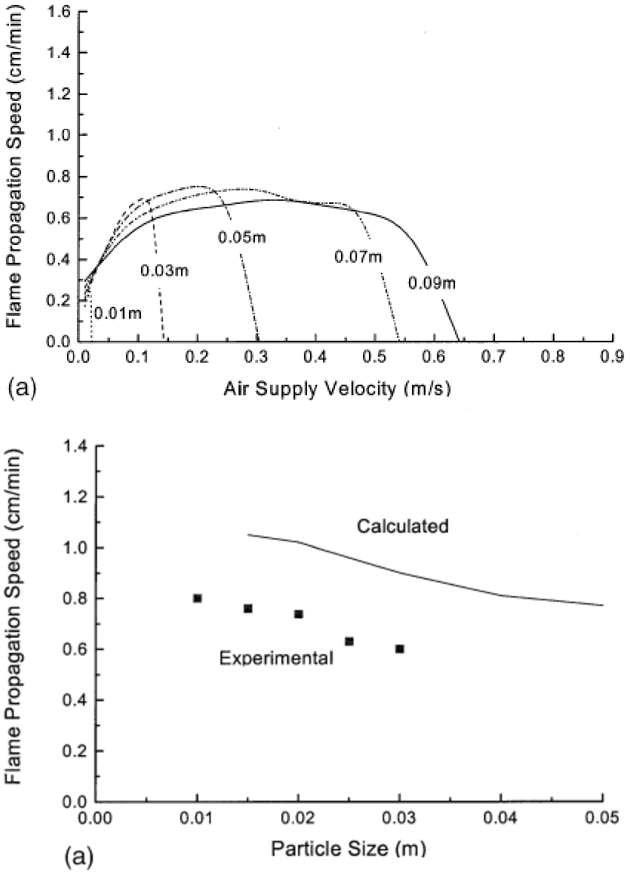

**Figure 1.** **Effect of particle size on flame propagation speed and air supply velocity [Shin].**

There can be other benefits, apart from improved combustion characteristics, as a result of the increased density of shredded MSW. A detailed field study conducted by Jones et al for Belcorp [2] has shown that the shredding of MSW increased the density by as much as 30%, effectively reducing the need volume by the same factor. This means that if designed correctly, the storage pit of a new WTE facility could be 30% smaller for the same tonnage of shredded MSW.

## BENEFITS OF PRE-SHREDDING FOR MODERN LANDFILLS

The MSW capacity of a sanitary landfill is governed by the available airspace determined by zoning restrictions and the in place density of said refuse. It is common practice in landfilling operations to use compactors to attempt to increase the density and stability of the refuse face. Several landfills operators have taken advantage of further extending the operating life of their landfills by the use of shredders. The operators of the Albany city landfill have been shredding MSW using a high speed hammermill for the past several years, and have extended the operating life of the landfill by over one full year. It has been proven to be economically feasible and profitable to operate with a shredder on site. The landfill receives monthly revenues of $1,000,000. A volume reduction of 30 % in the landfill can extend the expected the life of MSW management by 1 month for every 3 months of operating with the shredder, easily generating enough revenue to overcome initial capital costs. In a separate study of milled refuse in Madison Wisconsin, Reinhardt et al. produced similar results regarding density, with a 33 % increase in effective density on a wet basis and a 22 % increase on a dry basis. An additional benefit of increased MSW density is that a greater tonnage can be deposited each day, between the required daily applications of Daily Cover (e.g. 15 cm of soil is required by EPA).

| | Test Period | In-place Density ($kg/m^3$) | % Increase |
|---|---|---|---|
| **Shredded MSW** | 7/20/00 - 08/07/00 | 516.38 | 28.69 |
| | 08/07/00 - 09/01/00 | 534.07 | 15.96 |
| | 07/20/00 - 09/01/00 | 529.21 | 16.67 |
| | | | |
| **Non-Shredded MSW** | 07/20/00 - 08/07/00 | 401.24 | |
| | 09/02/00 - 09/25/00 | 460.55 | |
| | 09/25/00 - 10/12/00 | 475.11 | |
| | 07/20/00 - 10/12/00 | 453.61 | |
| **Average Increase** | | | 20.44 |

