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The Use of Waste Oils to Improve Densified Refuse Derived Fuels

Final Report
October 1980

MASTER

Prepared for:

U.S. Department of Energy

Assistant Secretary for Conservation and Solar Energy

Office of Buildings and Community Systems

Under Contract No. AC01-76CS201617

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Washington, D.C. 20036

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SECTION 1. SUMMARY

The preparation and properties of densified refuse-derived fuel (d-RDF) had previously been studied. The findings included recognition of several areas for potential process and product improvement and some of these became the objectives of this study; viz., reduction of the power consumption and increase in the throughput of the densifier, increase in the calorific value and of the resistance of the d-RDF to weathering during outdoor storage. It was believed that these objectives might be achieved by adding waste oils to RDF just before densification. However, at the same time it had to be recognized that the majority of such oil from local sources includes spent crankcase oils with a high content of lead. Therefore, a limit was placed on the amount of waste oil that could be added without increasing the total lead content of the fuel to the point where its use would likely emit excessive amounts of lead.

In the work reported here, office wastes were shredded, air classified, and reshredded prior to feeding to an animal feed densifier. The purpose of using office wastes, instead of mixed municipal waste, was to exercise greater control over the moisture content of the feed and the presence of small amounts of contrary materials such as pieces of textiles which might jam the equipment and disturb an experiment. Water was added to the densifier feed in order to investigate a range of moisture contents.

Waste oil (from a local dealer) was pumped through spray nozzles onto the densifier feed at controlled flows so as to investigate a range of oil contents. The sprays, and all other equipment, were operated for at least 15 minutes to reach a steady state before samples of materials were taken for analysis. During test periods, a recording wattmeter was used to record the pelletizer motor consumption. Approximately 250 "data points" were taken, each corresponding to power consumed by the pelletizer motor in two minutes of operation. Pelletizer throughputs measured were in the range of 0.3 to 2.0 tons/hour dry basis (TPH-dry). Over this range, a linear relationship was obtained between the power consumption and the pelletized material throughput on a dry basis. The correlation coefficients for the fits vary between 0.791 and 0.958 for various ranges of water and oil contents. It is observed that over the practical range of waste oil contents, the savings in power consumption with increasing oil content are small. For example, an increase of 3.7 wt% oil content indicated a 4.4% decrease in power consumption at 2 TPH-dry. The decrease in power consumption is not only due to the oil content but also the water content of the feedstock. Over the ranges investigated, the relative decreases of power consumption due to either of the liquids, are approximately equal. Therefore, adding water to the pelletizer feedstock would result as well in decreased power consumption.

The addition of waste oil (up to 15 wt%) to the feed did not cause noticeable improvements in throughput rates. As

expected, the calorific value of the fuel increases in proportion to the amount of waste oil. Pellets containing 13 wt% oil resulted in having a 20% higher calorific content. Increased waste oil levels in RDF led to reduction in pellet lengths and densities. Pellets with more than 13 wt% oil were "soggy" and broke easily. The addition of waste oil to RDF did not improve pellet water repellency. On the contrary, because the pellets are loosely bound (lower pellet density), they absorb more water, and would be expected to disintegrate when subjected to rain during outdoor storage.

SECTION 2. INTRODUCTION

Several plants are operating or under construction which have the capability of preparing and/or combusting a fluff form of refuse-derived fuel (RDF), intended to be burned either by itself or with pulverized coal. Similarly, densified forms of refuse-derived fuel (d-RDF) can be used in stoker-fed boilers either alone or with lump coal. The densification prepares the fuel in a form similar to lump coal. Densification is achieved by mechanical compaction to produce briquettes, pellets, etc., which can be easily transported, handled and stored.

Initial efforts to produce d-RDF were made by F. C. Stirrup in 1959 and Hollander and Cunningham (1) in 1971. Subsequent pilot and commercial efforts developed in several locations in Europe, Cockeysville, MD, Lehigh, PA, Los Gatos, CA, and at NCRR's Equipment Test and Evaluation Facility (ETEF) in Washington, D.C. The latter effort started in 1976 and continued into 1979, with support from the Environmental Protection Agency (2) and Department of Energy (3). Over this time period, NCRR produced approximately 1200 Mg (1300 tons) of 13 mm (1/2 inch) diameter and 91 Mg (100 tons) of 25 mm (1 inch) diameter pellets. The facility and its operation have been described (4, 5).

Densification at ETEF was achieved using a pellet mill, similar to those used to densify animal feeds, but with suitably modified live-bottom bin, metering feed screws and distribution deflectors and wipers (5). The mill consists of a die with

stationary rollers which form a nip for the feed to be forced into the die. Experience with the equipment suggested areas for possible technical improvements which led to the objectives for the work discussed here.

SECTION 3. OBJECTIVES AND TECHNICAL APPROACHES

The objective of this study is to investigate the effect of adding waste oil to the feed to the densifier on the following:

- (1) Densifier throughput.
- (2) Densifier power consumption.
- (3) Increase in d-RDF higher heating values.
- (4) Exterior "waterproofing" of d-RDF, so as to enhance their outdoor storage.
- (5) Physical integrity of the pellets after mechanical abuse such as from handling and storage.
- (6) Control of the lead content of the d-RDF by control of the addition of waste oils, especially waste crank-case oils.

SECTION 4. CONCLUSIONS

On the basis of production observations, analysis of oil/d-RDF samples, pelletizer power consumption, and measurement of throughput rates, the following conclusions are drawn.

