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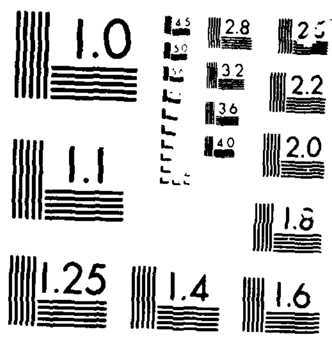

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An Investigation Conducted By
SYSTECH Corporation
Sponsored By Naval Facilities
Engineering Command

NCEL
Contract Report

OPERATIONAL TEST REPORT: EFFECTS OF MOISTURE AND COMPOSITION ON DENSIFIED REFUSE-DERIVED FUEL AND SYSTEM OPERATING PARAMETERS RDF-3 AND RDF-5

ABSTRACT Using simulated feed stocks, RDF-3 and -5 were produced on the Navy's RDF line at the Naval Air Station, Jacksonville, Florida. Manufacturing conditions, moisture and constituent components were systematically varied, using Simplex Lattice Experiment design for the ast group of variables. The products resulting were evaluated using a special battery of test procedures to describe eleven different RDF properties. Correlation analyses confirmed expectations concerning manufacturing and the moisture variable; compositional variations produced some interesting although not strong correlations. Regression analytical results were poor.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

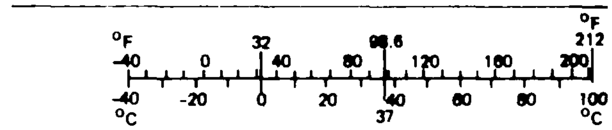
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, *Units of Weights and Measures*, Price $2.25, SD Catalog No. C13.10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Using simulated feed stocks, RDF-3 and -5 were produced on the Navy's RDF line at the Naval Air Station, Jacksonville, Fla. Manufacturing conditions, moisture and constituent components were systematically varied, using Simplex Lattice experiment design for the last group of variables. The products resulting were evaluated using a special battery of test procedures to

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ACKNOWLEDGMENT

This report documents the activities and the findings of two consecutive Delivery Orders (ZZ05 "RDF Test System Performance Evaluation and Laboratory Methodology Validation" and ZZ06 "Moisture and Composition Testing of Refuse-Derived Fuel") executed under U.S. Navy Contract No. N00123-83-D-0149. The Contracting Officer was Mr. Andrew Lendacky, the Project Engineer was Mr. R. M. Roberts, Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California.

SYSTECH gratefully acknowledges the guidance and support of Mr. Roberts in the performance of this work. SYSTECH also wishes to thank the Naval Air Station Jacksonville, Office of Public Works for their assistance in establishing operations at the RDF Test Facility and the personnel and management of the Military Construction Corporation for their outstanding contribution to the operation and maintenance of the facility during the test program. Thanks also go to Dr. Alan Berens of the University of Dayton Research Institute for his expert guidance in the complex statistical design and analysis of this program.

SECTION 1.0
INTRODUCTION

1.1 OBJECTIVES OF THIS RESEARCH

The overall objective of this research was to develop information pertinent to establishing specifications for a refuse-derived fuel (RDF) that would be acceptable as a supplementary fuel for existing and future multi-fuel capable boilers at Navy shore-based installations. In particular, the effort was focused on two forms of RDF, RDF-3[1] and RDF-5[2], because these are considered by NCEL to be the only two types of RDF that are technically and economically suitable for Navy boilers.

The specific objective of this effort was to perform testing required to evaluate the effects of refuse moisture and composition on the quality of prepared RDFs. The tests were performed at the NCEL's RDF test facility located at the Naval Air Station Jacksonville (NAS JAX), Florida.

In order to meet the major objective of obtaining test information that could be translated into information pertinent to establishing RDF specifications, three additional objectives dealing with the definition of proper test conditions had to be met. These preliminary objectives included:

1. Establish system operational readiness through a series of shakedown tests (see Appendix A).

2. Establish and validate the RDF analytical test methods.

3. Determine the optimum combination of system operating parameter values to be used as constants for the moisture and composition tests.

1.2 SUMMARY OF RESEARCH PLAN

In pursuit of the overall objective, the research program has been designed in five successive phases. Each phase has been designed to provide specific information pertinent to the execution of the subsequent phase, as

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[1]A shredded fuel derived from municipal solid waste (MSW) that has been processed so as to remove metal, glass, and other entrained inorganics. The material has a particle size such that 95 weight percent passes through a 2-in. square mesh screen (Reference 1, page 140).

[2]Combustible waste fraction densified (compressed) into the form of pellets, slugs, cubettes, or briquettes. RDF-3 is often utilized as the feedstock in the production of RDF-5 (Reference 1, page 140).

well as to address practical questions. A brief description of the program phases and objectives follows:

1. Establish the operational status of the RDF processing equipment at the NAS JAX test facility and establish the effectiveness of the measurement methods that will be utilized to determine RDF characteristic values in subsequent phases.

2. Perform critical component tests to determine the effect of processing equipment parameters (i.e., hammermill grid size and pellet mill die size) on RDF physical characteristics. The results will be used to select the optimum combination of processing equipment parameters for subsequent tests.

3. Perform feedstock composition tests to determine the effects of feedstock moisture and composition on RDF physical and chemical characteristics. The results will be analyzed to establish what relationships may exist between refuse moisture, refuse composition, and RDF characteristics or between RDF characteristics. A model (predictive equation) would then be developed and used to produce RDF with various characteristics to provide controlled feedstock variables for subsequent combustion tests.

4. Perform combustion tests (both laboratory and full scale) using RDF produced under predicted and controlled conditions in order to determine and quantify what relationships may exist between RDF physical and chemical characteristics and RDF combustion characteristics.

5. Having determined all of the above relationships, the last phase calls for the production and combustion of RDF prepared from actual municipal or military solid waste. These evaluations will yield the actual range of values for RDF physical, chemical, and combustion characteristics. The results will be evaluated to determine which characteristics and which values for those characteristics are critical to facility operations and the economic performance of the fuel. This would then permit the development of effective, but rational, RDF specifications.

The findings reported herein cover the activities of Phases 1, 2, and 3 above. Phases 4 and 5 may be performed at a later time. The conclusions regarding the results of the work performed to date are probably more relevant to the structuring of the content of future research programs, although many observations can be made that may aid in the correct practice of RDF processing. Some guidance can also be offered toward the development of interim purchasing specifications.

To a great extent, the criteria that govern which RDF characteristics and which values for those characteristics are critical to successful RDF utilization are dictated by site-specific equipment requirements. Therefore, generalizations are difficult to make. Although thousands of tons of RDF have been produced in commercial scale operations, there is still insufficient reliable information available regarding RDF storage, handling, and combustion characteristics to develop generally applicable RDF purchase specifications.

1.3 FACILITY DESCRIPTION

A number of Naval activities have considered developing solid waste resource recovery facilities, either independently or in cooperation with their adjacent communities. Possible approaches to Navy involvement in such projects include purchasing energy produced from incineration of the combustible wastes of the communities, purchasing RDF products prepared by the communities for co-firing in existing fossil fuel-fired or future multi-fuel capable Navy boilers (the focus of the present work), or disposing of Navy-generated wastes in heat recovery incinerators (HRIs) operated by the Navy or others. Each concept offers the Navy the potential benefit of reducing dependence on conventional fossil fuels such as oil and natural gas, while at the same time reducing the burden on land disposal sites.

There are considerable technical and economic risks involved in implementing waste-to-energy technology with respect to prepared RDF utilization. These risks stem from the following uncertainties and gaps in available information:

- Limited technical information on the achievable, as well as the required RDF handling and combustion characteristics.

- Proven processing technologies that can ensure the continuous availability of competitively-priced, specification-quality RDFs.

- The ability of the user to adequately specify the desired RDF characteristics.

- The ability to adequately and accurately measure the specified RDF characteristics.

In order to gather data to aid in the evaluation of these risks, an RDF preparation and test site was developed by NCEL at NAS JAX. This test site consisted of three subsystems: a pre-existing RDF combustion facility, a pre-existing refuse preprocessing line, and an added-on RDF processing line. The refuse preprocessing and combustion subsystems were installed by NAS JAX in 1979 as part of a MILCON project for the routine disposal and combustion of waste generated waste at the activity. The RDF processing equipment was installed by the NCEL in 1981 and 1982 to support a research project to investigate RDF-3 and RDF-5 production, handling, and combustion characteristics. The NCEL RDF processing line was designed to accept a portion of the shredded refuse from the refuse preprocessing line while it fed input fuel to the combustion system, which consisted of a battery of three HRIs. The NCEL RDF processing line is, therefore, dependent upon the refuse preprocessing line function to complete the sought-for RDF processing line configuration. The combustion system failed and was taken out of service in 1982, but was not required for the present investigations.