**Table 1. Tomoka Farms Road Landfill effective in-place density shredded and non-shredded MSW [Jones].**

The Tokoma Farms Road Landfill in south Florida has been shredding MSW since it started receiving waste in June of 1999. Belcorp Inc. preforms the shredding using a high speed low toqrue hammermill shredder with the goal of extending the life of the landfill. Belcorp contracted Jones, Edmunds & Associates, Inc. (JEA) to preform a year long investation on the effect shredding has on in-place density of MSW in a landfill. In-place density is defined as the relationship between the solid waste tonnages to the airspace volume used for a specific time period. The investigation has shown that shredding MSW can lead to an increase of nearly 30 % in the in-place density, with an average improvement of 20%.

The benefits of shredding are not limited to volume reduction. As seen with the case of increased rate of reactions in the combustion processes, the decomposition rate of waste in landfills is increased with shredded material. The increased rate of decomposition generates larger quantities of methane on an annual basis. The net production of landfill gas will remain the same; however the time frame for collection is decreased significantly due to decreased particle size. Landfill gas collection systems must be employed to both recover energy from the waste but also mitigate green house gas emission. The landfill gas production rate also benefits from the more uniform flow of leechate through out the refuse; the more evenly packed waste eliminates bridging that causes leechate to flow through channels. More densely compacted MSW can achieve the necessary saturation to enter the anaerobic zone more readily with less of a need for leechate recirculation. This leads not only to more rapid decomposition but more uniform decomposition lending to a LFG collection system with more simple controls and regulation.

## POTENTIAL BENEFITS OF SHREDDING AT WASTE TRANSFER STATIONS

The benefits of increased density go beyond just improved storage capacity; a higher MSW density can also save money in the transportation aspect of MSW management. As much as 70% of the cost of managing one ton of municipal solid wastes is due to collection and transportation. When it is necessary to transport MSW over long distances, either to landfills or WTE facilities, it is necessary for the small collection trucks usually 3-4 tons of MSW to unload at a Waste Transfer Stations (WTS) where front end loaders load the long distance trucks, or rail cars that will transport the wastes to their final destination with capacities of 20 tons for trucks and even higher for rail cars. Transfer stations are generally equipped with one or more waste compacting device setup to receive waste. The concept behind a transfer station is that higher capacity trailers are used to make the long distant trips between waste generation and disposal sites. This allows for fewer trips and a smaller crew resulting in decreased operation costs. Compactors are capable of increasing the in-transit density of MSW by a factor of 2 to 3 compared to loose MSW resulting in fewer trips.

It is clear that compacted raw MSW can achieve a higher density than non-compacted shredded MSW. However shredded MSW can compress further than unprocessed waste due to the increased packing efficiency that is posssible with smaller particles size. In the event that a landfill or WTE plant decides that it will benefit from shredding MSW, it could be beneficial to do this at the transfer station and thus capitalize twice on the increased density of shredded MSW.

## SHREDDING EQUIPMENT

Many devices capable of material size reduction are available on the market ranging from automobile shredders that are able to process almost anything, to granulators and paper shredders that can process only relatively soft materials. The composition of MSW is so widely varied that machines designed for MSW must be robust enough to handle both soft and ductile materials as well as tough and resilient materials such as metal and dense plastics. There are two prominent categories of shredders used in the management of MSW; high speed, low torque (HSLT) hammermills and low speed, high torque (LSHT) shear shredders. There exists little similarity in the principles behind size reduction via HSLT and that of LSHT shredders. This difference leads to some inherent advantages and disadvantages regarding the acceptable MSW feed as well as the size distribution of the product and overall process capacity. HSLT machines are available in a wide range of sizes and capacities. Some of the tub grinder type hammermills can reach capacities of up to 300 tons per hour of MSW size reduction; however this number is closely related to the desired particle size as well as the content. A more realistic value for continuous operation of such shredders will peak at about 150 tons/hour for the larger machines.