- For the production of d-RDF, there is a practical limitation on the amount of waste oil that can be added to the refuse-derived fuel. High liquid contents (30 wt%) in the feed produce weak and easily broken pellets. Office wastes or MSW having moisture levels of 15-20 wt% would limit the addition of oil to 10-15 wt%.
- The total quantity of d-RDF containing waste oil produced in this program was not sufficient to determine any effects on the wear or abrasion of the die and rollers.
- The addition of waste oil to the feed up to 15 wt% did not cause noticeable improvements in throughput rates.
- The pelletizer power consumption decreases with addition of waste oil in RDF for a range of throughputs of from 1 to 3 TPH (as processed) and oil levels of 1 to 15 wt%. However, the decrease is no more than 5%. The savings in power is not substantial; addition of moisture has a similar effect.
- As expected, the calorific value of the fuel increases in proportion to the amount of waste oil. Pellets containing 13 wt% oil resulted in having a 20% higher calorific content.
- Increased waste oil levels in RDF led to reduction in pellet lengths and densities. Higher oil contents also resulted in lower d-RDF compaction. Pellets with more than 13 wt% oil

were "soggy," broke easily, making them undesirable for storing and handling. Integrity tests were not conclusive.

- The analysis of the d-RDF/oil pellets does not indicate improved water repellency. On the contrary, because the pellets are loosely bound (lower pellet density), increased water absorption was measured. Therefore, outdoor storability of the pellets is not likely to be better after addition of waste oil.

- The lead contents of the waste lubricating oils varies considerably from location to location. On combustion, volatile lead compounds would be emitted to the atmosphere. Hence, use of waste oil would be limited by its lead content.

SECTION 5. FACILITY DESCRIPTION

The process flow was primary shredding, screening, air classification, secondary shredding, and densification (4).

Type of Solid Waste Utilized

Office wastes and not household wastes were used as feedstock for the waste oil investigation. Reasons for utilizing office wastes were:

- (1) Consist primarily of paper (Figure 1). The pre-dominance of paper and lower levels of food wastes and inert materials make the office wastes a useful and more homogeneous feedstock for fuel preparation, especially for an experimental program.
- (2) Ability to have some control over the moisture content. Some lubrication is required to reduce the friction during extrusion of the waste through the die and, consequently, to lower the power consumption of the pellet mill. The moisture content of household waste is unpredictable and varies widely.
- (3) The low content of textiles in office wastes is an advantage. Textiles are not easily shredded and often cause jamming of the pelletizer.

Type of Waste Oil Utilized

Waste crankcase oil was selected as the waste oil for the project because it is the greatest constituent (approximately 60%) of the waste oil generated in this country (6) and correspondingly generally available.

Figure 1

COMPARISON OF OFFICE VS MUNICIPAL SOLID WASTE COMPOSITION

The oil used in the tests was obtained from a company that collects waste oil from service stations in the Washington/Maryland area. Besides used crankcase oil, other constituents, water, lubricating oils, brake fluids and various solvents, were present. There have been several investigations of waste oil properties on samples obtained from a number of locations across the country (7, 8). Table 1 is a summary of average values and the range of selected properties of 30 samples of waste oil collected from 20 states and analyzed in one study (8).

Plant Modifications

Some modifications in the d-RDF preparation were necessary to accommodate processing of office waste and addition of waste oil. It was observed that office wastes were dry compared to household wastes. This resulted in greater dust generation and an increased fire and explosion hazard during processing at FTEF. Also, due to its lower bulk density, the office waste was more difficult to handle. Therefore, in order to increase (and hopefully control) the moisture content of the wastes, two manually adjustable water spraying systems were installed, one each before the primary and secondary shredders.

A pump and related hardware were installed to add waste oil from a 55-gallon drum, through spray nozzles located above the feeder to the densifier. The oil delivery system is shown in Figure 2. Oil discharge pressure was approximately 0.24 MPa (35 psi). For addition of 1-13 wt% waste oil onto RDF, the three spray nozzles were required to spray between 0.006-0.047 l/s (0.1-0.75 gallons/minute) of oil.

Table 1. Physical and Chemical Properties
of Automotive Crankcase Oils

<u>Properties</u>	<u>Range for 30 Samples</u>	<u>Average Values</u>
Viscosity SSU (38°C)	220 - 1261	378.6
Ash (wt%)	0.96 - 2.2	1.3
Flash Point °C	96 - 220	178
Specific gravity (16°C)	0.891 - 0.938	0.901
Lead content (ppm)	19.0 - 13885	7078
Moisture (wt%)	0.2 - 33.8	7.9

Figure 2
OIL DELIVERY SYSTEM

KEY

1. Strainer	7. Flow Meter
2. Pump	8. Check Valve
3. Pressure Regulator	9. Spray Nozzles
4. Pressure Relief Valve	10. Evenflow Feeder
5. Solenoid Valve	11. Pellet Mill
6. Needle Valve	

SECTION 6. PLANT OPERATION AND SAMPLING PLAN

The operating plan called for maintaining a uniform material feedrate to the pelletizer. Material surges affect the ability of the d-RDF product to be sampled. Sampling was accomplished by maintaining the material flow for 15 minutes followed by a defined 2 minute period during which time samples were taken. During the entire operating time, addition of water and oil was adjusted to maintain a controlled mixture.

The lead content of RDF and waste oil were calculated to determine the amount of waste oil that might be added to RDF so as to keep the lead content below what is permitted by air pollution control regulations. This calculation of the fuel indicated that no more than 15 wt % of the waste oil should be added. This limiting value will change under different circumstances but it will be seen later that acceptable pellets cannot be made by the addition of as much as 15 wt % waste oil.

Oil Sample

Waste oil was delivered and stored in 55-gallon drums. Each drum was identified by a number. Soon after the oil was received, four drums picked at random were sampled and analyzed. The sampling was from both the top and bottom of the drum. The four "top" samples were mixed together to form one sample. Similarly, so were the four "bottoms." A third sample was made as composite of tops and bottoms. The three samples were shipped to a commercial laboratory for analyses of moisture, ash, lead content, flash

point, specific gravity, viscosity and calorific value. Oil samples from different drum levels were analyzed to assess any property changes due to settling effects.

