

C.3

SERI/TP-33-348

SERI/TP-33-348

OCT 8 1979

GOLDEN, COLORADO 80401

BIOMASS DENSIFICATION
ENERGY REQUIREMENTS

T. B. REED
SOLAR ENERGY RESEARCH INSTITUTE

G. TREZEK
UNIVERSITY OF CALIFORNIA

L. DIAZ
CAL RECOVERY SYSTEMS, INC.

TO BE PRESENTED AT THE SYMPOSIUM ON
THERMAL CONVERSION OF SOLID WASTES
AND BIOMASS, AMERICAN CHEMICAL SOCIETY,
WASHINGTON, D.C., SEPTEMBER 10-14, 1979

Solar Energy Research Institute

1536 Cole Boulevard
Golden, Colorado 80401

A Division of Midwest Research Institute

Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

BIOMASS DENSIFICATION ENERGY REQUIREMENTS

T. B. Reed
Solar Energy Research Institute
Golden, Colorado 80401

G. Trezek
University of California
Berkeley, California

L. Diaz
Cal Recovery Systems, Inc.
Richmond, California 94804

Biomass materials, especially residues, are in many ways an attractive renewable fuel. However, they suffer from low volume energy content and occur in a wide variety of forms unsuitable for fuel use. Densification of biomass to pellets, briquettes, logs, or dense powders yields clean, renewable fuels with energy densities comparable to coal.⁽¹⁻⁴⁾ Yet the cost and energy required for densification must be considered in deciding whether densification is practical in a given situation. A knowledge of the dependence of this energy on various operating parameters also will make possible design of better densification processes.

The purpose of this study was to determine the work required for densification under various laboratory conditions and to compare this to the energy consumed by practical operating equipment.

Experimental Procedure

The apparatus used to study densification by compression is shown in Figure 1 (a). It consists of a steel die and piston 2.5 cm in diameter capable of being heated to various temperatures during pressing. The travel of the piston was measured as a function of applied pressure. Ten-gram samples of minus 10 mesh pine sawdust dried at 110 C were held at temperature for 15 min after initial cold compaction at 200 psi, and the pressure was then increased in 300-psi increments to 10,000 psi. The resulting densities are shown as a function of pressure in Figure 2 for temperatures from 100-225 C. Runs were made also at 250 and 300 C, but wood was heavily pyrolyzed in the process and the results were discarded.

Elemental and proximate analyses were run on the initial sawdust and a 225 C pellet and are shown in Table I. The energy contents of the sawdust and the resulting pellets are shown in Table II.

The experiment just described was designed to simulate the densification process by direct compression, a batch process. However, many commercial densification machines provide continuous extrusion of pellets. Sufficient pressure is built up to cause the material first to densify and then to flow through a constricting nozzle. The apparatus of Figure 1 (b) was designed to simulate this extrusion process. Twenty-gram samples

Table I. Analysis of Pine Sawdust and 225 C Pellet From Compression Experiments

Experiments ¹	Dry Sawdust ²	225 C Pellet
Proximate Analysis³-%		
Ash	0.83	0.99
Volatile Matter	83.19	85.05
Fixed Carbon	15.98	13.96
Sulfur	0.06	0.06
Ultimate Analysis-%		
Carbon	49.89	52.09
Hydrogen	6.40	6.28
Oxygen	42.48	40.36
Nitrogen	0.36	0.22
Chlorine	—	—
Sulfur	0.05	0.06
Ash	0.86	0.99
Heating Value - kJ/g	19.3	21.4
Btu/lb	8290.0	9200.0

¹ Analysis and heats of combustion by Hazen Assoc., Golden, Colo.

² Average of 3 runs.

³ The C, H, O correspond to an elemental formula $CH_{1.57} O_{0.65}$ for sawdust and $CH_{1.32} O_{0.58}$ for the 225 C pellet.