A flow diagram of the combined refuse preprocessing and NCEL RDF processing line is presented in Figure 1-1. The refuse preprocessing system starts with a subfloor pan conveyor leading to a Kleco shear shredder. The shear shredder was used for primary size reduction, yielding an output that had a 6- to 8-in. nominal particle size. The output of the shear shredder is conveyed over an Eriez Magnetics three-stage electro/permanent magnet that removed any ferrous metals from the shredded refuse stream. Next, the shredded and magnetically-cleaned refuse moves through a 4-ft diameter, 8-ft long trommel. The trommel, which is essentially an inclined rotary screen (with 1/2-in. holes), separates the processed waste into two size fractions: less than 1/2 in. and greater than 1/2 in. The purpose of this unit operation is to eliminate fines and their associated inert materials from the processed waste. Since this research program was designed to utilize a controlled composition (synthetic) waste stream, such a separation function was not desired. Therefore, the trommel holes were blinded, thus converting it to a rotary mixer/conveyor. The tumbled, mixed waste exiting from the trommel is normally conveyed to a 340-cubic yard, live-bottom storage bin. This bin, however, could be and was bypassed for the majority of the test work.

The material exiting from the waste preprocessing line (RDF-2) becomes the feedstock for the RDF processing line, which further refines the material into RDF-3 and RDF-5. The RDF processing line (that line of equipment installed by NCEL) begins with a feed conveyor and a 150-horsepower (hp) hammermill, with a throughput capacity rate of 1.5 to 2 tons per hour (TPH). The hammermill was used for secondary size reduction, yielding a particle size of less than 2 in., which thus comprises RDF-3. This material is then pneumatically conveyed from the hammermill to a 250-cubic yard Sprout-Waldron, live-center surge bin. The surge bin provides an even flow of refuse to the centrifeeder of a 250-hp Sprout-Waldron pellet mill that has a throughput capacity of up to 0.7 TPH. This pellet mill provides the compaction mechanism for producing RDF-5 from the RDF-3 feedstock. The process line ends with a 20-ft long × 5-ft wide Sprout-Waldron pellet cooler. In this device, air is drawn through a perforated steel conveyor, thus cooling and drying the pellets.

1.4 SUMMARY OF DATA ANALYSIS

The primary data resulting from this investigation are derived from the physical and chemical analysis of representative samples of RDF-3 and RDF-5 produced in three series of evaluations: equipment evaluations (selection of optimum parameter values), moisture evaluations, and composition evaluations.

The data collected during the system operating parameter tests and moisture evaluation tests were analyzed to determine which set of conditions produced the best overall quality pellets. The selected conditions were than utilized throughout the subsequent composition tests. In order to make these selections, the data were subjected to a one-tailed hypothesis test. This test provided a mechanism for determining significant differences between RDF characteristics resulting from each set of test conditions. Based on these results, the data were ranked and a set of values was selected.

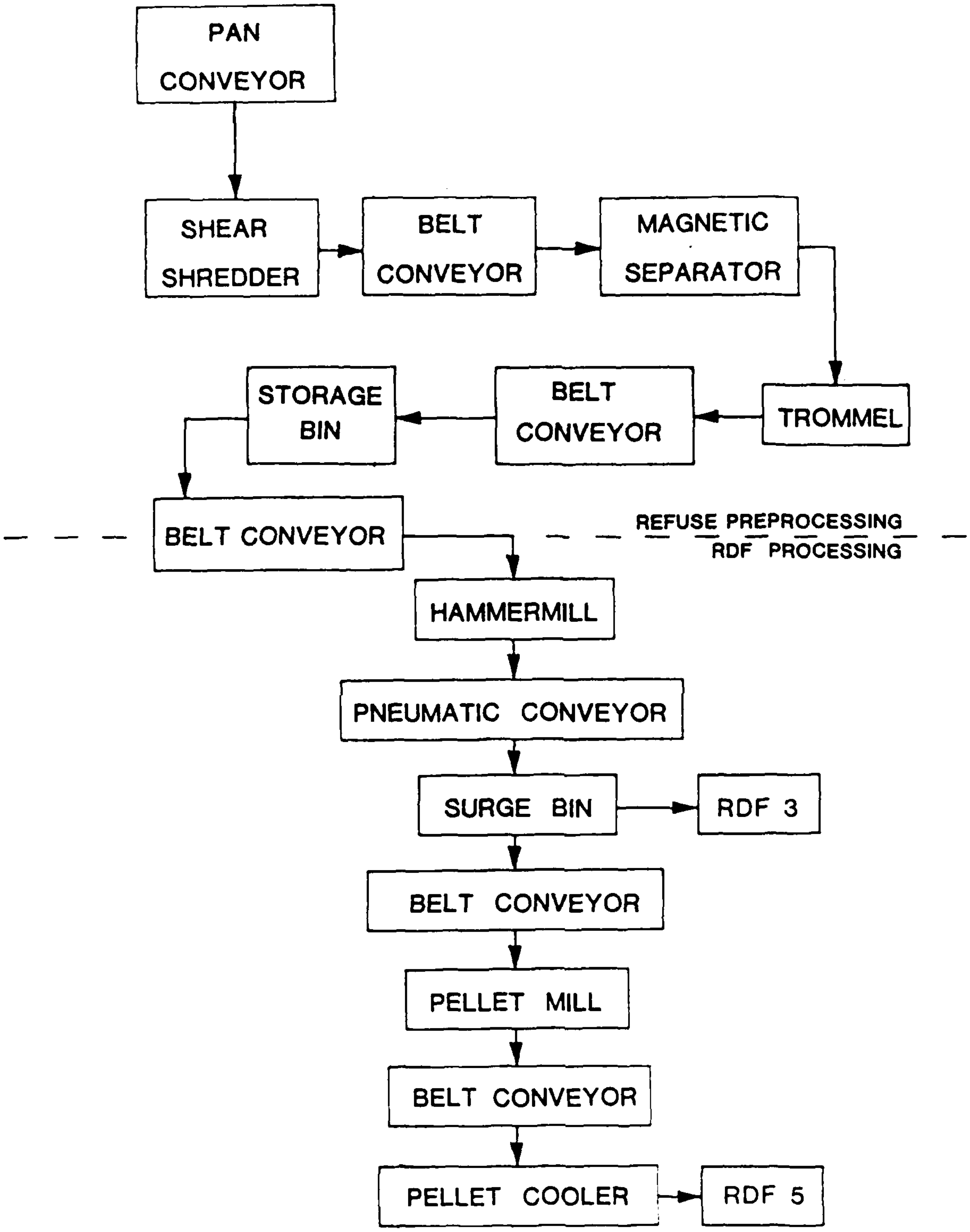

Figure 1-1. Refuse preprocessing and NCEL RDF processing line.

The data collected from the composition tests were subjected to two distinct statistical analyses. The first analysis was to determine one-to-one correlations. Specifically, the correlation of each dependent variable to each refuse component, as well as to all the other dependent variables, was calculated.

The second analysis was done to develop a model (predictive equation) whereby an RDF characteristic can be predicted if the RDF feedstock composition is known. This regression analysis considers the interactive effects of all five compositional elements on each individual RDF characteristic. This resulted in 23 separate predictive equations.

SECTION 2.0
TEST PROGRAM DESCRIPTION

2.1 INTRODUCTION

During the course of this program, three distinct groups of tests were performed, requiring approximately 50 separate refuse runs. These three groups consisted of evaluations regarding the effects of system operating conditions, refuse moisture, and refuse composition on the resultant RDF-3 and RDF-5.

2.2 INITIAL SHAKEDOWN--ESTABLISH OPERATIONS

Before the test and evaluation work could be initiated, the status of the NAS JAX processing equipment had to be determined and operational experience had to be gained. The RDF processing line was for the most part unused at the beginning of the research program. The hammermill and pellet mill both had less than 5 hours of operation logged on their hour meters. Preliminary activities included lubrication and no-load running to determine general operability, electrical control logic, and subcomponent interactions. Both the hammermill and pellet mill had overload control circuits ana conveyor kill circuits that needed corrective maintenance or modifications to meet the planned program requirements. Several lots of reclaimed mixed paper were processed to observe the equipment under load. A detailed description of and the status found for the refuse preprocessing and RDF processing equipment is presented in Appendix A.

2.3 EXPERIMENTAL DESIGN

This program endeavored to validate the assumption that system operating parameters, refuse feedstock moisture, and refuse feedstock composition are prime factors in determining the resultant quality of RDF-3 or RDF-5. To attempt to measure the interactive effects of all three variables would have required more than 400 tests. Therefore, the individual effects of each variable were measured by holding two constant while changing the third through its possible range of values. This produced three distinct sets of tests. Table 2-1 presents the test variable matrix. It was imperative that only the desired experimental conditions be varied during any given test. Without such experimental control, it would be difficult, if not impossible, to establish that a measured RDF characteristic was obtained as an effect of controlled changes in the test variable rather than an effect of random changes in the process. Thus, it was necessary to control the moisture and composition of the refuse. Control was achieved by compositing or "synthesizing" the refuse. Each component was obtained from either raw material or scrap markets. Moisture content was controlled by wetting the materials with a controlled quantity of water.