Secondary Shredded Sample

Power consumption of the pellet mill is expected to be dependent on the liquid content (water and oil) and throughput. Therefore, in order to be able to interpret the power measurements, it was necessary to know the moisture content of the feed. During test runs, secondary shredded samples were obtained at regular intervals from the mill live-bottom feeder. These samples were placed in plastic bags, sealed, and each bag tagged and later analyzed. The procedures used are described in Appendix A.

d-RDF Sample

Grab samples of pellets were taken from the discharge of the pellet mill during each two-minute test period. Because of normal fluctuations in the feedrate to the pelletizer, the oil content of the d-RDF varied somewhat during the test run. On conclusion of the test run, throughput rates were calculated and by measuring the oil flow rates, the oil content during the test period was computed. The d-RDF samples were bagged, identified and later analyzed.

Samples with similar computed oil contents were grouped in the following eight categories:

Group

1	0.5 - 1.5% oil	}	Average Moisture Content 15.0%
2	2.5 - 3.5% oil		
3	4.5 - 5.5% oil		
4	6.5 - 7.5% oil		
5	9.5 - 10.5% oil		
6	12.5 - 13.5% oil		
7	No oil (baseline)	}	Average Moisture Content 25.0%
8	No oil (baseline)		

Pellets from each group were mixed, sub-divided, and analyzed according to the scheme shown in Figure 3. About a quarter of the pellets from each sampling period was saved for later reference. Physical and chemical tests were conducted on pellets from each group. Physical testing procedures for pellet integrity, length distribution, fines content, density and water repellency are described in Appendix A. Chemical analyses for moisture, ash, calorific value, lead and oil contents were done by a commercial laboratory.

Power Measurement

A recording wattmeter (Esterline Angus, Model 601) was used to record the pelletizer motor power consumption. On conclusion of a test, the recorded area on the stripchart was integrated with a planimeter and the power consumption calculated.

SECTION 7. TEST RESULTS AND DISCUSSION

This section describes the physical and chemical properties of the waste oil sample and the characteristics and integrity of the d-RDF products with varying contents of oil.

Waste Oil Analysis

Chemical analyses results of the waste oil samples pumped from the "tops" and "bottoms" of drums are in Table 2. Table 2 indicates no appreciable change in the waste oil properties is caused by settling. After 12 weeks, samples were again pumped from similar locations and analyzed. The results were consistent with Table 2.

Table 2. Properties of the Waste Oil Sample

	<u>Location in Drum</u>		
	<u>Top</u>	<u>Bottom</u>	<u>Top and bottom composite</u>
Viscosity 25°C (SSU)	270.2	281.6	N/A
Ash (wt%)	0.68	0.69	N/A
Flash Point (°C)	84.4	85.6	N/A
Moisture Content (wt%)	N/A	N/A	1.0
Specific Gravity	0.8922	0.8927	N/A
Lead (ppm)	1500	1500	N/A
Calorific Value (MJ/kg)	N/A	N/A	43.7

N/A - Not analyzed

d-RDF Sample Analysis

The oil concentration in the d-RDF produced from each test period was computed from oil flow and waste feedrate measurements. The samples from each test were combined, as described in Figure 3. Subsequent laboratory analyses confirmed the computed oil contents for each grouping.

Chemical analyses results are in Table 3. The calorific content of the two baseline samples averaged 16.4 MJ/kg (7000 Btu/lb), on a dry basis. As expected, the heating value of the samples increased with the amount of waste oil added. A 20% increase in calorific value corresponded to adding 13 wt % waste oil.

Table 3. d-RDF Chemical Analysis Results

Group No.	Average Oil Content (wt%)	Ash (wt%) dry basis	Moisture (wt%) as- received	Calorific Value (MJ/kg) dry basis	Lead content (ppm)
1	1%	8.12	19.58	16.7	50
2	3%	7.66	15.20	17.2	90
3	5%	10.05	17.55	18.6	110
4	7%	6.67	17.50	18.4	150
5	10%	6.51	14.81	19.1	170
6	13%	6.96	15.82	19.6	220
7	0%	6.92	17.34	16.6	40
8	0%	6.29	22.01	16.3	30

Figure 3

PREPARATION OF d-RDF PELLETS FOR TESTING

Similarly, due to high lead levels in waste oil, the lead content in the d-RDF increases with the amount of waste oil added, up to six times the baseline lead level at 13 wt % oil. Note, in Tables 1 and 2, the lead content of the waste oil sample (1500 ppm) is significantly lower than the average of 30 samples (7078 ppm) reported in reference 8.

Table 4 summarizes analytical results of pellet density, pellet length, bulk density and fines content (material <6.4 mm) for each group. The data indicate that the pellet density steadily decreases with increasing addition of oil. This trend is comparable to similar observations made on the effect of increasing moisture on pellet density (5). Probably, liquid contents (moisture + oil) of more than 25% decrease the friction through the die and result in decreased compaction and lower pellet densities.

Pellet lengths are limited by the position of a breaker bar installed on the interior surface of the shell cover of the pelletizer die, and impacts from loose pellets within the shell cover cause the pellets to break off from the die at random lengths. Table 4 shows that the mean pellet length decreases at higher oil contents. The d-RDF produced with 7 to 13 wt% oil has a lower bulk density (a difference of about 128 kg/m³) than the baseline pellets.

The weight percentage of fine particles (6.4 mm or 1/4 inch) is a measure of the amount of unpelletized material in the d-RDF product. This "fines content" would be expected to increase with

Table 4.. Comparison of Physical Characteristics

Group No.	Average Oil Content	Pellet Density (g/cm ³)	Mean Length (mm)	Bulk Density kg/m ³ lb/ft ³	Wt% Fines (<6.4 mm)
1	1%	1.12	15.6	592.6 37.0	5.1
2	3%	1.12	15.8	584.6 36.5	3.0
3	5%	1.10	15.4	579.8 36.2	4.4
4	7%	1.00	11.6	512.5 32.0	3.6
5	10%	1.02	13.4	526.9 32.9	5.6
6	13%	1.02	8.3	512.5 32.0	4.0
7	0%	1.16	14.9	658.3 41.1	4.0
8	0%	1.17	20.2	639.0 39.9	1.7

decreasing pellet length, as the more loosely bound pellets break off flakes. However, the data in Table 4 show no such trend.