Table II. Heats of Combustion of Pine Sawdust and Pellets Made at Various Temperatures at 10,000 psi Pressure

Form	Temp. °C	Density g/cm ³	Weight Remaining %	Energy Content	
				kJ/g	Btu/lb
Pine sawdust	—	—	100.0	19.3	8290
Pellets	100	1.278	99.3	—	—
Pellets	150	1.340	97.6	19.6	8420
Pellets	175	1.374	96.5	19.6	8440
Pellets	200	1.422	95.6	19.6	8450
Pellets	225	1.435	91.2	21.4	9200
Pellets	250	1.316	71.2	23.0	9890

of screened solid municipal waste (SMW) were loaded into the container and heated to the desired temperature for 15 min. Pellets were then extruded at a rate of 5, 10, or 20 cm/min and the pressure was recorded as a function of deflection. The deflection versus pressure is shown in Figure 4 for four temperatures and in Figure 5 for three rates of extrusion at room temperature. The resulting pellets were well formed, especially those made at higher temperatures, and had a density of about 1.0 g/cm³.

The work done during densification is given for both processes by:

$$W = A \int_0^x P dx = A \int_0^x P dx \quad (1)$$

where P is the applied pressure, x is the sample thickness, and A is the cross sectional area of the die and piston. In the compression apparatus of Figure 1 (a) the density at each point was calculated from:

$$P = m/xA \quad (2)$$

where m is the sample mass. The work of compression is shown as a function of density, calculated from these equations, in Figure 3. The total work of extrusion was obtained by integrating the curves of Figures 4 and 5 and is shown in Table III.

Table III. Work of Extrusion of RDF¹

	Energy	
	kWh/tonne	kWh/ton
<u>Temperature²</u>		
°C		
25	7.76	7.06
93	6.09	5.54
149	6.23	5.67
204	4.45	4.05
<u>Extrusion Rate³</u>		
cm/min		
5	7.76	7.06
10	10.93	9.95
20	10.90	9.92

¹From integration of Figure 5.

²Extrusion rate 5 cm (2 in.)/min.

³At 25 C.

Discussion of Results

Three basic types of pressure application are used in commercial densification processes: (1) Straight compression in a die; (2) Extrusion through a constriction; and (3) Shear of precompacted material to produce heat and flow under pressure. Approximate energy consumptions supplied by the manufacturers are compared to the laboratory tests reported here in Table IV but it must be stressed that these figures are only approximate, depending critically on type of material, size, temperature, etc.

Table IV. Comparison of Reported Energy Requirements For Commercial Densification Apparatus with Laboratory Results

	Material	Density	Work	
			kWh/tonne	kWh/ton
<u>Compression</u>				
In Laboratory ¹	Sawdust	1.0	4.0	3.6
	Sawdust	1.2	6.6	6.0
Commercial ²	Sawdust	~1.2	37.4	34.0
<u>Extrusion</u>				
In Laboratory ³	MSW	1.0	7.76	7.06
Commercial ⁴	MSW	1.0	16.4	14.9
	Sawdust	1.0	36.8	33.5

¹This study, 2.5 cm pellet, Figure 1 (a) at 100 C and Figure 3.

²From specifications of 150 hp Hausmann briquettor No. FH 2/90/200 for 8 cm diameter log.

³This study, 1.2 cm pellet made at 25 C, 5 cm/min, Figure 1 (b) and Table III.

⁴From Ref. 1, data supplied by California Pellet Mill Corp.

The work of compression measured in this study is seen to be lower by a factor of two to ten than that consumed in operating compression machines. This is to be expected because the work measured here does not include motor and bearing losses associated with commercial equipment, and the measurements were made under idealized conditions. Given these differences, the agreement is satisfactory and the laboratory results probably represent a lower limit to the work required.

An important result of this study is the finding that the work and pressure of compression or extrusion can be reduced by a factor of about two by preheating the feedstock to 200-225 C before densification. This requires extra thermal energy for complete drying and to heat the biomass (heat capacity about 1.8 J/g-C) to the higher temperature; however, these are offset by lower electrical power costs, lower equipment costs because of the lower pressure requirements, possibly reduced die wear due to improved lubricity of the biomass at increased temperatures, and increased fuel value due to complete water removal and prepyrolysis. These factors must be tested at the commercial scale before any conclusions can be drawn on the desirability of preheating feedstock.