TABLE 2-1. TABLE OF TEST VARIABLES

Test	Controlled variables	Independent variable	Dependent variable
Configuration	Refuse composition Refuse moisture	System parameters	RDF characteristics
Moisture	Refuse composition System parameters	Refuse moisture	RDF characteristics
Composition	System parameters Refuse moisture	Refuse composition	RDF characteristics

2.3.1 Selection of System Operating Conditions

Using NCEL equipment available at NAS JAX, four unique combinations of values for two system operating parameters were possible. Two different sized hammermill grates and two sizes of pellet mill dies were available. While utilizing a consistent composition of synthesized refuse at a fixed moisture, RDF-3 and RDF-5 were produced from each of the four combinations of equipment. Based on RDF characteristics, the optimum combination was selected. Selection of the optimum combination as the first step eliminated potential masking effects caused by these parameters on RDF quality during the subsequent tests.

The RDF produced during these tests was also utilized to ensure that the analytical test methods employed were appropriate to measure RDF characteristics. Furthermore, this opportunity was used to determine the number of analytical replicates which would be required to achieve an acceptable level of precision in subsequent tests. The details of the analytical methodology selection and evaluation are presented in Appendix B.

2.3.2 Selection of RDF-3 Moisture Levels

Having selected the final values for the system operating parameters, they were held constant, refuse composition was held constant, and RDF-3 moisture ranges were evaluated. Moisture has long been assumed to be a critical factor in the successful production of RDF-5. Therefore, the objective of this test sequence was to establish critical moisture levels and determine the sensitivity of RDF characteristics to moisture variability. Of further consideration were the factors of processing and repeatability. The range of moisture levels ultimately selected for the composition evaluations had to be such that they did not have an adverse effect on the processing equipment and could be repeated consistently throughout the composition evaluations.

Should the absolute control of the RDF-3 moisture level prove to be difficult in the composition evaluations, it was desirable to know which RDF-5 characteristics would be effected most and, if possible, to establish a range of moisture values in which the most sensitive characteristics would be least affected. The establishment of a moisture "null range" would allow all subsequent observations to be attributed solely to the effects of composition, rather than minor fluctuations in moisture.

Various moisture levels were obtained by adding known quantities of water to the refuse while it was being composited. Four test runs were made to evaluate high, low, and intermediate RDF-3 moisture values.

2.3.3 Composition Evaluation Tests

The final test sequence determined the effects of refuse composition on RDF characteristics and quantified these effects through correlation and multiple regression analyses. Refuse composition has been assumed to be a major factor in the resultant RDF quality. To verify this quantitatively and thus provide information pertinent to establishing RDF specifications, RDF was produced from various refuse compositions while holding refuse moisture and system operating parameters constant. Changes in RDF characteristics observed in the final test sequence could therefore be attributed solely to the effects of refuse composition.

To develop predictive equations representing the interactive effects of refuse composition on RDF characteristics through regression analyses, and to determine one-to-one correlations, a specialized experimental design was needed. Several experimental designs were considered, including "one at a time," full factorial, fractional factorial, and Simplex Lattice. The "one at a time" approach is simple and would have required relatively few tests; however, the significance of how the refuse components interact to influence the dependent variables (RDF characteristics) could not have been determined. The full factorial design was not selected because the number of tests required by such a design would have been prohibitive. The fractional factorial design would have reduced the number of tests to a manageable number; however, because it would have required an unbalanced matrix, any difficulties encountered in performing the tests could have easily rendered the data almost impossible to analyze.

Ultimately, the design chosen for this experiment was the Simplex Lattice. It is a design method that was developed for studying the functional relationships in mixture data and accounts for the fact that the sum of the proportions of the components must total unity. It provides a mechanism for selecting which compositions to test in order to provide sufficient data to perform regression analyses and develop mathematical models of response to the dependent variables. Reference 2 presents a complete description of the design and analysis of mixture experiments.

In this test sequence, each RDF characteristic, Y, was to be estimated as a function of the mixture proportions,

$$Y = f\ (X_1, \ldots X_n) \quad \text{(Equation 2-1)}$$

As a practical matter, the functional form of the relations must be limited to a low order polynomial and is further restricted by the constraints on the independent variables. In mixture experiments, the linear model is written as:

$$Y = \sum_{i=1}^{n} B_i X_i \qquad \text{(Equation 2-2)}$$

Note the absence of a constant term in the linear model. The coefficient B_i is actually the sum of a constant term, μ, plus the coefficient of X_i in the full linear model (see Reference 2, page 20). Similarily, the second order model is written as:

$$Y = \sum_{i=1}^{n} B_i X_i + \sum_{i<j}\sum B_{ij} X_i X_j \qquad \text{(Equation 2-3)}$$

To determine the number of design points required, the following equation applies, where m refers to the degree of the polynomial equation and q to the number of components:

$$\text{Number of design points} = q + q\ (q-1)/m \quad \text{(Equation 2-4)}$$

Refuse is often considered to consist of 13 subcomponents (Table 2-2 and Reference 3). By using Equation 2-4 and assuming a second order model, utilization of those 13 subcomponents would have required: 13 + 13 * (13-1)/2 = 91 processing runs with 91 distinct compositions. Such an experiment, though appropriate, would not be economically tolerable. Therefore, the original 13 subcomponents were combined, based on similarities in physical and chemical characteristics, into five main components (Table 2-2). The proportions of the subcomponents within each main component were held constant while the main components percentages were varied. This resulted in the potential for investigating a second order relation between the RDF characteristics and the refuse component proportions.

The design of the field test conditions consisted of specifying 16 test compositions and randomizing the testing order. Since there are practical bounds on the proportions of refuse components in the feedstock, these bounds were also imposed on the experimental design. The range through which each component is varied represents a range that could realistically be obtained in processed military or municipal solid waste. In particular, Table 2-3 lists the assumed bounds on the proportions of the five components. The XVERT algorithim (Reference 2, page 127) was used to specify the design points. This complex iterative algorithim is designed to minimize the sum of the variances of the estimates of the coefficients in the estimation model. Table 2-4 lists those compositions.

TABLE 2-2. MATERIALS USED TO SIMULATE THE COMPOSITION OF PROCESSED SOLID WASTE

Components	Subcomponent	Subcomponent percent of total	Component percent of total
Paper			65
	Office	45	
	News	20	
Plastic			14
	Polyethylene	5	
	Rubber	3	
	Leather	1	
	Textiles	5	
Organics			17
	Cardboard	10	
	Hay	3	
	Wood	2	
	Produce	1	
	Dog food	1	
Glass			3
Inerts			1
	Aluminum	1	

2.3.4 Analysis Overview

The data collected during the equipment operating parameters and moisture level selection tests were subjected to one-tailed t tests. These tests are designed to measure whether a statistically significant difference exists between the RDF characteristics measured under the various operating or moisture conditions. Detection of such differences allows for selection of the optimum operating and moisture scenario for the composition tests.

The data collected during the composition tests were subjected to two different statistical analyses. The first, one-to-one correlations, was designed to determine if the relative value of a single characteristic could be estimated by knowing the value of either one other characteristic or one refuse component.

The second analyses was based on the interactive effects of the five refuse components on each RDF characteristic. This regression analyses was designed to develop a series of equations which could be used to estimate the value of each RDF characteristic based upon refuse composition.

TABLE 2-3. ASSUMED RESTRICTIONS ON REFUSE COMPOSITION

Refuse component	Minimum percent	Maximum percent
Paper	50	80
Plastic	0	15
Organics	10	30
Glass	0	10
Inerts	0	5

TABLE 2-4. COMPOSITION MIXTURES FOR THE EXPERIMENT

Test no.	Paper percent	Plastic percent	Organic percent	Glass percent	Inerts percent
1	80	5	10	0	5
2	80	5	10	5	0
3	50	15	30	5	0
4	50	15	20	10	5
5	75	15	10	0	0
6	75	5	10	10	0
7	70	5	10	10	5
8	70	15	10	0	5
9	65	15	10	10	0
10	65	5	30	0	0
11	60	15	10	10	5
12	60	5	30	0	5
13	55	15	30	0	0
14	55	5	30	10	0
15	50	15	30	0	5
16	50	5	30	10	5

To determine how well the equations model the characteristic, the standard error of the estimate (SEE) is calculated. The SEE is the key measurement of the uncertainty in the resultant equations. Small values of the SEE relative to the standard deviation of the RDF characteristic indicate that the equation is as good or better an estimator of the RDF characteristic than the physical measurement.