### High-Speed, Low-Torque Hammermills

Low torque shredders such as the vertical hammermill utilize high speed rotating shafts (700-1200 rpm) that are equipped with fixed or pinned hammers. The principal difference between these machines and the LSHT devices is that hammermills rely heavily on impact forces to smash the refuse into smaller particles. Figure 2 shows an axial cross section of the rotating shaft and hammer, this drawing highlights the impact forces used in these machines. It is important to notice that the hammermills do not have tight tolerances with the cutting surfaces; this is because size reduction is primaraly a result of the hammer smashing the MSW. Due to their reliance on impact force, hammermills are generally more effective in processing brittle materials and can have problems with rags and stringy materials which can wrap around the shaft and cause overloading and disruption of the operation, these issues are a result of the low torque of the system. The impact force of the hammers is damped by ductile material while energy is absorbed and wasted in softening mechanisms lowering the intensity of the impact force. Hammermill shredders produce a less homogeneous product with brittle materials making up a higher portion of the fines than ductile materials. This is especially true for glass which is a non-combustible. Generally the materials with higher heating values such as paper and petroleum based plastics are more ductile and may end up receiving less than the average size reduction meaning energy and cost is wasted on size reduction of the material which benefit least from size reduction.

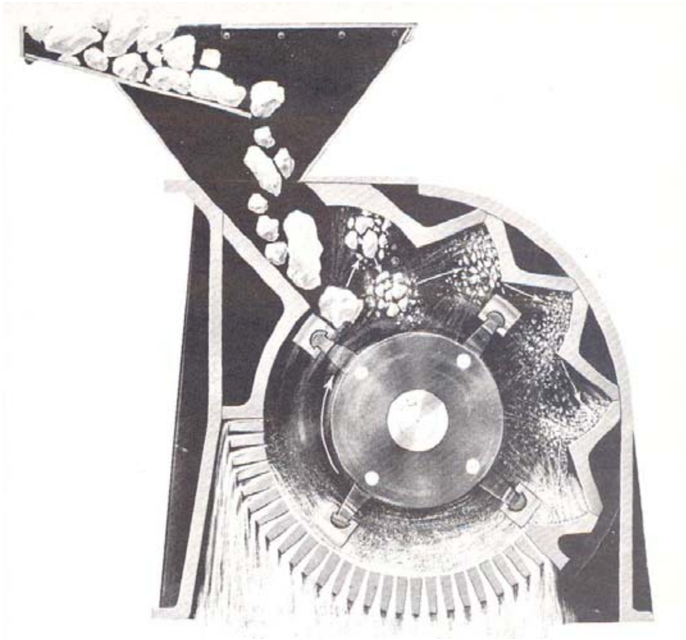

**Figure 2. Operating principle of the high-speed, low-torque hammermill.**

The HSLT shredders have specific energy consumptions ranging from 6-22 kWh/ton depending on the characteristic size of the shredded refuse and the material composition. A study by Trezek on MSW size reduction has shown that the specific energy consumption of a hammermill can be optimized by lowering the rotor speed. In this test, when the rotor speed was reduced from 1200 to 790 rpm, there was a 26 % reduction in power consumption for an equivalent amount of MSW processed. The reason for this can be attributed to the fact that up to 20 % of a HSLT shredders power is used to overcome bearing friction and windage of the rotor. If the machine is not loaded properly and consistently, a large fraction of the energy is used in idle spinning of the rotor. It has also been shown that higher rotor speeds generate finer particles at a higher energy cost. It is therefore necessary to choose the rotor speed according to the desired particle size because processing MSW to sizes smaller than necessary can result in large energy costs. Figure 3 shows that the relationship between specific energy and particle size is non-linear. The energy required to achieve a desired particle size follows a geometric relationship between energy and particle size, this non-linear relationship is an important characteristic when considering size reduction. Shredding the MSW unnecessarily can lead to even greater operation costs.

