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Project Summary

Fundamental Considerations for Preparing Densified Refuse-Derived Fuel

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A series of pilot-scale tests were conducted to determine the effects of various parameters on the densification of refuse-derived fuel (RDF). The experiments included a series of bench-scale experiments involving a single die arrangement, as well as larger-scale studies in which a commercial pellet mill was used.

The bench-scale tests in which the pellets were individually formed were conducted both to provide data needed for an analysis of the basic dynamics of pellet formation and as an aid in the interpretation of results obtained with the pellet mill. The energy required to overcome die friction was studied independently of the energy consumed in material deformation and compression. By so doing, it became possible to determine the specific effects of die length, diameter, and taper. The results also suggested explanations for the excessive die wear and why less energy is needed to increase the mass throughput observed in commercial pellet mills.

With the use of data obtained in the tests with the pellet mill, the relationship between specific energy of densification and mass flow rate through a mill was found to be as follows:

$$E_n = aM_D^b$$

where a and b depend upon the die dimensions and characteristics of the feedstock. Other data were developed that relate feed moisture content to pellet density and feed size to maximum achievable pelletization rate.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. Environmental Protection Agency (EPA) assigned the Municipal Environmental Research Laboratory (MERL) in Cincinnati, Ohio, major responsibility for research and development in the field of recovery and use of municipal solid waste. One concept investigated involves the recovery of energy from solid waste. Refuse is combusted either directly for steam recovery or in combination with fossil fuels for power generation. The latter involves processing the refuse to remove the combustibles for use in a modified power generation boiler, usually in combination with coal. The processed refuse is usually referred to as refuse-derived fuel (RDF).

The RDF concept in the United States has generally been limited to power generating facilities that burn pulverized coal. The use of RDF need not be limited to large users, however; it may, in fact, be more valuable to small power generating facilities. Small industrial and institutional boiler owners may find

RDF an attractive and cheaper alternative to fossil fuels, for which they receive no quantity discounts, as do the large users. In addition, small users may have increased flexibility in negotiating contracts for RDF (especially with regard to length of commitment). Many small power generators are economically marginal because their boiler facilities are older, coal-burning models that require costly air pollution equipment. The use of RDF may help such facilities absorb the cost for such controls.

RDF prepared for large utility boilers is typically composed of the light fraction of shredded refuse that has been air-classified, screened, or otherwise processed to remove the noncombustibles. In this fluffy form, it can be pneumatically fed into the suspension utility boiler. For the smaller, stoker-fed boilers, however, a densified form of RDF is used.

Densification imparts to RDF many attractive features in terms of combustion characteristics, not the least of which are compatibility with other (conventional) fuels in co-firing and efficiency of transport. A growing awareness of these characteristics is expanding the potential for using densified RDF (d-RDF) as an energy source. Before this potential can be fully realized, however, insight into the relatively complex densification process must be acquired. This acquisition is difficult because the machines currently used to produce d-RDF were originally designed to densify much different materials, e.g., animal feedstocks and a number of agricultural products.

The limited field experience with the densification of RDF has not been entirely satisfactory, e.g., the actual output from a pellet mill typically falls short of its rated output; dies, rollers, and other moving parts show signs of excessive wear; and the machines are difficult to feed and easily jammed. Because little information was available on the production and burning of d-RDF, EPA implemented parallel programs to (1) determine the engineering and economic aspects of preparing d-RDF and (2) assess the technical and environmental implications of using d-RDF as a coal substitute. In addition to the report summarized here, the following reports have been prepared as part of these programs: "Densification of Refuse-Derived Fuels: Preparation, Properties, and Systems for Small Communities", "Coal: d-RDF Demonstration Tests in an Industrial Spreader Stoker Boiler"; and "A Field Test Using Coal: d-RDF Blends in Spreader Stoker-Fired Boilers."

Pellet Mill Studies

Procedure

To gain insight into the physics of the densification of RDF, i.e., of the so-called "light" fraction of municipal solid waste (MSW), two interrelated courses of action were persued: one in which pellets were produced by means of a single die under laboratory conditions and the other in which a commercial densification machine was used.

The processing began with the delivery of a packer-truck load of MSW to the processing facility. The MSW was then processed through shredding, air classification, and trommel screening unit operations. A model 48-4 horizontal Gruendler swing hammermill was used for size reduction; a vertical-type, straight, rectangular column device was used for air classification. A California Pellet Mill* was installed in the light fraction processing line. By suitably arranging the conveyor system, the densifier could be fed either with the air-classified light fraction or with the screened light fraction. Three sizes of pellets were produced by interchanging the dies, which had different length-to-diameter ratios (1/2 by 4 in., 3/4 by 3 in., and 1 by 5 in.). The effect of die configuration and feed material on the net power and specific energy consumption were evaluated. Measurements were made of power consumption, throughput, pellet density, and moisture content. A portable, power-measuring apparatus determined mill power consumption. The free-wheeling power of the mill was subtracted from its gross power consumption to determine the net power consumption.