d-RDF Integrity Testing

Pellet integrity is defined as its ability to maintain stable dimensions and density after mechanical abuse, such as from the handling during transport, storage or feeding. A tumbler test was adopted from a coal test (ASTM D-441) in order to compare the integrity of pellets from each group. Before tumbling (or abuse) of the d-RDF, pellet length distributions and fines content of the sample were determined. After tumbling the pellets for one hour, the pellet length distribution and fines content were recalculated. Test results are reported in Table 5. The results indicate that the abuse of tumbling physically degraded the pellets, whereby, the pellet lengths were shortened and the fines content increased. A statistical analysis (Table 5) shows that the pellet length changed significantly in all but one group. Also, there was a significant shift in distribution from the results, it is not possible to conclude or make integrity comparisons between the eight groups.

d-RDF Hydrophobic Properties

If the d-RDF could be made hydrophobic by addition of oil (or other means), then possibly it could be stored outdoors, not under cover.

Standard methods for determination of moisture absorption rates or, conversely, water repellency characteristics of d-RDF pellets are not available. Nevertheless, two types of tests were

Table 5. PELLET INTEGRITY TEST RESULTS

Group No.	Oil Content	Test			Pellet mean length (mm)		% Fines (<6.4 mm)	
		<u>F</u>	<u>t</u>	<u>χ^2</u>	<u>Before Test</u>	<u>After Test</u>	<u>Before Test</u>	<u>After Test</u>
1	1%	*	**	**	15.6	12.6	5.1	11.0
2	3%	**	**	**	15.8	11.6	3.0	8.9
3	5%	*	**	**	15.4	11.7	4.4	11.0
4	7%	*	*	**	11.6	10.2	3.6	10.3
5	10%	**	**	**	13.4	7.9	5.6	12.6
6	13%	*	**	**	8.3	6.1	4.0	9.7
7	0%	*	**	**	14.9	12.2	4.0	11.1
8	0%	*	**	**	20.2	14.9	1.7	6.1

* Hypothesis of no change accepted at 95% level of confidence.

** Hypothesis of no change rejected at 95% level of confidence.

conducted in the laboratory to investigate the quantity of water absorbed by the pellets. The first was an immersion test whereby samples were fully immersed in water and the rate of absorption measured. In the second, a percolation test, an attempt was made to simulate rainfall conditions by showering water on a column of d-RDF and measuring its weight gain. Test procedures are given in Appendix A.

Immersion Test:

Approximately 100 g of pellets from each group were immersed in water. Every minute, the samples were removed, shaken, weighed and reimmersed. The gain in weight is plotted in Figure 4, showing that Group 8 samples (baseline) absorb less water than other groups. This is contrary to what was expected. It had been expected that the addition of oil would result in an oil coating on the d-RDF surface which would retard water penetration in the pellets. The data show such is not the case.

The rate of absorption is related to the physical characteristics of the pellets. The most water resistant group (number 8) had the highest pellet density and lowest fines content (Table 4). Fines have a larger free surface area and absorb more water. High pellet density indicates more tightly packed pellets and these were the least susceptible to water penetration. On the other hand, Group 6 had the lowest pellet density and, therefore, absorbed the most water. Groups 7 and 8 are both baseline samples and might be expected to be identical. Differences in their absorption rates could be attributed to the samples differing in initial moisture and fines content.

Figure 4

d-RDF MOISTURE ABSORPTION RATE
BY IMMERSION METHOD

Percolation Test:

Equal samples of 3 kg from each of the 8 groups were placed in an acrylic plastic column (600 mm high by 152 mm diameter). Three liters of water were showered evenly from the top of the column across the sample. Water that percolated through the sample was collected and weighed, with the difference representing the water absorbed. The amount of water absorbed is reported in Table 6, showing that groups 4, 5, 6 and 7 absorbed more water, consistent with the immersion test. Any relationship between the oil content and water absorbed is not clearly defined.

Table 6

Percolation Test Results

Group Number	Oil Content	Percent Water Absorbed (oil free basis)
1	1%	5.6
2	3%	6.3
3	5%	5.8
4	7%	9.3
5	10%	6.4
6	13%	7.2
7	0%	8.4
8	0%	3.8

SECTION 8: PELLETTIZER POWER CONSUMPTION DATA

Approximately 250 "data points" were taken, each corresponding to periods of 2 minutes of operation. The feedrate to the pelletizer was controlled by adjusting the speed of the metering feed screws in the live-bottom feeder. The quantities measured or computed from these measurements were:

TPHR:	Waste mass flow rate, as-received basis.
M_R :	Moisture content, wt%, as-received basis.
W_O :	Waste oil content, wt%, as-received basis.
PC:	Electric motor power consumption, kW (averaged over 2 minutes).

Other records were logged, such as jams, trouble in operation, whether or not a moisture sample was taken, etc.

In view of the large number of variables and points, an attempt was made to unify the presentation of the results by choosing a self-consistent system of dependent and independent variables, with a further objective of determining relationship between the variables. Appropriate computer programs were written (in Fortran IV) and used on the DEC-10 computer at Johns Hopkins University. (See Appendix B.)

Choice of Variables (Dependent and Independent)

In order to clearly separate the "dry" material in the pelletizer throughput from the liquids (oil, water), the throughput was expressed on a dry basis, i.e., in mass per unit time of material not including moisture or waste oil. The oil content, dry basis, is W_D . Data points for which W_D exceeded 30% were rejected at the outset as outliers (their number was 18, out of 248).

The result of the sorting of the 237 data points on the computer is a matrix, the rows of which correspond to a specific range of oil content, and the columns of which are for a specific range of moisture content. The matrix is given in Table 7.

It is seen that the matrix is rather sparse, with some classes empty or poorly populated (less than 10 elements). The highest concentrations are for lower oil contents (0 to 2.5%) and intermediate moisture levels (10 to 30%). Between brackets are the number of elements in classes having less than 4 data points. On these sparse or empty classes, no relation of power consumption was attempted.