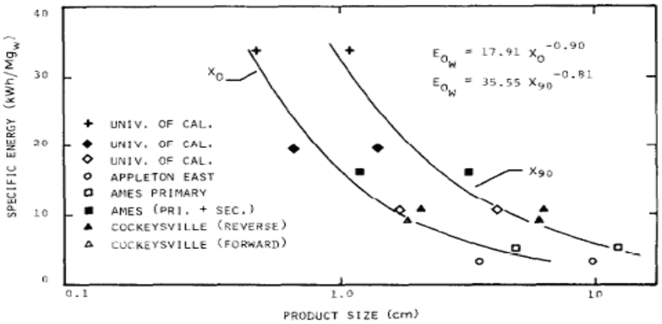

**Figure 3. Particle size effect on specific energy of LSHT shreddrers [Trezek].**

Moisture content in MSW can also vary widely from as little as 10% all the way up to 60 % as seen in some food waste. This moisture content can have a large effect on the power consumption of a shredder. Some of the more common materials found in MSW, such as paper, lose their tensile strength when wet; thus, the energy required in tearing paper decreases with increased moisture content. However, Trezek et al. have shown that the specific energy used (energy per unit of material) decreases with moisture content of MSW up to about 35%; at higher % moisture, the specific energy again increases. This is unique to HSLT shredders because at high moisture content, the wet materials tend to absorb the impact energy of the hammer and deform rather than break, causing the product of moist materials to contain higher number of large particles. The wet material is also said to interfere with the smooth flow of the shredder as a result of material “wadding”.

As in the case of all industrial processes, the safety of operators is of the utmost concern. One of the more common and dangerous safety issues involved with MSW shredding is that of unexpected explosions during shredding. Explosions are almost inevitable in the shredding of MSW and are often caused by the build up of volatile explosive vapor around the rotor. This explosive vapor can come from propane and other compressed tanks that somehow make it past the floor pickers. The danger with high speed hammers is that they have a tendency to create sparks during the impact with metallic objects. To make things even worse, the rotating hammers mix the combustible gases in turbulent flow, thus potentially bringing the mixture to its lower explosive limit. These types of incidents can be avoided in some cases by an observant operator who is constantly checking the feed for hair spray, spray paint, gas cans or any such highly flammable object but such vigilance is not practical in processes that handles ten to fifty tons of MSW per hour.

## LOW-SPEED, HIGH-TORQUE SHREDDERS

Low speed, high torque shredders, such as rotary shear shredders operate on a different principle than the hammermill. Rotary shear devices rely on shear cutting and tearing forces with little to no impact force involved. Rotary shears are made in single, double or quad shaft configurations so that increased shaft numbers produce a smaller mean particle size. The counter rotating shafts are fitted with cutting knives that intermesh and create large shear forces on any material trapped between them. These cutting kinves or hooks are shown in the quad shaft configuration in figure 4, the hooks must be designed such that they grab the incoming MSW and pull it between the neighbooring shafts to achieve the shear cutting forces. The definition of LSHT shredders generally assumes a speed of between 10 and 50 rpm. The low shaft speed can have some hindering effects on capacity and they are often available in lower capacities than HSLT. The capacity of the shredder depends on the rotor speed and the volume available between cutting knives. Although industrially available shear shredders have capacities topping out around 70 tons per hour, they have many positive features that make up for this.