Results

The general nature of the results from this series of exploratory tests indicated that net power and net specific energy consumption are a function of the mill throughput. For certain situations, it was found that the basic relationship between energy and throughput was also parametic with pellet density, and in some cases, with both pellet density and moisture content.

The specific energy data for the screened light fraction processed through a 0.75- by 3.0-in. die indicate a discernable dependence upon density. In attempts made to describe the relation of net power to mill throughput analytically in terms of either exponential or power law relations, a power law relation of the type

$$E_n = aM_D^b$$

provided the best analytical description. The coefficient, n, and exponent, b, vary with density. In this case, the mill throughput was evaluated on a net basis. The moisture content of the feed material was on the order of 15 percent.

Laboratory Densification Studies

Procedure

A special die arrangement was constructed for formating pellets in a single die. The basic assembly consisted of a rod, container, die, and support plate. The dies used had inside diameters of 1/2, 5/8, and 3/4 in. In addition to straight dies, taper angles of 2.4, 7.1 and 14 degrees on the radius were evaluated for the 3/4-in. die. Tapers of 0 (straight die) and 14 degrees were evaluated for the 1.2- and 5/8-in. diameter dies. The assembly was mounted in a standard laboratory Tinius Olsen Universal Testing Machine. Its motion, i.e., the distance the die is pressed into the container, is measured with a deflectometer. A graph of force versus deflection is generated on a high magnification recorder.

In experiments concerned with the effects of temperature and moisture content on the densification process, the moisture content of the material was varied by adding a measured amount of water to air-dried material. To evaluate the effect of temperature, it was necessary to heat the material while it was in the die and container. In commercial applications, the material most likely would be heated in a feeding chamber arrangement before being introduced into the die.

To determine die friction, a rod, slightly smaller in diameter than the internal diameter of the die, was used to push the material through the preloaded die. Essentially, the rod replaced the container in the test apparatus.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Results

The force-compression curve (Figure 1) is an example of the actual plots made by a recorder controlled by the Tinius-Olsen compression tester and deflectometer. Each of the four curves in the figure represent results obtained with one of four pellets. Essentially, each curve is a plot of the compressive force (in pounds) versus the distance to which the die is pressed into the container. Each division on the horizontal axis corresponds to 0.4 in. of compression (or crosshead motion).

The curves form four distinct regions of interest:

- In region 1, the loose material is compressed to form a compact cylinder in the container. The force in this region rises exponentially as the material is compressed.
- In region 2, the material begins to move through the die. The onset of motion results in a precipitous drop in force that correspondes to the transition from static to kinetic friction.
- In region 3, the pellet is extruded from the die. The force fluctuations are attributable to nonhomogeneity of the material.
- In region 4, the force surges rapidly as the amount of material remaining in the container approaches zero. The surge occurred consistently whenever the length of the material remaining in the container was less than about 1/4 in.

Within the range of conditions prevailing or applied in the experiments, flow rate and temperature did not significantly influence the deformation pressure. The influence of moisture content is somewhat analogous to that observed in soil mechanics. Essentially, as the moisture content increases, the material becomes less viscous. As a result it becomes easier to deform and, in effect, easier to push through the die. The addition of moisture does not, however, serve to lubricate the die walls.

No difference could be discerned between the strength of pellets formed in the 0° and those formed in 7° taper dies. On the other hand, pellets formed with the 14° die were consistently better in quality than were those formed with the 0° and the 7° dies. Even though the pellets produced with the 14° die had a lower density, they were in effect better formed because the material was interwoven such that the pellets could not easily be broken.

At the lower moisture content, the outside surface of the pellet tended to be flaky. Increasing the moisture content brought about the formation of a smoother surface. As the moisture content began to exceed 20 percent, the surface again tended to flake and the pellet became weak and spongy.