SECTION 3.0
WORK PERFORMED

3.1 INTRODUCTION

The overall test program was designed to evaluate the individual effects of three different independent variables on RDF characteristics. The independent variables were system operating parameters, refuse moisture, and refuse composition. The following sections describe how each independent variable was evaluated. In each evaluation, RDF characteristics were the dependent variables. Table 3-1 lists the RDF physical characteristics with a brief description of the analytical approach. The column labeled "Appendix" identifies the location of the detailed analytical procedure. Appendix B describes how these methodologies were chosen and/or developed. In addition to the 10 physical characteristics, 12 chemical characteristics were measured. These included ash fusion temperatures (initial, softening, hemispherical, fluid), carbon, fixed carbon, hydrogen, oxygen, ash, chlorine, sulfur, and higher heating value (HHV). These analyses apply to both RDF-3 and RDF-5 and were measured utilizing standard ASTM RDF analytical methodologies.

TABLE 3-1. SUMMARY OF RDF PHYSICAL CHARACTERISTICS

RDF type	Characteristic	Appendix	Approach
3	Moisture	C	Weight loss
3	Size	D	Sieve analysis
3	Bulk density	E	Volumetric/gravimetric
5	Bulk density	F	Volumetric/gravimetric
5	Pellet density	G	Volume displacement
5	Size	H	Manual measurement
5	Durability	I	Mechanical tumbler
5	Funnel angle	J	Geometric
5	Water absorption	G	Weight gain
5	Moisture	K	Weight loss

As a means for providing feedback on the RDF production and to ensure that all the appropriate data were collected, a test laboratory was set up on site. The laboratory was equipped with all the analytical tools required to perform all the RDF physical characteristic measurements. By having the laboratory on site, it was possible to quickly identify the need to repeat an evaluation while samples were still representative of as-produced conditions.

3.2 SYSTEM OPERATING PARAMETERS

3.2.1 Objectives

The objective of this phase of the test program was to select the best equipment operating parameter options for use in subsequent testing. Two operating parameters in the NCEL RDF processing line could be varied: the hammermill grid and the pellet mill die. Two pellet mill dies (1/2 in. and 3/4 in.) and two hammermill grids (2 × 1 in. and 2 × 1.5 in.) were available. By alternately changing hammermill grids and pellet mill dies, four distinct operating conditions could be obtained. The final selection was based upon a statistical comparison of the RDF characteristic data resulting from each of the four operating conditions tested.

3.2.2 Test Conditions

Throughout the system operating parameter evaluations, refuse composition and refuse moisture were the controlled variables. It was determined that the most effective way to control the refuse composition was to "synthesize" the refuse from its individual components. Each of the refuse subcomponents listed in Table 2-2 were obtained from commercial or scrap material markets. For these tests, the composition listed in the same table was used. That particular composition represents "normal" solid waste which has been shredded, trommeled, and magnetically separated (Reference 3).

Each refuse composition was synthesized by following a procedure developed specifically for this test application. The procedure consisted of weighing out each individual component and storing the measured quantity in an appropriately sized container, such as a 5-gal bucket, a 55-gal drum, or a 1/2-cubic yard dump cart. The newspaper and office paper components were then combined in a 1-cubic yard dump cart. Moisture was controlled by weighing out the appropriate quantity of water and adding it to the newspaper and office paper components as they were layered into the 1-cubic yard cart. The paper-filled carts were then covered and left overnight to allow time for the papers and the added water to equilibrate. During processing, all the components were manually proportioned on the slow-moving pan conveyor that feeds the shear shredder. This provided a thoroughly mixed uniform blend throughout the processing run.

The independent variables for the equipment evaluation were the system operating parameters, which were varied according to the four possible combinations presented in Table 3-1. The dependent variables were the RDF physical characteristics presented in Table 3-2.

3.2.3 Test Execution

Four tests were planned for this evaluation, one at each of the four possible combinations of parameter values. However, prior to this test program, when attempts were made to process peat pellets, peat residue was left in the 3/4-in. die. Before the evaluation of the 3/4-in. die could be made, the peat had to be removed with a pneumatic chisel. The first two RDF-5 evaluations were then performed with the 3/4-in. pellet mill die in place and alternating the hammermill grids. When the 3/4-in. die was removed (in preparation for the 1/2-in. die evaluation) it was noticed that the dies still contained considerable amounts of peat residue. Concern arose that the residual peat deposits had interfered with proper pellet formation and, therefore, may have caused lower quality 3/4-in. pellets (see Results, Section 4). To determine if the peat was a factor, the 3/4-in. dies were cleaned with steel brushes and the 3/4-in. evaluations were repeated. Therefore, six tests were completed.

TABLE 3-2. RDF-3 AND RDF-5 PHYSICAL AND CHEMICAL CHARACTERISTICS

Chemical RDF-3 and RDF-5	RDF-3 physical	RDF-5 physical
Ash fusion temperature	Moisture	Moisture
	Characteristic size	Initial size
Initial deformation	Bulk density	Initial fines
Softening		
Hemispherical		Durability
Fluid		
		Final size
Higher heating value		Final fines
Proximate analysis		Bulk density
Moisture		
Volatiles		
Fixed carbon		
Ash		
Ultimate analysis		
Carbon		
Hydrogen		
Oxygen (by difference)		
Nitrogen		
Sulfur		
Chlorine		

Throughout this evaluation, plugs in the pellet mill were a frequent occurrence. Dense plugs were often formed when mats of RDF-3 entered the pellet mill. These mats were most prevalent during start-up, and were the result of the compression which occurs in the bottom of the surge bin. To eliminate the formation of these mats, "spider arms" were welded to the end of the surge bin discharge augers. These "spider arms" were successful in breaking up the RDF-3 before it was discharged to the pellet mill feed conveyor.

To further improve the ability to control pellet mill feedrate, the pellet mill feed conveyor was slowed down. The conveyor ran at a constant speed of 300 ft/min over a distance of only 10 ft. This high speed made it difficult to feed the pellet mill at a smooth even rate and caused considerable material spillage. The speed was reduced 30 to 40 percent by changing the sheaves on the motor and gear drive. The slower speed provided much better pellet mill feed control and significantly reduced the amount of material spillage.

A final modification, which significantly reduced pellet mill plugging, was the inversion of the pellet mill roller assembly. The roller assembly consists of three rollers in a triangular configuration, with the base of the triangle at the top of the pellet mill. This configuration provided a ledge on which loose material could accumulate. Eventually, this loose material would build up and create a plug. By inverting the assembly, there was no longer a natural location for material to accumulate and, therefore, reduced plugging resulted.

Although the modifications described above did significantly reduce the frequency of pellet mill plugs, they did still occur. However, by monitoring the pellet mill ammeter, processing could be stopped temporarily and plugs could be cleared before they developed into significant problems. This procedure was used throughout the remaining test evaluations.

3.2.4 Data Analysis

The RDF produced under each set of operating parameters was sampled according to the procedures detailed in Appendix B. The samples were then subjected to the physical tests listed in Table 3-2. The results of these tests were analyzed to determine if any significant differences in RDF characteristics could be attributed to system operating parameters. The statistical method used for this analysis was the Students one-tailed t test at a 95 percent significance level. The results of these analyses are presented in Section 4.0.

3.3 MOISTURE EVALUATIONS

3.3.1 Objectives

The objective of these tests was to identify a range of RDF-3 moisture values that have the least impact on RDF-5 characteristics. This range would then be used during the composition tests. Selection of a range of moisture values that have limited impact on RDF-5 characteristics was required to be certain that minor fluctuations in moisture would not mask the effects of refuse composition on RDF-5 characteristics during the composition tests.

3.3.2 Test Conditions

Throughout the moisture evaluation testing, refuse composition and system operating parameters were controlled variables. Refuse composition was held constant at the "normal" composition (as it was for the system parameters evaluation). The system operating parameters were set at the 1.5-in. hammermill grate and the 0.5-in. pellet mill as being typical manufacturing conditions.

The independent variable was refuse moisture. Trial test runs were made during the earlier phases of this test program to serve as range-finding experiments. During these trials, reclaimed mixed paper was processed "as received" as well as with varying amounts of water added prior to processing. Samples were taken to determine the moisture content of the RDF-3 prior to the pelletizing process. This preliminary evaluation identified a process achievable working range of 10 to 30 percent moisture. At or below 10 percent moisture, which was the approximate as-received value, the pellet mill overheated causing severe smoking and charring of the material in the pellet dies. At or above 30 percent moisture, it was very difficult to control the feed rate to the pellet mill. Slugs of wet refuse would enter the pellet mill and cause dense plugs to form. These plugs would then have to be removed by manually prying the refuse out of the pellet mill.

As in the system parameter evaluation, RDF physical characteristics were the dependent variables (Table 3-2). The results of the characteristic analyses were then statistically tested to determine which characteristics exhibited significant differences due to RDF-3 moisture content. A one-tailed Student's t test was used.