Fitting of Data in Subclasses

Linear fit in subclass

For the remaining twelve subclasses, numbered 1 through 12, a linear regression fit was computed using a computer program (WASCØR described in Appendix B). In a first round, all data points were included. The linear fit

$$PC^* = PC_O^* + m \text{ TPHD}$$

in which TPHD = dry throughout, PC^* = (power consumption), was determined by computing the y-intercept, PC_O^* (kW) and the slope m (kW/ton/h). The standard error of estimate, $S_{Y/X}$, and correlation coefficient r , were also computed (9).

The independent variables considered are:

M_D	moisture content of material being pelletized, dry basis;
W_D	oil content of material being pelletized, dry basis.

Table 7

Number of Data Points in each Subclass (Oil Content, Moisture Content)

MOISTURE LEVEL (wt %)						
	(0-10)	(10-20)	(20-30)	(30-40)	(40-60)	Total
<u>OIL LEVEL, Wt. %</u>						
(0-2.5)	[3]	39 (<u>1</u>)	40 (<u>2</u>)	19 (<u>3</u>)	[1]	102
(2.5-7.5)	[0]	32 (<u>4</u>)	12 (<u>5</u>)	[1]	[0]	45
(7.5-9.5)	[1]	11 (<u>6</u>)	[3]	[3]	[0]	18
(9-12.5)	[2]	4 (<u>7</u>)	10 (<u>8</u>)	[2]	[0]	18
(12.5-17.5)	[2]	11 (<u>9</u>)	14 (<u>10</u>)	[2]	[0]	29
(17.5-30)	[0]	10 (<u>11</u>)	13 (<u>12</u>)	[2]	[0]	25
Total	8	107	92	29	[1]	237

[] - Less than 4 elements

(_) - Subclass code number

The dependent variable is:

P_c electric motor power consumption

The dependence of PC on the dry throughput (TPHD) was investigated, using as variable parameters

M_D , W_D

and the "total liquid level" defined as

$$TLQ = M_D + W_D$$

Subclasses of Data Points

Moisture contents ranged from close to zero to more than 60%. Waste oil contents ranged from zero (no oil added) to more than 30%, dry basis. The latter value would occur when a given mass of oil was sprayed at an unexpected low mass flow rate of the waste.

It was judged that the following subclasses could reasonably be selected:

Subclasses

W_D (for oil)	M_D (for water)
0-2.5	0-10
2.5-7.5	10-20
7.5-9.5	20-30
9.5-12.5	30-40
12.5-17.5	40-60
17.5-30.0	

All are weight percents, dry basis.

Some of the points were known (from experimental observations) to be outliers. In a second round of calculations, such points were removed from their subclass if the absolute value of the difference between the measured value, PC, and the above fit,

PC^* , exceeded 1.28 times the standard error of estimate. This corresponds to a probability of $p = 20\%$ for a normal distribution (10). After removal, some of the subclasses had less than 10 elements and were also those for which the results were judged to be unreliable. After this elimination of outliers, six subclasses remained, (1) through (5) and (10). The results are given in Table 8 and graphed in Figure 5.

Baseline Data

It is of interest to distinguish, in the first line of the matrix of subclasses (Table 8), between the data points corresponding to moisture alone or no oil (so-called "baseline" case) and those corresponding to a low, but non-zero oil content (up to 2.5 wt %).

The subclasses on the first line of Table 7 contain 1, 12, 12, 2 and 1 elements with non-zero oil content. After removal of the outliers in two subsets with 12 elements (only 10 and 9 elements, respectively, remain), and these sets should not be considered separately (correlations were 0.274 and 0.503).

The overall linear regression fit for the baseline data points, regardless of moisture level, was performed over the 72 elements corresponding to zero oil content and moistures less than 50%. The result of the second round of calculations (outliers removed) is as follows:

Class	# Elements	PC_O^* (KW)	m (kWh/ton)	Correlation Coefficient	Standard error on Estimate**
Baseline	61	21.8	50.5	0.964	5.78

**First round

The equation of fit for the consolidated baseline data is

$$PC^* = 50.5 \text{ TPHD} + 21.8$$

and describes the power consumption of the pelletizer operating on waste only.

Results of Subclass Analysis

From Table 8 and Figure 5, tentative conclusions can be drawn, over the range of interest (0.3 to 2 TPH-dry). Note that these conclusions should not be extrapolated at either side of the range. At zero throughput the y-intercept of the power curve represents the idling power and is independent of oil or moisture content. Above the upper limit of the range, physical observations and engineering experience would indicate that power consumption, as a function of throughput, levels off at higher throughputs. The lines in Figure 5 (and Figure 6 in the following) are merely linear fits to small portions (small ranges of the throughputs) of such curves.

a) The conclusions are: There is a linear relationship between the power consumption and the pelletized material throughput, TPHD. The correlation coefficients for this fit vary between 0.791 and 0.958.

$$PC^* = (PC_O^*) + m \text{ TPHD}$$

The equation holds for a given range of moisture and oil contents.

b) The standard error of the estimate for the linear fit is in the range of 7 kW to 13 kW, with an overall average (for all subclasses) of 11 kW.

c) For a given oil level, there appears to be a tendency for the lines in Figure 6 to rotate clockwise (decreasing slopes)

Table 8. Results of Second Round of Calculations, by Moisture and Oil Ranges
(Linear Regression Fit)

Class	No. of Elements	PC _O * (kW)	m (kWh/ton)	Correlation Coefficient r	Standard error on estimate, S _{y/x} , kW
(1)	31	18.1	52.2	0.958	13.4
(2)	34	27.3	41.9	0.877	10.4
(3)	15	30.4	38.4	0.943	7.7

(4)	26	20.0	47.1	0.791	16.0
(5)	10	18.7	43.8	0.805	11.7

(10)	10	16.4	44.4	0.922	7.2

Average of S_{y/x} over the 6 classes: $\bar{S}_{y/x} = 11.1$ ($\sigma_{S_{y/x}} = 3.1$)