The analyses reported in Tables I and II show that the pellet made at 225 and 250 C had considerably higher energy contents than those made at lower temperatures. The energy content of the pellet made at 225 C is 20.2 J, essentially all of the energy in the sawdust from which it was made (91.2% of 21.4 J/g). This suggests that there is a "prepyrolysis" reaction for biomass, similar to that which occurs for lignite, in which CO₂ and H₂O are driven off with little or no energy loss.

Many commercial densification machines use extrusion rather than straight compression, because extrusion can be adapted to continuous rather than batch processing. An examination of Figures 4 and 5 suggests that there is an initial stage in which the feedstock is compressed to a pressure sufficient to overcome the static friction at the throat. At this point the pressure drops slightly to a value necessary to overcome the sliding friction encountered as the biomass passes through the constriction. The data of Figure 4 and Table I clearly show the same trends observed in Figures 2 and 3—that the work of densification drops by a factor of about two as the feedstock is preheated to 200 C.

Although the data are not directly comparable because they were taken on different feedstocks, it seems clear that the work required for compression is less than the work required for extrusion. In commercial equipment, the friction involved in extrusion performs a useful function—the heating and drying of the pellets.

Although the data in Figure 5 and Table I suggest that the work of extrusion increases with increasing rates, the effect is small here. Other data taken in pilot plant and commercial operation generally show a dramatic decrease of extrusion work with flowrate.

Conclusions

- The pressure required for densification is reduced a factor of two by heating to 225 C.
- The energy required for both compression and extrusion is decreased by a factor of about two as temperature increases from room temperature to 225 C.
- The energy content of the pellets rises with temperature of densification.

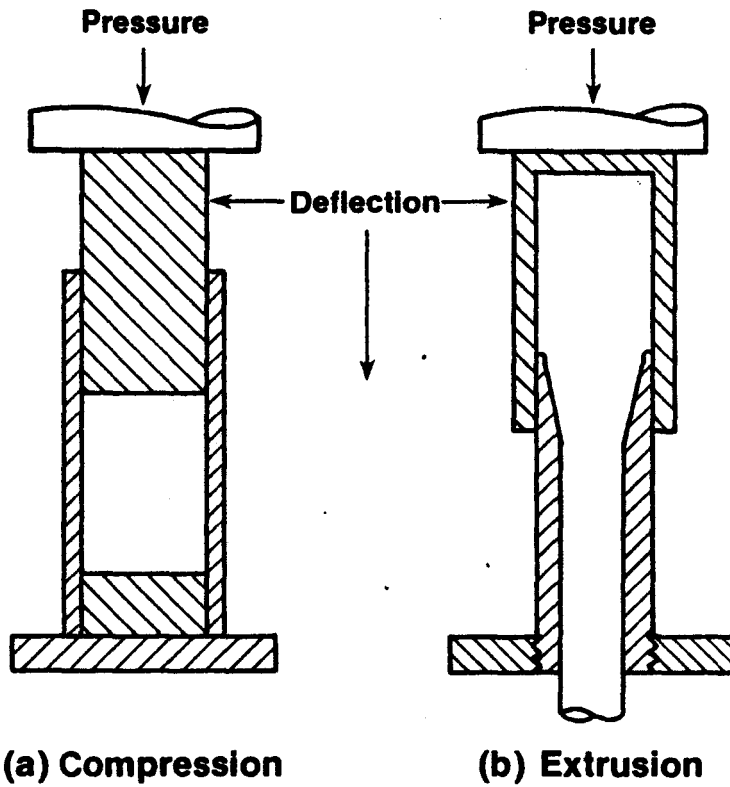
- Energies measured for densification in the laboratory are comparable to but smaller than those required in commercial equipment.

Acknowledgements

We would like to thank the Coors Ceramic Division for performing the compression experiments and Mr. John Lawson of Hazen Research for the proximate and ultimate analyses.

References

1. T. Reed and B. Bryant, "Densified Biomass: A New Form of Solid Fuel." SERI report 35. The Solar Energy Research Institute, Golden, CO 80401. July 1978.
2. T. Reed and B. Bryant, "Energetics and Economics of Densified Biomass Fuel (DBF) Production." In "Biochemical Engineering No. 181," Vol. 74, p. 26, J. M. Nystrom and S. M. Barnett, eds. (AIChE Symposium Series) 1978.
3. R. A. Currier, "Manufacturing Densified Wood and Bark Fuels." Report 490, Oregon State University Extension Service, July 1977.
4. Cohen and Parrish, "Densified Refuse Derived Fuels." Bulletin 6, No. 1, National Center for Resource Recovery, Washington, D. C., Winter 1976.