3.3.3 Test Execution

Four moisture evaluations were planned: high, low, and two intermediate values. The preliminary evaluations indicated that by adding water in 50-lb increments and starting at 50 lbs, the desired range should be achieved. For each evaluation, 1000 lbs of standard composition refuse was composited by alternately layering the components into 1-cubic yard carts. The specified quantity of water (50, 100, 150, and 200 lbs) was then added during the compositing procedure. The carts were sealed and left overnight to allow time for the water to be absorbed by the refuse components. RDF characteristics were then measured at moisture levels of 11.8, 14.3, 16.5, and 20.1 percent.

3.3.4 Data Analysis

RDF physical characteristics were the dependent variables in the moisture tests (Table 3-2). The results of the tests were statistically analyzed to determine which characteristics exhibited significant differences due to RDF-3 moisture content. Again, a one-tailed Student's t test was utilized.

3.4 COMPOSITION EVALUATION

3.4.1 Objectives

The objective of this phase of the test program was to determine the effects of varying refuse composition on RDF quality and to develop a mathematical relationship whereby RDF characteristics could be estimated if refuse composition was known. In addition to determining the interactive effects of the five refuse components on each individual RDF characteristic, it was also an objective to determine what the one-to-one relationships were among the dependent variables and between the dependent variables and the refuse components (such as glass to bulk density).

The final objective was to draw upon all the information gained from each of the test evaluations in order to present possible guidance on the development of RDF specifications.

3.4.2 Test Conditions

Throughout this evaluation, refuse moisture and system operating parameters were held constant as the controlled variables. As determined by the results of the moisture evaluation (Section 4.4.2), the target moisture range for the composition evaluation was 14 to 18 percent. If the actual measured RDF-3 moisture content was outside that range, that particular composition test was rerun. The system operating parameters, consisting of the 1 1/2-in. × 2-in. hammermill grid and the 1/2-in. pellet mill die that were determined to yield the best pellet quality (see Section 4.0), were used throughout these tests.

RDF physical and chemical characteristics were the dependent variables. Up to this point, chemical characteristics were not measured because the independent variables of moisture and system operating parameters would not affect these characteristics. Therefore, chemical characteristics were not of interest until refuse composition was varied.

Refuse composition was the independent variable. Using the statistical design method described in Section 2.0, 16 refuse composition evaluations were planned.

3.4.3 Test Execution

For each evaluation, the refuse was composited as described in Section 3.3.2 and according to the compositions listed in Table 2-4. To help maintain moisture levels, all refuse components were obtained at the same time from the same source. To achieve the desired final moisture range, 100 lb of water was added to the refuse as it was composited. In two instances, the resultant moisture was outside the desired range. Those two composition evaluations were repeated at the end of the test program.

During this test sequence, the RDF processing equipment operated very smoothly. Nearly all the operational "bugs" had been detected and corrected in previous tests. As a result, time was available at the end of the program to test four additional compositions. Addition of these tests significantly improved the experiment by completing all the end points in the Simplex Lattice design. Table 3-3 lists the final compositions that were evaluated. Composition 1 through 20 were derived from the XVERT algorithim (Section 2.0), with 17 through 20 being the additional four. Test 21 was included as a baseline test, as it represents standard composition refuse (see Table 2-2).

TABLE 3-3. COMPOSITION MIXTURES FOR THE EXPERIMENT

Test no.	Paper percent	Plastic percent	Organic percent	Glass percent	Inerts percent
1	80	5	10	0	5
2	80	5	10	5	0
3	50	15	30	5	0
4	50	15	20	10	5
5	75	15	10	0	0
6	75	5	10	10	0
7	70	5	10	10	5
8	70	15	10	0	5
9	65	15	10	10	0
10	65	5	30	0	0
11	60	15	10	10	5
12	60	5	30	0	5
13	55	15	30	0	0
14	55	5	30	10	0
15	50	15	30	0	5
16	50	5	30	10	5
17	80	10	10	0	0
18	80	5	15	0	0
19	50	10	30	10	0
20	50	15	25	10	0
21	65	14	17	3	1

3.4.4 Data Analysis

The data collected during the composition tests were subjected to two different statistical analyses. The first, one-to-one correlations, was designed to determine if the relative value of a single characteristic could be estimated by knowing the value of any one other characteristic or one compositional component.

The second analyses quantified the interactive effects of the five compositional components on each characteristic. For all the dependent variables, the parameters (B_i and B_{ij}) of the Equations 2-2 and 2-3 were estimated using Program PLR, "Multiple Linear Regression" (Reference 5). Output was obtained to determine the linear (Equation 2-2) and the second order (Equation 2-3) fits for all RDF characteristics measured. To determine if the second order model is more appropriate, the hypothesis

$H_o: B_{ij}=0$ for all i and j (Equation 3-1)

versus

$H_i: B_{ij} \neq 0$ for some i and j (Equation 3-2) was tested. The application of this regression analyses is the development of predictive equations which can be used to estimate the value of each RDF characteristic by applying refuse composition to the equation.

SECTION 4.0
TEST RESULTS

4.1 INTRODUCTION

This section presents the results of all tests for quantifying the influence on RDF characteristics of equipment, moisture, and composition. Table 4-1 is a summary of the controlled and independent variable conditions for each test. The remaining data tables are organized according to each dependent variable (RDF characteristic). Therefore, all the replicate results obtained for any one RDF characteristic, whether from the equipment, moisture, or composition evaluation, can be found on one table.

4.2 PRESENTATION AND ANALYSIS OF FIELD DATA

4.2.1 Results of System Operating Parameter Tests

Pellets were produced under each of the four possible combinations of hammermill grids and pellet mill dies while maintaining moisture and composition as controlled variables (as discussed in detail in Section 3.1). The third (lowest) data block of Table 4-1 presents a summary of the specific test conditions under which these evaluations were actually performed.

The data resulting from the analysis of the RDF-3 and RDF-5 physical characteristics are presented in the third block of each RDF characteristic summary data table (Tables 4-2 through 4-18).

The moisture content of the RDF-3 averaged 15 percent (Table 4-2); the RDF-5 produced (Table 4-5) averaged 11.9 percent. This represents an average feedstock moisture loss of 3.5 percent due to processing through the pellet mill and pellet cooler.

To establish which RDF characteristics (dependent variables) changed significantly in response to the independent variable (operating conditions), a one-tailed Student's t test at a 95 percent confidence level was performed. Only the characteristics of pellet density (Table 4-7), water absorption (Table 4-8), and fines generation (Table 4-15) showed a significant response to changes in equipment. Table 4-19 lists these characteristics with their resultant values in the descending order of pellet quality. No significant difference could be established between pellet densities produced in Runs 1 and 2, but there were significant differences between the values for all other characteristics. This method of statistical ranking made it possible to determine and, therefore, select the best set of system operating parameters to use for the subsequent tests.

TABLE 4-1. SUMMARY OF EXPERIMENTAL INDEPENDENT VARIABLES AND THEIR RESPECTIVE VALUES

COMPOSITION EVALUATION TEST CONDITIONS

RUN #	RDF-3 H2O %	SHREDDER GRID inch	PELLET DIE inch	COMPONENTS Paper %	Plastic %	Organics %	Glass %	Inerts %
1	15.4	2x1.5	0.5	80	5	10	0	5
2	15.1	2x1.5	0.5	80	5	10	5	0
3	14.3	2x1.5	0.5	50	15	30	5	0
4	14.0	2x1.5	0.5	50	15	20	10	5
5	14.3	2x1.5	0.5	75	15	10	0	0
6	14.9	2x1.5	0.5	75	5	10	10	0
7	15.0	2x1.5	0.5	70	5	10	10	5
8	13.7	2x1.5	0.5	70	15	10	0	5
9	14.1	2x1.5	0.5	65	15	10	10	0
10	15.8	2x1.5	0.5	65	5	30	0	0
11	14.1	2x1.5	0.5	60	15	10	10	5
12	16.0	2x1.5	0.5	60	5	30	0	5
13	14.7	2x1.5	0.5	55	15	30	0	0
14	16.3	2x1.5	0.5	55	5	30	10	0
15	15.5	2x1.5	0.5	50	15	30	0	5
16	18.4	2x1.5	0.5	50	5	30	10	5
17	12.6	2x1.5	0.5	80	10	10	0	0
18	13.7	2x1.5	0.5	80	5	15	0	0
19	14.7	2x1.5	0.5	50	10	30	10	0
20	13.6	2x1.5	0.5	50	15	25	10	0
21	11.8	2x1.5	0.5	65	14	17	3	1
MOISTURE EVALUATION TEST CONDITIONS								
1	14.3	2x1.5	0.5	65	14	17	3	1
2	16.5	2x1.5	0.5	65	14	17	3	1
3	20.1	2x1.5	0.5	65	14	17	3	1
4	11.8	2x1.5	0.5	65	14	17	3	1
EQUIPMENT EVALUATION TEST CONDITIONS								
1	15.7	2X1.0	0.75	65	14	17	3	1
2	17.8	2X1.0	0.5	65	14	17	3	1
3	13.4	2x1.5	0.75	65	14	17	3	1
4	14.9	2x1.5	0.5	65	14	17	3	1