Figure 5

LINEAR REGRESSION FITS (OIL & MOISTURE SUBCLASSES):
POWER VS. THROUGHPUT

with increasing moisture content, resulting in an increase in the apparent y-intercept (PC_0^*) and hence a decrease in power consumption over most of the operating range (throughputs larger than 1 TPH-dry). This is due to the leveling off of the curve at higher throughputs. For example, at low oil contents (0 to 2.5%), there is an estimated decrease in power of 9 kW at 2 TPH-dry throughput when the moisture increases from 10%-20% to 30%-40%.

d) At a given content of moisture, there is a slight overall decrease in power consumption when the oil content (dry basis) is increased. For example, in the 10%-20% moisture range, an increase of the oil content from 0%-2.5% to 2.5%-7.5% results in an expected saving of 5 kW, for a throughput of 2 TPH-dry. Comparing lines 5 and 10, it is seen that this advantage becomes negligible when going from the 2.5%-7.5% range to the 12.5%-17.5% range of oil contents.

In conclusion, it is possible to define a band within which all representative linear regression lines are contained, and which allow predictions of power consumption vs. throughput at various levels of moisture and waste oil. Estimates can be given for the decrease in power consumption at the upper end of the range investigated (2 TPH), namely:

8% decrease when raising the moisture content from 15 wt% to 35 wt%

4.4% decrease when raising the oil content from 1.3 wt% to 5 wt%

0.5% decrease when raising the oil content from 5 wt% to 15 wt%.

It is seen that over the practical range of waste oil contents, the savings in power consumption with increasing oil content are indeed very small and could probably more simply be effected by adding an acceptable amount of moisture to the material being pelletized.

Representation of Results with Total Liquid Level as a Parameter

From the results of the previous section, it is possible to compute the decrease in power (at 2 TPH-dry) corresponding to a one-point increase in moisture level,

$$\text{Decrease} = \frac{8}{20} = 0.4\%/\text{point}$$

and the corresponding quantity for oil

$$\text{Decrease} = \frac{4.9}{13.8} = 0.4\%/\text{point}$$

It is seen that over the ranges investigated, the effects of one or the other liquid are numerically equivalent. No judgment is implied as to the physical phenomena which may be involved. Then, it is possible to define a total "liquid level" as

$$\text{TLQ} = \text{Water content} + \text{Oil content}$$

Ranges were defined for TLQ (see Table 9), and linear regression fits were obtained for each range of TLQ. The results are illustrated graphically in Figure 6.

Excluding the 40-50% total liquid level class, it is seen from Table 9 and Figure 6, that over the ranges of 0.3 to 2 TPH-dry,

- linear regression lines with correlation coefficients varying from 0.751 to 0.981, and standard error of the estimate from 5.1 kW to 10.2 kW are obtained;

Table 9. Results of Second Round of Calculations, by Total Liquid Level

Total Liquid Level (dry basis) Percent	No. of Elements	PC _O * (kW)	m (kWh/ton)	Correlation Coefficient r	Standard error on estimate, S _{y/x} ' kW
0-15	11	20.4	49.8	0.981	5.1
15-20	31	27.7	42.1	0.843	10.2
20-25	49	20.4	46.3	0.845	10.1
25-30	23	22.5	41.0	0.751	8.1
30-40	47	19.7	45.7	0.899	6.7
40-50	29	34.3	16.0	0.479	7.5] *

* Poor correlation

Average of S_{y/x} over 6 classes: $\bar{S}_{y/x} = 7.95 \text{ kW}$ ($\sigma_{S_{y/x}} = 1.80$)

Figure 6

LINEAR REGRESSION FITS (TOTAL LIQUID LEVEL): POWER VERSUS THROUGHPUT

- again, the trend is for the lines to rotate clockwise with increasing total liquid level, resulting in higher apparent intercepts (PC_O^*) and a decrease in the power required at the upper end of the range of throughputs (2 TPH-dry). Using the difference between the average values of TLQ classes (25-30), (30-40), and the value for the class (0-15), the decrease in power consumption can be estimated. It is on the order of 12 kW (at 2 TPH-dry) when the total liquid level increases from 7.5% to 31.2%, or $\frac{10.0}{23.7} = 0.42\%$ /point, of power decrease per added point of liquid content, in agreement with the results obtained for water and oil, separately.

REFERENCES

1. Alter, H., J. Arnold, Preparation of d-RDF on a Pilot Scale, Proceedings of the Sixth Mineral Waste Utilization Symposium, U. S. Bureau of Mines and IIT Research Institute, Chicago, Ill., May 2-3, 1978, pp. 171-177.
2. Wiles, C. Carlton, Production and Use of d-RDF, U.S. Environmental Protection Agency, Cincinnati, Ohio.
3. Department of Energy, Grant No. ES-76-C-01-3851, Production of d-RDF for GSA Pentagon Test Burn.
4. Natof, S., J. Arnold, The Preparation of Densified Refuse-Derived Fuel: Initial Operating Report TR 77-1, NCRR, Inc., 1977.
5. National Center for Resource Recovery, Inc. Preparation and Properties of Densified Refuse-Derived Fuels: Part I. Final Report (Draft) to U.S. Environmental Protection Agency, Office of Research and Development, Grant 804150, Cincinnati, Ohio, December, 1979.
6. "Waste Oil Study," Report to Congress, April, 1974, by Environmental Protection Agency, Washington, D.C.
7. Shansky, S., J. Carroll, Waste Automotive Lubricating Oil Reuse as a Fuel, September, 1976, GCA Corporation, Bedford, Massachusetts.
8. Whisman, M. L., Waste Lubricating Oil Research: Part 4, Department of Energy/BERC, RI-76/4, October, 1976.