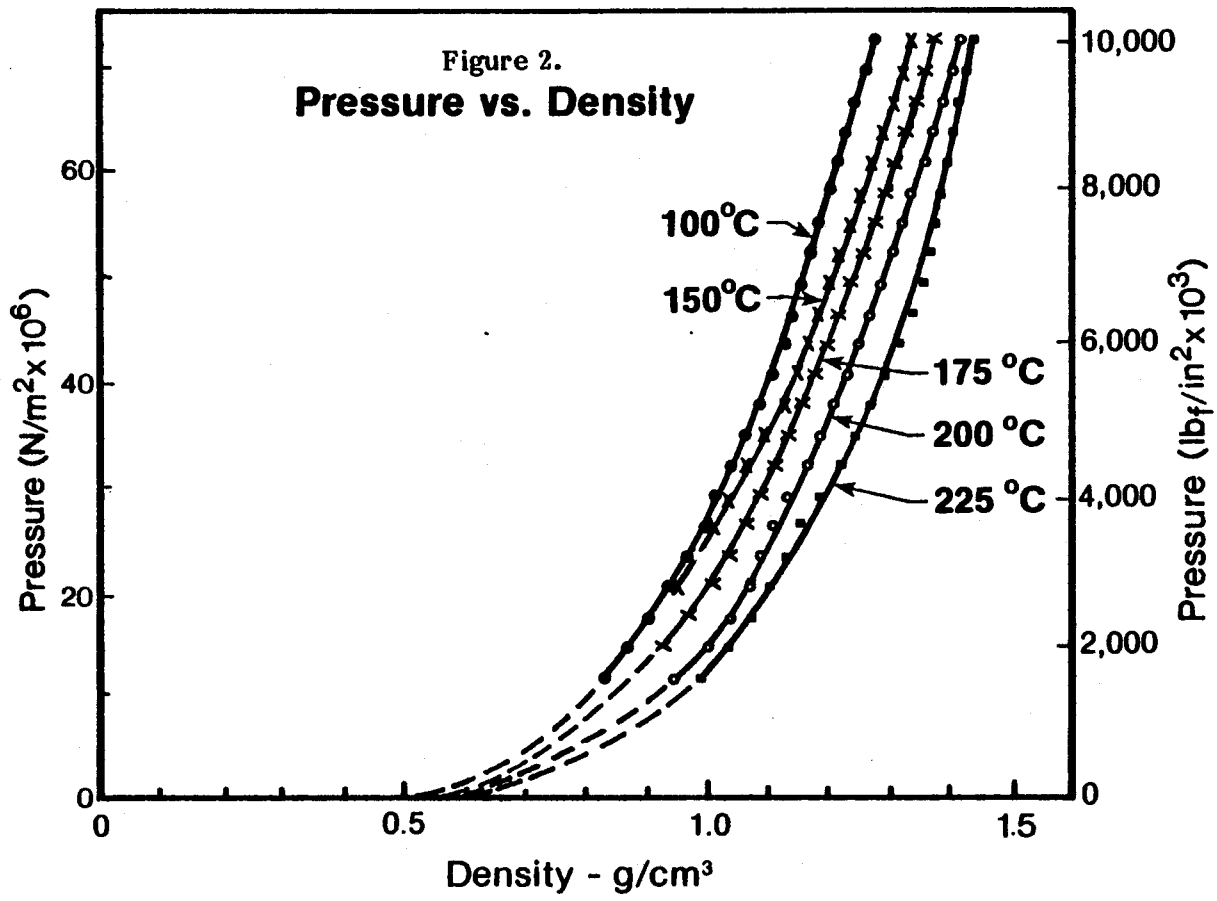


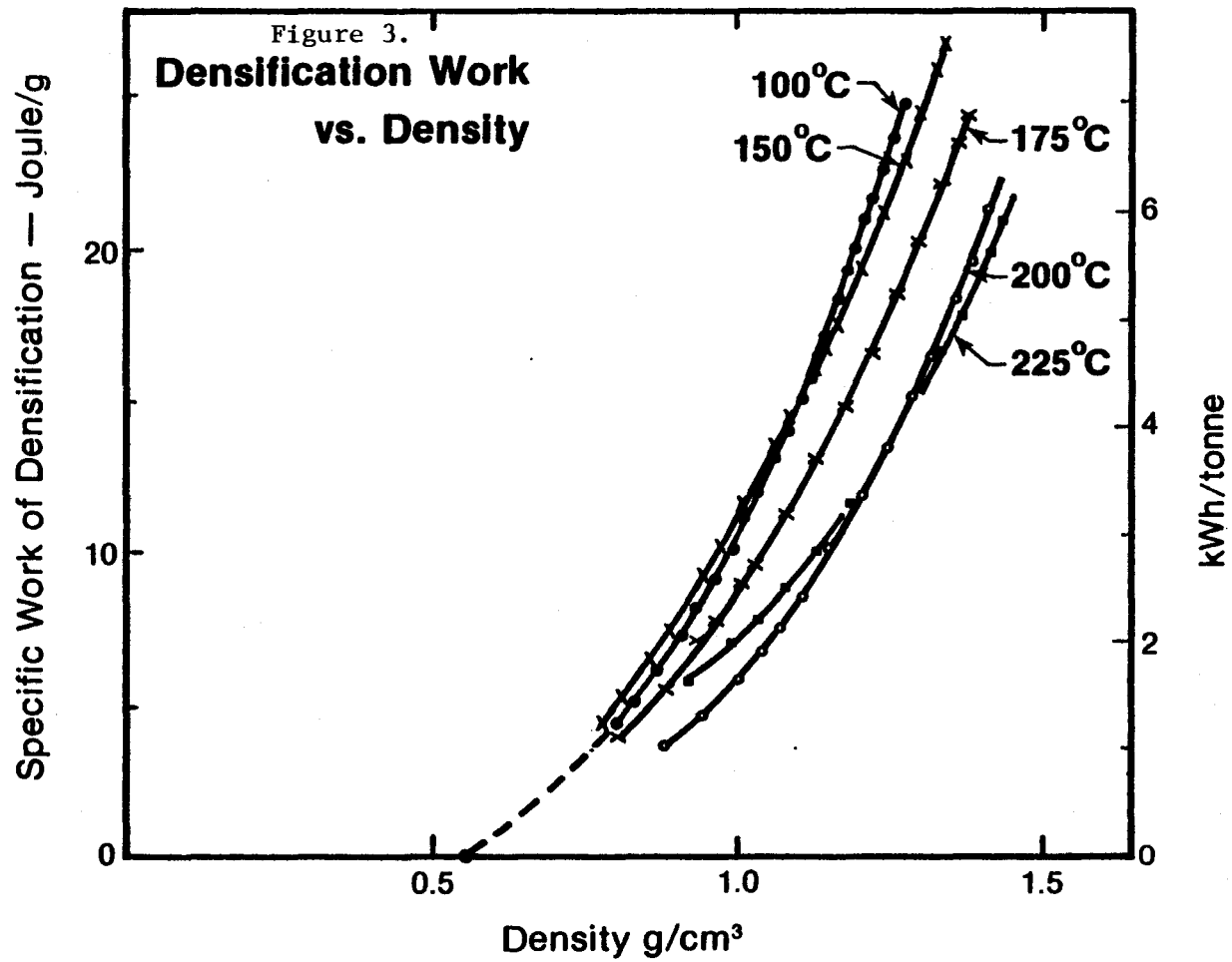
(a) Compression