TABLE 4-2. RDF-3 MOISTURE ANALYSIS RESULTS (percent)

COMPOSITION EVALUATION DATA											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	15.4	15.3	14.8	14.5	14.4						14.9	0.41	15.4	14.4	1.0
2	15.1	14.6	14.7	15.1	14.3						14.8	0.32	15.1	14.3	0.9
3	14.3	14.3	14.2	14.1	13.9						14.2	0.16	14.3	13.9	0.5
4	14.0	14.2	13.5	13.7	13.5						13.8	0.28	14.2	13.5	0.7
5	14.3	13.4	13.9	13.3	13.9						13.8	0.35	14.3	13.3	1.0
6	14.9	14.6	14.7	14.7	14.5						14.7	0.14	14.9	14.5	0.4
7	15.0	15.2	15.7	15.2	15.2						15.3	0.25	15.7	15.0	0.7
8	13.7	13.7	14.3	13.9	13.1						13.7	0.36	14.3	13.1	1.1
9	14.1	13.7	13.9	14.2	14.4						14.1	0.23	14.4	13.7	0.6
10	15.8	15.6	15.8	15.8	16.1						15.8	0.16	16.1	15.6	0.5
11	14.1	14.1	14.1	13.4	14.7						14.1	0.42	14.7	13.4	1.3
12	16.0	15.8	15.8	16.2	16.1						16.0	0.16	16.2	15.8	0.4
13	14.7	14.5	14.9	14.5	14.4						14.6	0.18	14.9	14.4	0.5
14	16.3	16.3	16.1	15.7	16.0						16.1	0.24	16.3	15.7	0.6
15	15.5	15.1	16.1	16.3	16.4						15.9	0.50	16.4	15.1	1.3
16	18.4	18.1	17.6	18.3	18.7						18.2	0.35	18.7	17.6	1.1
17	12.6	12.7	13.1	13.3	13.2						13.0	0.26	13.3	12.6	0.6
18	13.7	13.7	14.1	13.8	13.7						13.8	0.18	14.1	13.7	0.5
19	14.7	14.4	14.6	14.1	14.3						14.4	0.23	14.7	14.1	0.7
20	13.6	13.8	14.1	14.1	14.2						14.0	0.22	14.2	13.6	0.6
21	11.8	11.4	12.1	11.3	12.2						11.8	0.36	12.2	11.3	0.9
MOISTURE EVALUATION DATA															
1	14.3	14.4	14.7	14.0	14.3						14.3	0.22	14.7	14.0	0.7
2	16.5	16.5	15.9	16.9	16.6						16.5	0.32	16.9	15.9	1.0
3	21.2	19.9	20.4	20.2	18.8						20.1	0.78	21.2	18.8	2.4
4	11.8	11.4	12.1	11.3	12.2						11.8	0.36	12.2	11.3	0.9
EQUIPMENT EVALUATION DATA															
1	17.2	15.9	14.3	13.7	13.7	16.7	16.4	16.4	15.9	16.4	15.7	1.21	17.2	13.7	3.5
2	17.8	17.9	17.5	18.2	17.8	17.3	17.7	17.9	17.7	17.8	17.8	0.23	18.2	17.3	0.9
3	13.4	13.3	13.6								13.4	0.12	13.6	13.3	0.3
4	14.9	14.8	14.7	15.0							14.9	0.11	15.0	14.7	0.3

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	18.2	20.1	17.8
min	11.8	11.8	13.4
range	6.5	8.3	4.3

TABLE 4-3. RDF-3 SIZE ANALYSIS RESULTS (mm)

COMPOSITION EVALUATION DATA							ANALYTICAL REPLICATE STATISTICS				
	RUN #	------ANALYTICAL REPLICATES----					mean	std	max	min	range
	1	15	14	15	15		14.8	0.43	15.0	14.0	1.0
	2	13	14	13	13		13.3	0.43	14.0	13.0	1.0
	3	15	16	15	18	16	16.0	1.10	18.0	15.0	3.0
	4	13	14	14	13		13.5	0.50	14.0	13.0	1.0
	5	14	14	15	14		14.3	0.43	15.0	14.0	1.0
	6	14	14	14	14		14.0	0.00	14.0	14.0	0.0
	7	14	14	13	14		13.8	0.43	14.0	13.0	1.0
	8	15	16	16	15		15.5	0.50	16.0	15.0	1.0
	9	15	15	15	16		15.3	0.43	16.0	15.0	1.0
	10	16	16	14	15		15.3	0.83	16.0	14.0	2.0
	11	16	14	14	14	14	14.4	0.80	16.0	14.0	2.0
	12	14	14	13			13.7	0.47	14.0	13.0	1.0
	13	14	14	14			14.0	0.00	14.0	14.0	0.0
	14	12	13	13			12.7	0.47	13.0	12.0	1.0
	15	16	16	15			15.7	0.47	16.0	15.0	1.0
	16										
	17	16	16	17	17		16.5	0.50	17.0	16.0	1.0
	18	16	15	16	15		15.5	0.50	16.0	15.0	1.0
	19	15	15	16	16		15.5	0.50	16.0	15.0	1.0
	20	16	16	14	15		15.3	0.83	16.0	14.0	2.0
MOISTURE EVALUATION DATA											
6.4%	A	13.0	14.0	14.0	14.0	13.0	13.6	0.49	14.0	13.0	1.0
17.4%	B	14.0	14.0	14.0	14.0	15.0	14.2	0.40	15.0	14.0	1.0
EQUIPMENT EVALUATION DATA											
	1										
1.0 in	2	14.0	14.0	14.0	14.0	15.0	14.2	0.40	15.0	14.0	1.0
1.5 in	3	20.0	18.0	19.0	17.0	17.0	18.2	1.17	20.0	17.0	3.0
	4										

	SUMMARY STATISTICS FOR EACH EVALUATION		
	COMPOSITION	MOISTURE	EQUIPMENT
max	16.5	14.2	18.2
min	12.7	13.6	14.2
range	3.8	0.6	4.0

TABLE 4-4. RDF-3 BULK DENSITY ANALYSIS RESULTS

RUN #	BULK DENSITY
1	3.1
2	3.5
3	3.6
4	3.8
5	3.9
6	3.4
7	3.4
8	3.4
9	3.4
10	3.6
11	3.5
12	3.8
13	3.1
14	3.7
15	3.0
16	
17	2.7
18	2.5
19	3.6
20	3.7
max	3.9
min	2.5
range	1.4

TABLE 4-5. RDF-5 MOISTURE ANALYSIS RESULTS (percent)

RUN #	ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS				
											mean	std	max	min	range
COMPOSITION EVALUATION DATA															
1	10.3	10.2	10.3	10.5	10.1						10.3	0.13	10.5	10.1	0.4
2	10.8	10.9	10.8	10.8	10.7						10.8	0.06	10.9	10.7	0.2
3	10.9	10.9	10.9	11.0	11.0						10.9	0.05	11.0	10.9	0.1
4	10.2	10.1	10.1	10.1	10.2						10.1	0.05	10.2	10.1	0.1
5	10.7	10.8	10.7	10.9	10.6						10.7	0.10	10.9	10.6	0.3
6	10.4	10.4	10.5	10.4	10.4						10.4	0.04	10.5	10.4	0.1
7	10.0	9.7	9.9	10.0	10.2						10.0	0.16	10.2	9.7	0.5
8	9.5	9.6	9.5	9.6	9.5						9.5	0.05	9.6	9.5	0.1
9	9.8	9.7	9.6	9.4	9.4						9.6	0.16	9.8	9.4	0.4
10	11.4	11.4	11.5	11.5	11.4						11.4	0.05	11.5	11.4	0.1
11	9.6	9.5	9.5	9.6	9.6						9.6	0.05	9.6	9.5	0.1
12	10.7	11.2	11.0	10.8	10.8						10.9	0.18	11.2	10.7	0.5
13	10.6	10.6	10.4	10.3	10.3						10.4	0.14	10.6	10.3	0.3
14	11.2	11.3	11.3	11.2	11.2						11.2	0.05	11.3	11.2	0.1
15	10.8	10.9	11.0	10.9	11.0						10.9	0.07	11.0	10.8	0.2
16	13.0	13.1	13.2	12.9	12.7						13.0	0.17	13.2	12.7	0.5
17	9.7	9.9	9.7	9.7	9.8						9.8	0.08	9.9	9.7	0.2
18	10.3	10.3	10.2	10.2	10.4						10.3	0.07	10.4	10.2	0.2
19	10.4	10.4	10.4	10.3	10.4						10.4	0.04	10.4	10.3	0.1
20	11.1	11.1	11.0	11.1	10.9						11.0	0.08	11.1	10.9	0.2
21	8.6	8.5	8.7	8.6	8.8						8.6	0.10	8.8	8.5	0.3
MOISTURE EVALUATION DATA															
1	10.4	10.6	10.6	10.7	10.5						10.6	0.11	10.7	10.4	0.3
2	11.7	11.8	11.9	11.9	11.6						11.8	0.12	11.9	11.6	0.3
3	15.7	15.6	15.5	15.5	15.8						15.6	0.12	15.8	15.5	0.3
4	8.6	8.5	8.7	8.6	8.8						8.7	0.09	8.8	8.5	0.3
EQUIPMENT EVALUATION DATA															
1	14.5	14.5	14.5	14.3	14.2	14.3	14.3				14.4	0.12	14.5	14.2	0.3
2	14.1	14.3	14.2	14.2	14.2	14.2	14.0	14.4	14.0	14.0	14.2	0.13	14.4	14.0	0.4
3	8.3	8.3	8.5	8.3	8.3						8.3	0.08	8.5	8.3	0.2
4	10.7	10.6	10.6	10.6	10.6	10.8	10.6	10.8	10.8	10.9	10.7	0.11	10.9	10.6	0.3