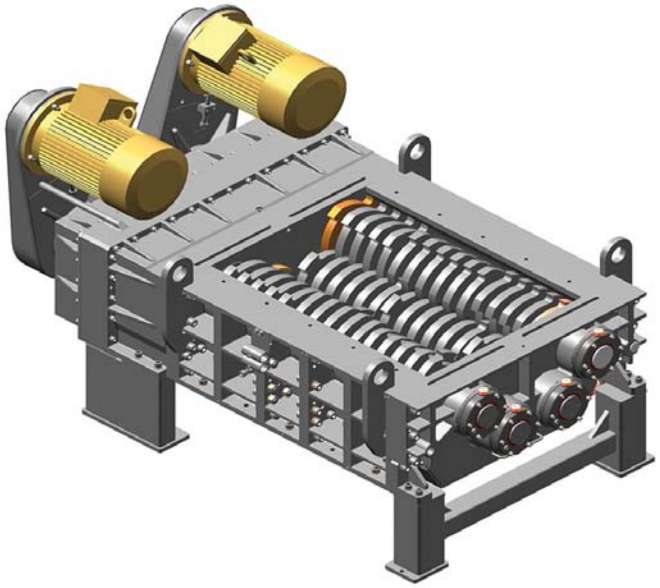

**Figure 4**. **CAD drawing of Tryco Untha Quad shaft shredder [Tyrco].**

In comparison to the specific energy range for HSLT devices of 6-22 kWh/ton, the LSHT machines tend to have lower power consumption, in the range of 3 -11 kWh/ton, depending on material composition and feed rate. The lower speed rotors do not need to overcome as much frictional resistance as the HSLT hammermill, lending to higher energy efficiency per ton processed. The lower specific energy required in rotary shear devices allows for more compact and space efficient designs. The high torque produced can vary depending on design, from 50-350 kNm as compared to the 1-4 kNm achieved with the hammermill. The high torque results in a more even particle distribution, because shear forces are the major breakage mechanism and are less sensitive to material properties.

A unique feature of rotary shears is their ability to quickly stop shredding the incoming feed and reverse the rotors to discharge a non-shreddable object in the feed. Many of LSHT machines use hydraulic transmission to drive the shafts. A simple control system can be employed that detects pressure spikes in the hydraulic lines, thus indicating a large increase in torque; this signal can be used to recognize non-shreddable items and automatically reject them. This ability has no counterpart in HSLT shredders because they rely on stored rotational energy to manage tough objects resulting in high energy loss and potential damage when a non-processable item is encountered. The low speed in combination with hydraulic drive lines allows for the shaft to cycle from forward to reverse in the matter of a few seconds, a favorable option when stopping and starting of the feed through the machine is a frequent occurrence.

Safety issues such as explosions and ejected materials are of less concern when dealing with low rpm machines. Explosions require a flamable mixture of fuel and oxidizer as well as a source of ignition, both of which is less likely to occur in a low speed system. With the absence of impact forces, it is difficult for the machine to produce a spark necessary for combustion. The low speed also means that when a flammable vapor is encountered it is not vigorously mixed with surrounding air making it more difficult to reach the lower explosive limit. The ejection of materials is also less common in these devices because there are no fast moving parts that can project dangerous objects out of the hopper.

## SHREDDER MAINTENANCE

Both HSLT and LSHT shredders undergo severe wear and tear when processing material such as MSW. When operating a hammermill, it is essential to the productivity of the machine that the cutting surfaces of the hammer be maintained, for this reason hammer replacement is a very common procedure and can be necessary as often as every 20 hours of operation. As a result of operating at high speeds, the components of a hammermill are subjected to large amounts of vibration and impact that require more maintenance than the shear cutters. Rotary shears also require replacement cutting surfaces but less frequently. An added bonus to the operator is that LSHT devices generally operate with a lower dust production rate and with less noise.

A potential problem with the LSHT shredders is their ability to “grab” or “bite” the incoming MSW stream. Some materials, e.g. cardboard boxes or suitcases, may tend to bridge between the two rotating shafts avoiding being pulled down into the cutting surface. However, this problem can be avoided by the addition of a pushing ram or sufficient head of material above the rotors. These shredders can also face difficulties in processing some of the more tough metals that can be found in MSW because, in contast HSLT machines, the shear shredders do not have the benefit of stored rotational energy that can be used to rip apart tough objects, when necessary. However, as noted above, this problem is somewhat avoided by their ability to reject materials that cause too high a resistance in the shaft rotation.

The rotor speed of LSHT shredders tends to have an effect on the power consumption and capacity of the device. As the rotor speed is decreased, the specific energy required to process a ton of waste is increased, which is the opposite trend that is encountered with HSLT shredding where energy is wasted in idle rotor spinning. Figure 5 shows this trend where specific energy is inversely proportional to the rotor speed. Another interesting aspect of LSHT shredders is that the ratio of the shredders bulk volume to its capacity tends to decrease with increased rotor speed, in other words higher rotor speeds can achieve a higher energy density and therefore process more material in a smaller space. In general the low speed high torque shredders can be designed to be more compact than HSLT of equivalent capacities. The figure below demonstrates how the energy density of the LSHT shredders increases as the rotor speed is increased.