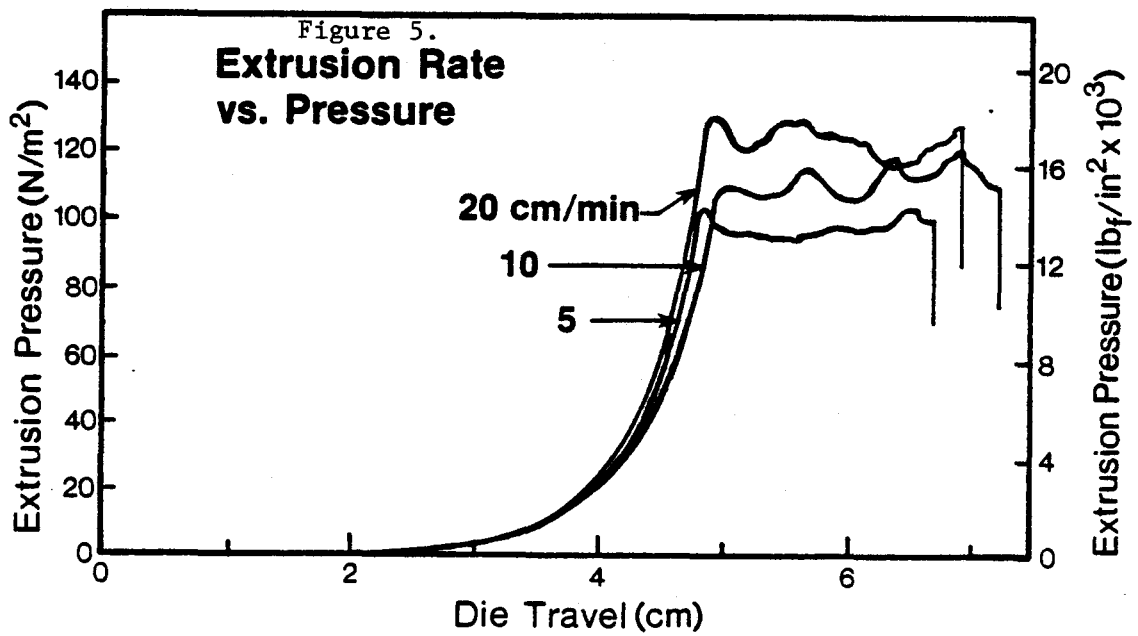
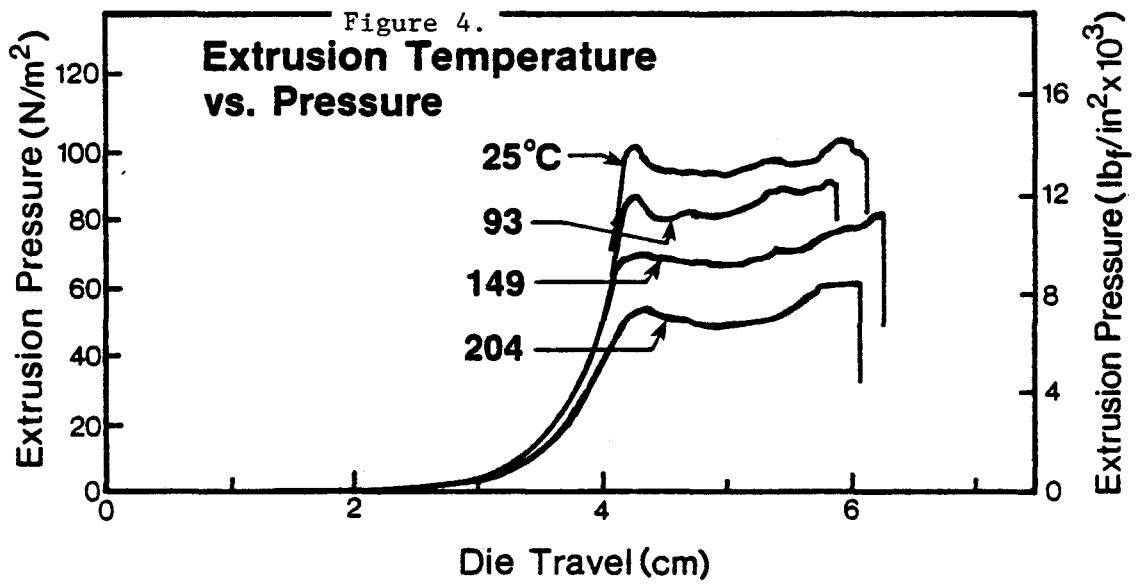
(b) Extrusion

Figure 1.

Densification Test Configurations









National Renewable
Energy Laboratory



02LIB092500