9. Spiegel, M. R., Theory and Problems of Statistics, Schaum Publishing Company, New York, 1961.

10. Ibid. Pages 252 and 343.

APPENDIX A

TEST PROCEDURES

Appendix A1

Secondary Shredded Light Fraction: Moisture Content Determination

1.0 Apparatus

1.1 Drying pans - 450 mm x 450 mm x 40 mm. Stable at temperatures of 110°C .

1.2 Drying oven - Freas Model 845 - $0-200^{\circ} \pm 1^{\circ}\text{C}$ range. Interior dimensions 480 mm D x 940 mm W x 630 mm H. Forced-draft to remove moisture-laden air.

1.3 Balance with Precision of 0.1 mg

2.0 Laboratory Sample Collection

2.1 Collect 100-150g secondary shredded material in a tared polyethylene bag. Immediately seal the bag air-tight.

2.2 Label sample as to sample number, date, time, contents, and collection point.

3.0 Test Procedure

3.1 Weigh bag with sample and record weight. Subtract tare weight from gross to obtain as-received secondary shredded sample weight.

3.2 Empty contents of bag onto clean, tared drying pan, spreading evenly across pan so burden height does not exceed 50 mm. If height exceeds 50 mm, sample is split between two or more pans.

Appendix A1

4.0 Calculations

4.1 Percent moisture, dry weight basis = $\frac{A - B}{B} \times 100$

4.2 Percent moisture, as-received basis = $\frac{A - B}{A} \times 100$

where:

A = weight of as-received sample

B = weight of dry sample

Appendix A2

d-RDF Bulk Density Determination

1.0 Apparatus

- 1.1 Bulk Density weigh box, interior dimensions
300 mm x 300 mm x 300 mm.
- 1.2 Weighing scale - Platform type with precision of
0.1 lbs.

2.0 Sample Collection

- 2.1 At the discharge point of pellet mill, collect a
gross sample of approximately 100 lbs. of d-RDF
in a clean container.

3.0 Test Procedure

- 3.1 Cone and quarter the 100 lb d-RDF. Retain two
quarters for measurement of Bulk Density.
- 3.2 Record weight and volume of empty weigh box.
- 3.3 Pour a quarter of the gross sample (from 3.1)
into the weigh box. Tamp box three times by
lifting about 6 cm off the ground and dropping.
Level the contents to the box edges.
- 3.4 Record weight and volume of weigh box with the
sample.
- 3.5 Repeat steps 3.2-3.4 for the second sample.

4.0 Calculations

- 4.1 Bulk Density - as received (kg/m^3) = $\frac{W-W_1}{V}$

where: W = Weight of box full

W_1 = Weight of box empty

V = Volume of the weigh box

Appendix A2

4.2 Report average of two determinations.

Appendix A3

d-RDF Pellet Density Determination

1.0 Apparatus

- 1.1 Vernier Calipers - range 0 to 120 mm in 0.1 mm divisions.
- 1.2 Balance with precision of 0.1 mg.

2.0 Laboratory Sample Collection

- 2.1 Collect 4-7 kg of d-RDF from the discharge point of the pellet conveyor in a polyethylene bag.
- 2.2 Riffle sample to obtain 10 to 20 pellets. Discard pellets less than 5.0 mm in length.

3.0 Test Procedure

- 3.1 Measure and record diameter of each pellet twice.
- 3.2 Measure and record the length of each pellet twice. In measuring, keep the jaws of the calipers at right angles with a discernible side of the pellet. Measure a length most nearly representative of an average length.
- 3.3 Weigh and record sum weight (M_s) of measured pellets.

4.0 Calculations

- 4.1 Calculate the average diameter of each pellet (D_i).
- 4.2 Calculate the average length of each pellet (L_i).

Appendix A3

- 4.3 Calculate the as-received pellet volume (V_i) of each pellet.

$$V_i = \frac{\pi \times (D_i)^2 \times L_i}{4}$$

- 4.4 Calculate the sum pellet volume (V_s)

$$V_s = \sum_{i=1}^n V_i$$

where:

n = number of pellets measured

- 4.5 Calculate pellet density (g/cc) = $\frac{M_s}{V_s}$

Appendix A4

d-RDF Fines Content, <6.4 mm (<1/4 inch) Determination

1.0 Apparatus

- 1.1 Screen - Rotex Model #12 GP, equipped with
(6.4 mm) opening sieve

2.0 Sample Collection

- 2.1 Collect a 4-7 kg sample of d-RDF in a polyethylene bag. Make sure to sample entire width of belt.
Immediately seal the bag air-tight.
- 2.2 Label sample as to sample number, date, time,
contents, and collection point.

3.0 Test Procedure

- 3.1 Riffle sample to 1000 g portion.
- 3.2 Spread 1000 g d-RDF sample onto screen.
- 3.3 Run machine for three minutes.
- 3.4 Weigh and record weight of screen unders.

4.0 Calculations

- 4.1 Calculate percent fines content.

$$\text{Percent fines} = \frac{B}{A} \times 100$$

where:

B = total screen unders weight

A = sample weight placed on screen

Appendix A5

d-RDF Integrity Test

(Modification of ASTM D-441 Coal Testing Method)

1.0 Apparatus

- 1.1 Porcelain Jar Tumbler - internal cylindrical dimensions: 290 mm diameter, 200 mm depth.
Inside of the jar is fitted with three equally spaced lifting metal shelves protruding 380 mm.
Jar is rotated about its cylindrical axis on a support rack of a tumbler machine at approximately 40 rpm.
- 1.2 Rotex screen, equipped with 6.4 mm (1/4 inch) opening sieve
- 1.3 Vernier calipers
- 1.4 Balance, precision of 0.1 g

2.0 Preparation of Sample

- 2.1 Riffle sample to approximately 1000 g portion.
Weigh and record weight of portion.
- 2.2 Place sample on 6.4 mm sieve and screen.
- 2.3 Weigh and record weight of >6.4 mm material.
- 2.4 Riffle >6.4 mm material to approximately 20 pellets.
Measure each pellet length with vernier calipers.
Record each length to nearest 1.0 mm. Recombine the 20 pellets with the majority of >6.4 mm material.