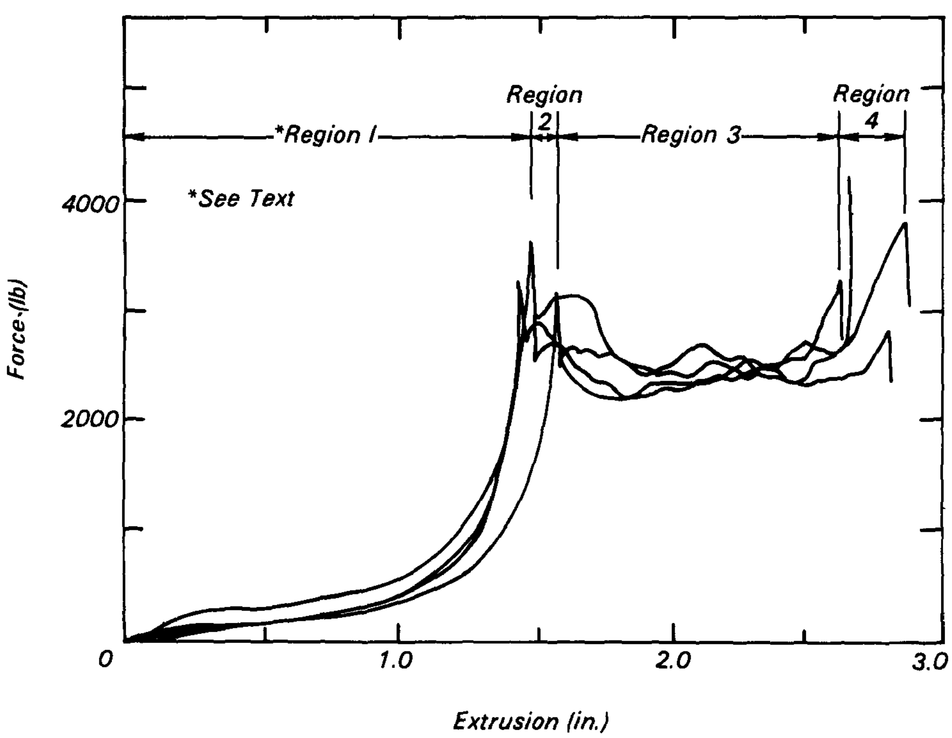

Figure 1. *Typical force versus extrusion curves for single die studies.*

Conclusions

Pellet Mill Tests

1) The specific net energy of pelletization can be related to mass throughput by the equation

$$E_n = aM_D^b$$

where a and b depend on die and feed characteristics.

2) Over a throughput range of 0.05 to 1.3 metric tons per hour (MTPH) the specific energy requirements decrease from 180 to 8 kWh/metric ton.
3) The maximum throughput capacity of the pellet mill (rated at 2 MTPH) for a characteristic feed size of 1.0 cm is 0.8 MTPH. The capacity decreases almost linearly to a value of 0.35 MTPH for 2.0 cm feed.
4) With pellets formed of screened light fraction material that has been passed through a shredder equipped with grates having 1/2-in. openings, and then desified in a 1/2-in. x 4-in. die, the density of the pellets falls from 1.31 to 1.12 g/cc as the moisture content is increased from 13.6 percent to 26.4 percent.

Laboratory Densification Studies

Trends exhibited in a single die studies must be considered in light of the basic differences between the procedure used and a full scale densification process. With this precaution in mind, the following conclusions can be drawn:

1) Energy is required in the pelletization process to accomplish three distinct functions: precompress the loose feed, deform the feed as it enters the die, and balance the die frictional force as the pellet passes through the die.
2) The frictional force can be related to die length and diameter by the equation

$$F = F_o \exp\frac{4\mu L}{D}$$

3) Static friction necessitates applying a greater force to begin the flow of a pellet than is needed to maintain the flow. Thus, stopping and starting the flow results in an increase in energy requirements.
4) The force required for deformation rises dramatically when the thickness of feed above the die inlet is less than one-half of the die diameter. This phenomenon may be attributed to changes in the orientation of material flow lines, and it might significantly contribute to the wear encountered in a commercial pellet mill as well as to the energy requirements.
5) Although the pressure required for pellet deformation increases with extent of deformation, the classical model for homogenous crystaline materials, $P_D = Y \ln (A/a)$ does not consistently and accurately predict the magnitude of this pressure.
6) A 1 percent increase in the moisture content of the feed decreases the deformation pressure by approximately 300 psi. However, if the moisture content exceeds 20 percent, a very weak pellet is formed.
7) Increasing the proportion of newsprint in the feed is accompanied by a dramatic rise in pressure.
8) Variations in feed and die temperatures apparently exert no effect on extrusion pressures.
9) Pellets formed by a die having an inlet taper of 14° consistently have a higher quality and a lower deformation pressure than do those formed by dies having a 0°, 2°, or 7° taper.
10) Typically, the specific energy consumed in deformation and friction at a moisture content of 15 percent is 14.4 kWh/MT.

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The complete report, entitled "Fundamental Considerations for Preparing Densified Refuse-Derived Fuel," authored by G. J. Trezek, G. M. Savage, and D. B. Jones of the University of California, Department of Mechanical Engineering, Berkeley, CA 94607 (Order No. PB 82-101 668; Cost: $8.00, subject to change) will be available only from:

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