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	13.0	15.6	14.4
min	8.6	8.7	8.3
range	4.3	6.9	6.0

TABLE 4-6. RDF-5 BULK DENSITY ANALYSIS RESULTS (lb/cf)

RUN #	ANALYTICAL REPLICATES																mean	std	max	min	range
COMPOSITION EVALUATION DATA																					
1	44.0	44.6	44.4	43.9	43.9	43.9	43.6	43.6	43.1	42.7							43.8	0.53	44.6	42.7	1.9
2	43.9	44.4	44.0	44.3	43.9	44.0	44.0	43.3	42.9	43.0							43.8	0.49	44.4	42.9	1.5
3	39.1	40.0	39.7	37.9	37.6	38.6	38.1	38.0	37.4	38.9							38.5	0.84	40.0	37.4	2.6
4	41.7	40.4	40.7	40.6	39.6	39.6	39.6	39.6	39.1	39.0							40.0	0.80	41.7	39.0	2.7
5	40.0	40.4	41.0	39.9	40.1	40.1	40.0	39.4	40.1	39.9							40.1	0.39	41.0	39.4	1.6
6	46.6	46.0	46.1	45.7	45.6	45.3	45.9	46.0	46.1	45.4							45.9	0.36	46.6	45.3	1.3
7	45.6	46.0	45.6	44.7	44.4	43.9	43.6	44.6	44.0	43.7							44.6	0.82	46.0	43.6	2.4
8	45.4	44.0	43.1	42.4	43.0	42.6	42.6	42.3	41.4	43.0							43.0	1.02	45.4	41.4	4.0
9	41.3	42.1	42.1	41.3	41.3	40.9	40.4	40.0	39.6	39.6							40.9	0.88	42.1	39.6	2.5
10	43.3	43.0	42.1	42.3	42.3	42.9	43.1	42.9	43.0	42.1							42.7	0.43	43.3	42.1	1.2
11	42.4	42.0	41.6	41.0	40.4	40.6	39.0	40.0	39.7	40.1							40.7	1.02	42.4	39.0	3.4
12	43.1	42.6	42.7	42.8	42.1	42.4	42.4	42.5	42.1	41.7							42.4	0.38	43.1	41.7	1.4
13	41.4	40.3	40.5	39.7	39.5	39.5	39.6	37.5	38.0	37.8							39.4	1.20	41.4	37.5	3.9
14	45.1	43.4	42.8	42.6	43.4	42.6	42.1	42.3	42.5	42.0							42.9	0.87	45.1	42.0	3.1
15	41.9	42.4	40.5	38.9	40.4	37.8	38.3	38.2	37.8	37.9							39.4	1.67	42.4	37.8	4.6
16	43.1	42.4	42.4	41.4	42.9	41.2	41.2	41.7	40.7	40.4							41.7	0.87	43.1	40.4	2.7
17	43.1	42.4	43.0	42.7	42.7	43.9	43.3	42.3	42.9	42.6							42.9	0.45	43.9	42.3	1.6
18	44.4	44.1	44.9	45.4	44.1	43.3	44.1	44.6	44.4	44.4							44.4	0.53	45.4	43.3	2.1
19	42.4	42.6	42.0	43.0	41.4	42.7	42.7	41.1	41.0	41.1							42.0	0.74	43.0	41.0	2.0
20	40.3	39.4	39.0	39.7	39.7	39.7	40.1	39.0	39.7	39.6							39.6	0.39	40.3	39.0	1.3
21	41.7	42.0	42.0	42.9	41.0	41.7	42.1	41.1	41.1	40.9							41.7	0.60	42.9	40.9	2.0
MOISTURE EVALUATION DATA																					
1	40.0	39.3	39.3	39.7	42.7	41.6	41.7	39.7	41.3								40.6	1.18	42.7	39.3	3.4
2	38.4	38.4	38.3	39.6	39.7	39.7	40.3	39.7	39.0	39.0	39.6						39.2	0.63	40.3	38.3	2.0
3	39.1	38.7	35.9	38.6	36.4	36.9	37.3	38.0	36.7	37.7							37.5	1.03	39.1	35.9	3.3
4	41.7	42.0	42.0	42.9	41.0	41.7	42.1	41.1	41.1	40.9							41.7	0.59	42.9	40.9	2.0
EQUIPMENT EVALUATION DATA																					
1	37.0	34.6	36.9	35.3	33.1	34.3	32.3	36.3	33.6	33.0	33.3	36.4	35.3	33.4			34.6	1.52	37.0	32.3	4.7
2	37.6	37.7	38.4	37.7	38.7	37.9	38.0	37.6	37.6	37.4	37.1	38.3	37.4	36.3	37.4	36.7	37.6	0.59	38.7	36.3	2.4
3	34.6	32.9	32.7	31.7	31.9	31.4	31.9	31.1									32.3	1.04	34.6	31.1	3.5
4	40.4	39.9	40.6	40.0	39.0	39.3	39.4	38.7	37.4	41.7	42.1						39.9	1.28	42.1	37.4	4.7

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	45.9	41.7	39.9
min	38.5	37.5	32.3
range	7.3	4.1	7.6

TABLE 4-7. RDF-5 PELLET DENSITY ANALYSIS RESULT (g/cc)

RUN #	ANALYTICAL REPLICATES								ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
COMPOSITION EVALUATION DATA													
1	1.35	1.37	1.38	1.39	1.36				1.37	0.014	1.39	1.35	0.04
2	1.35	1.37	1.38	1.35	1.36				1.36	0.012	1.38	1.35	0.03
3	1.27	1.31	1.30	1.33	1.33				1.31	0.022	1.33	1.27	0.06
4	1.30	1.33	1.31	1.32	1.34				1.32	0.014	1.34	1.30	0.04
5	1.33	1.30	1.[illegible]	1.28	1.31				1.31	0.019	1.33	1.28	0.05
6	1.43	1.40	1.39	1.42	1.43				1.41	0.016	1.43	1.39	0.04
7	1.44	1.41	1.43	1.41	1.43				1.42	0.012	1.44	1.41	0.03
8	1.36	1.39	1.40	1.37	1.35				1.37	0.019	1.40	1.35	0.05
9	1.34	1.34	1.34	1.37	1.37				1.35	0.015	1.37	1.34	0.03
10	1.36	1.36	1.36	1.33	1.36				1.35	0.012	1.36	1.33	0.03
11	1.36	1.39	1.37	1.37	1.37				1.37	0.010	1.39	1.36	0.03
12	1.34	1.38	1.35	1.35	1.33				1.35	0.017	1.38	1.33	0.05
13	1.30	1.32	1.30	1.32	1.32				1.31	0.010	1.32	1.30	0.02
14	1.34	1.35	1.35	1.32	1.33				1.34	0.012	1.35	1.32	0.03
15	1.30	1.28	1.30	1.29	1.29				1.29	0.007	1.30	1.28	0.02
16	1.41	1.41	1.40	1.40	1.39				1.40	0.007	1.41	1.39	0.02
17	1.31	1.34	1.35	1.37	1.35				1.34	0.020	1.37	1.31	0.06
18	1.35	1.36	1.35	1.36	1.37				1.36	0.007	1.37	1.35	0.02
19	1.33	1.38	1.37	1.35	1.37				1.36	0.018	1.38	1.33	0.05
20	1.37	1.35	1.36	1.37	1.35				1.36	0.009	1.37	1.35	0.02
21	1.32	1.36	1.32	1.34	1.33				1.33	0.015	1.36	1.32	0.04
MOISTURE EVALUATION DATA													
1	1.32	1.29	1.28	1.29	1.32				1.30	0.017	1.32	1.28	0.04
2	1.28	1.30	1.32	1.32	1.30				1.30	0.016	1.32	1.28	0.05
3	1.29	1.29	1.29	1.29	1.28				1.29	0.004	1.29	1.28	0.01
4	1.32	1.36	1.32	1.34	1.33				1.34	0.014	1.36	1.32	0.04
EQUIPMENT EVALUATION DATA													
1	1.16	1.16	1.18	1.20	1.20				1.18	0.018	1.20	1.16	0.04
2	1.21	1.20	1.20	1.21	1.20				1.20	0.005	1.21	1.20	0.01
3	1.15	1.13	1.10	1.12	1.13				1.13	0.016	1.15	1.10	0.05
4	1.27	1.29	1.28	1.28	1.21	1.28	1.27	1.28	1.27	0.023	1.29	1.21	0.08