- 2.5 Repeat 2.4 twice so three groups of approximately 20 pellets are measured.
- 2.6 Recombine screen unders (<6.4 mm) with overs (>6.4 mm) material.

3.0 Procedure

- 3.1 Place the approximately 1000 g sample in jar and close lid.
- 3.2 Rotate jar for 1 hour on the tumbler test machine.
- 3.3 Remove sample and repeat steps 2.2, 2.3, 2.4, and 2.5.

4.0 Calculations

- 4.1 Calculate amount of fines (<6.4 mm) before tumbling

$$\text{Percent fines} = \frac{A-B}{A} \times 100$$

where: A = tumbled sample weight

B = weight of >6.4 mm sample before tumbling

- 4.2 Calculate amount of fines (<6.4 mm) after tumbling.

Percent fines = as in 4.1 except

where: B = weight of >6.4 mm, sample after tumbling.

- 4.3 Calculate change in fines content.

$$\text{Percent change of fines} = X-Y$$

where:

X = percent fines before tumbling

Y = percent fines after tumbling

Appendix A6

d-RDF Percolation Test

1.0 Apparatus

- 1.1 Transparent acrylic plastic column - 600 mm height, 152 mm diameter.
- 1.2 Screen - 0.5 mm opening, 200 mm diameter.
- 1.3 Precalibrated container - 10 liter capacity.
- 1.4 Buchner funnel - 150 mm plate diameter.
- 1.5 Tripod - 200 mm high.

2.0 Test Procedure

- 2.1 Place tripod in collection container. Seat screen on tripod. Set and secure the column upright atop screen.
- 2.2 Riffle 3.0 kg of d-RDF sample. Transfer the weighed sample into the column. Invert and secure Buchner funnel atop the column.
- 2.3 Measure 3.0 liters of water.
- 2.4 Pour the 3.0 liters water into the inverted Buchner funnel so as to maintain a steady flow of about 2.2 liters/minute.
- 2.5 After the water has been poured, allow exactly 2 minutes for water to drain in the collection bucket.

Appendix A6

2.6 Measure and record volume of water accumulated in the collection bucket.

3.0 Calculations

3.1 Percent moisture absorbed by the sample

$$= \frac{A-B}{C} \times 100$$

where:

A = initial volume of water (3 liters)

B = volume of water collected in bucket

C = sample weight

Appendix A7

d-RDF Immersion Test

1.0 Apparatus

- 1.1 Beakers - 400 ml capacity.
- 1.2 Cylindrical screens - 1 mm openings, 70 mm. diam., 94 mm high.
- 1.3 Water trough - 250 mm L x 100 mm W x 125 mm D.
- 1.4 Stopwatch.
- 1.5 Wire - 600 mm long and 1 mm in diameter.

2.0 Procedure

- 2.1 Place screen in the beaker. Record weight of screen and beaker.
- 2.2 Riffle sample to approximately 150 g. Place the riffled sample in the screen and weigh beaker, screen and sample together.
- 2.3 Thread wire through top of screen. Lift it up and immerse screen with its pellets into the water trough. Start stopwatch.
- 2.4 After exactly 1 minute, remove the immersed screen/pellets from the water.
- 2.5 Drain excess water by rotating the screen 45° clockwise for 10 seconds, and 45° anti-clockwise for 10 seconds.

Appendix A7

2.6 Replace the screen/pellets back in the beaker.

Record weight of the beaker with screen and pellets.

3.0 Calculations

3.1 Calculate the percentage of moisture absorbed by sample for each minute of immersion.

$$\text{Percent of moisture absorbed} = \frac{A-B}{C} \times 100$$

where:

A = beaker + screen + sample + absorbed water

B = beaker + screen + sample

C = sample weight

4.0 Report

4.1 Report mean of duplicate tests as percent of moisture absorbed after 1 min., 2 min.,
5 min.

Appendix A8

d-RDF Chemical Analysis Procedures

Oil Content Determination: Toluene Extraction Method

Lead: Determined by ashing at 500° C, extraction with nitric acid and using atomic absorption spectrophotometer.
(ASTM-3335)

Higher Heating Value: Determined on Parr adiabatic calorimeter.

Ash: Ignition in porcelain crucible at 900° C.

Appendix B

Short Description of Data Processing Programs

Four programs written for processing and fitting the data from the waste oil experiments are briefly described below. They were written in Fortran IV, for use on a DEC-10 computer at Johns Hopkins University. Sample outputs and listings are available upon request.

PROGRAM WASTØL

This program reads in cards on which all relevant measured or computed quantities and variables have been punched (1 card per test). Outliers, having an oil content (dry basis) exceeding a prescribed threshold, are identified by name and removed from the original deck.

PROGRAM WASTWØ

Starting with the output of WASTØL, a number of oil levels defining upper bounds of ranges of interest are specified. The program ranks and counts the elements by oil content class.

PROGRAM WASTRE

Starting with as many decks (outputs of WASTRE) as there were oil levels, a ranking is made in each oil class for moisture content, using moisture ranges specified in the data. The output of the program are the elements and ranking shown in Table 8.

PROGRAM WASCØR

Starting with any of the deck outputs of WASTRE, this program computes a linear regression fit to the data, including y-intercept,

slope, correlation coefficient and standard error on estimate. It also identified by address those elements in the class which could be labeled outliers on the criterion:

$$|y_{\text{measured}} - y_{\text{est}}| > 1.28 S_{y/x}$$

This would correspond to the 20% probability "tail ends" of a normal distribution.

New runs for the linear fit can then be made, if desirable, with these outliers removed.

SAMPLE OUTPUTS

PROGRAM WASTØL

Input data: cards
teletype
Output: teletype

PROGRAM WASTWØ

Input data: decks from WASTØL
teletype
Output: teletype

PROGRAM WASTRE

Input data: decks from WASTWØ
teletype
Output: teletype

PROGRAM WASCØR

Input data: decks from WASTRE
teletype
Output: teletype

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