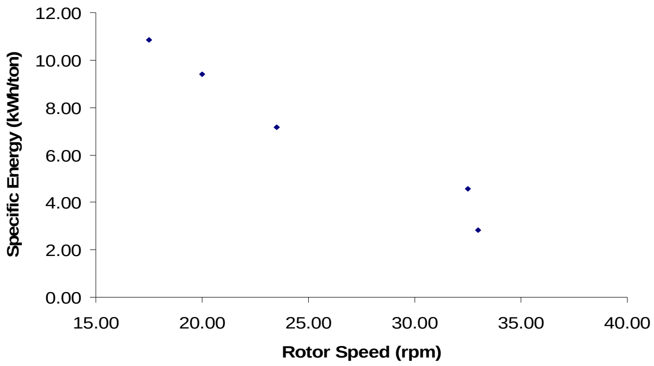

**Figure 5**. **Rotor speed relationship to specific energy for LSHT.**

Integration of such MSW size reduction machines into the waste-to-energy process requires that the benefits outweigh the initial cost. Operational costs of low speed shredders seem to prevail over the hammermill, both with regard to energy consumption and maintenance. It is also beneficial that the LSHT devices tend to require less space than an equivalent capacity hammermill. Hammermill shredders were not originally designed to process MSW but because of their robustness and ability to process nearly anything they have been adopted in many MSW size reduction applications. It is necessary to design these devices with specific capabilities in mind; in the case of LSHT shredders, they can reject non-shreddable which are also generally non-combustible. Because of this ability, the device does not need to be over designed but rather intelligently designed such that it only shreds what needs to be shredded.

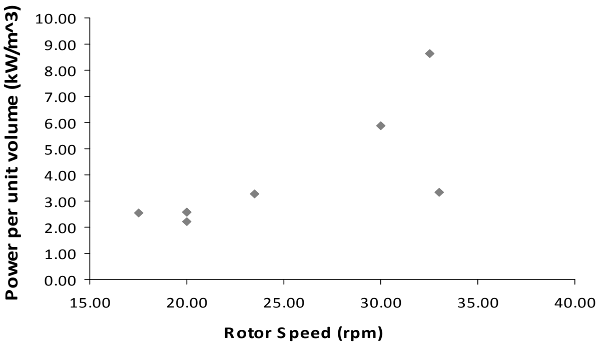

**Figure 6. Energy density trends for LSHT shredders.**

## CONCLUSIONS

The general conclusion from this study favors LSHT shredders over the older hammermills. However, because these high torque shredders have not been tested and documented on a very large scale, to the extent of hammermills, more research and onsite evaluation is needed. Due to the lower capacity of LSHT shredders an array of several lines will be necessary to handle tonnages typical of landfills and WTE facilities. The costs of such machines of course will play a large roll on which type of shredder a facility chooses to use. If the feed is made up more of C & D material with a higher metal and concrete fraction it may make sense to use a high speed shredder. The auto-reversing option on LSHT shredders cold become a nuisance if the feed is heavily laden with non-shreddable items causing the machine to be rejecting more often than shredding.

Shredding of MSW prior to landfilling has already been demonstrated to be profitable using HSLT shredders solely for increased density. The RDF plants have shown that shredding and sorting MSW can be a costly process, however a more streamline application of the LSHT shredders could lead to a decrease in these operation cost. The improvement on shredding technology in the high torque devices could be just what is needed to make shredding MSW for WTE a common practice. By using a LSHT shredder as opposed to HSLT the floor plan of shredding room can be decreased lowering initial capital expenses. Higher efficiencies and lower operating costs point in the direction of such devices. The limiting factor in this debate may end up being initial investment costs of the high torque shredders being higher because more machines will be necessary to process the same quantity as a single hammermill.

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