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	1.42	1.34	1.27
min	1.29	1.29	1.13
range	0.13	0.05	0.14

TABLE 4-8. RDF-5 WATER ABSORPTION ANALYSIS RESULTS (percent weight gain)

COMPOSITION EVALUATION DATA											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	14.0	13.7	13.6	13.9	14.2						13.9	0.21	14.2	13.6	0.6
2	15.8	17.9	16.5	17.7	17.9						17.2	0.86	17.9	15.8	2.1
3	21.2	28.0	23.5	24.4	26.3						24.7	2.33	28.0	21.2	6.8
4	15.9	16.9	19.1	15.1	15.3						16.5	1.46	19.1	15.1	4.0
5	16.3	17.7	14.5	15.6	15.0						15.8	1.12	17.7	14.5	3.2
6	18.3	18.9	19.2	19.6	19.4						19.1	0.45	19.6	18.3	1.3
7	17.6	16.1	16.3	15.3	17.1						16.5	0.80	17.6	15.3	2.3
8	22.8	22.5	23.1	22.6	23.6						22.9	0.40	23.6	22.5	1.1
9	18.1	19.4	17.6	15.1	19.8						18.0	1.66	19.8	15.1	4.7
10	26.5	27.9	25.4	26.3	25.9						26.4	0.84	27.9	25.4	2.5
11	17.8	16.8	16.1	21.2	17.3						17.8	1.77	21.2	16.1	5.1
12	15.6	15.8	17.4	16.8	16.9						16.5	0.69	17.4	15.6	1.8
13	13.3	17.8	15.7	17.7	15.5						16.0	1.66	17.8	13.3	4.5
14	18.1	16.3	15.7	18.2	18.0						17.3	1.05	18.2	15.7	2.5
15	20.7	26.1	24.1	24.0	20.0						23.0	2.29	26.1	20.0	6.1
16	17.4	17.9	18.3	15.6	17.8						17.4	0.94	18.3	15.6	2.7
17	20.3	19.8	19.6	21.4	19.4						20.1	0.72	21.4	19.4	2.0
18	21.0	20.5	21.0	19.1	20.7						20.5	0.71	21.0	19.1	1.9
19	21.2	20.4	22.2	20.9	20.5						21.0	0.65	22.2	20.4	1.8
20	24.6	27.4	25.0	26.0	25.0						25.6	1.01	27.4	24.6	2.8
21	9.1	9.9	9.2	9.4	7.3						9.0	0.88	9.9	7.3	2.6
MOISTURE EVALUATION DATA															
1	14.6	12.8	13.1	13.0	12.9						13.3	0.67	14.6	12.8	1.8
2	16.9	17.2	21.2	17.9	18.8						18.4	1.54	21.2	16.9	4.3
3	22.4	20.3	20.9	21.3	23.3						21.7	1.05	23.3	20.3	2.9
4	9.1	9.9	9.2	9.4	7.3						9.0	0.88	9.9	7.3	2.6
EQUIPMENT EVALUATION DATA															
1	35.4	35.0	34.8	36.3	37.6						35.8	1.02	37.6	34.8	2.8
2	22.1	22.0	24.0	24.8	24.9						23.6	1.26	24.9	22.0	2.9
3	44.8	51.0	51.6	56.6	51.3						51.1	3.75	56.6	44.8	11.8
4	21.4	21.0	19.5	20.8	18.1	20.1	17.6	18.1	17.3	17.9	19.2	1.48	21.4	17.3	4.1

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	26.4	21.7	51.1
min	9.0	9.0	19.2
range	17.4	12.7	31.9

TABLE 4-9. RDF-5 SIZE ANALYSIS RESULTS FOR AS-PRODUCED PELLETS (Initial size/mm)

COMPOSITION EVALUATION DATA											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	38.0	42.0	42.0	40.0	40.0						40.4	1.50	42.0	38.0	4.0
2	37.0	36.0	37.0	39.0	39.0						37.6	1.20	39.0	36.0	3.0
3	37.0	37.0	38.0	37.0	37.0						37.2	0.40	38.0	37.0	1.0
4	43.0	47.0	45.0	43.0	40.0						43.6	2.33	47.0	40.0	7.0
5	40.0	39.0	43.0	40.0	41.0						40.6	1.36	43.0	39.0	4.0
6	37.0	37.0	36.0	37.0	40.0						37.4	1.36	40.0	36.0	4.0
7	45.0	45.0	40.0	42.0	42.0						42.8	1.94	45.0	40.0	5.0
8	37.0	35.0	34.0	37.0	35.0						35.6	1.20	37.0	34.0	3.0
9	46.0	48.0	47.0	46.0	44.0						46.2	1.33	48.0	44.0	4.0
10	30.0	30.0	32.0	32.5	32.5						31.4	1.16	32.5	30.0	2.5
11	42.0	47.0	42.0	42.0	44.0						43.4	1.96	47.0	42.0	5.0
12	32.0	37.0	36.0	35.0	36.0						35.2	1.72	37.0	32.0	5.0
13	44.0	42.0	40.0	37.0	40.0						40.6	2.33	44.0	37.0	7.0
14	39.0	42.0	40.0	40.0	38.0						39.8	1.33	42.0	38.0	4.0
15	36.0	35.0	37.0	35.0	35.0						35.6	0.80	37.0	35.0	2.0
16	39.0	36.0	39.0	38.0	38.0						38.0	1.10	39.0	36.0	3.0
17	37.0	37.0	40.0	39.0	37.0						38.0	1.26	40.0	37.0	3.0
18	38.0	36.0	37.0	36.0	39.0						37.2	1.17	39.0	36.0	3.0
19	39.0	40.0	37.0	42.0	40.0						39.6	1.62	42.0	37.0	5.0
20	43.0	41.0	39.0	44.0	42.0						41.8	1.72	44.0	39.0	5.0
21	38.0	42.0	42.0	39.0	42.0						40.6	1.74	42.0	38.0	4.0
MOISTURE EVALUATION DATA															
1	34.0	34.0	37.0	35.0	36.0						35.2	1.17	37.0	34.0	3.0
2	36.0	35.0	33.0	36.0	35.0						35.0	1.10	36.0	33.0	3.0
3	32.0	32.0	35.0	34.0	33.0						33.2	1.17	35.0	32.0	3.0
4	38.0	42.0	42.0	39.0	42.0						40.6	1.74	42.0	38.0	4.0
EQUIPMENT EVALUATION DATA															
1	22.5	18.0	22.0	20.5	22.0						21.0	1.64	22.5	18.0	4.5
2	27.5	27.5	30.0	32.5	27.5						29.0	2.00	32.5	27.5	5.0
3	22.5	23.0	23.0								22.8	0.24	23.0	22.5	0.5
4	32.0	27.5	28.0	32.5	30.0	31.0	28.0	30.0	26.0	26.0	29.1	2.22	32.5	26.0	6.5

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	46.2	40.6	29.1
min	31.4	33.2	21.0
range	14.8	7.4	8.1

TABLE 4-10. RDF-5 SIZE ANALYSIS RESULTS FOR MECHANICALLY-TUMBLED PELLETS (final size/mm)

COMPOSITION EVALUATION DATA 15 Minutes											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	32.0	31.0	31.0	31.0	29.0						30.8	0.98	32.0	29.0	3.0
2	30.0	29.0	28.0	29.0	30.0						29.2	0.75	30.0	28.0	2.0
3	32.5	30.0	32.5	30.0	30.0						31.0	1.22	32.5	30.0	2.5
4	37.0	38.0	37.0	35.0	37.0						36.8	0.98	38.0	35.0	3.0
5	38.0	33.0	35.0	32.0	32.0						34.0	2.28	38.0	32.0	6.0
6	30.0	30.0	27.0	31.0	30.0						29.6	1.36	31.0	27.0	4.0
7	33.0	34.0	34.0	32.5	36.0						33.9	1.20	36.0	32.5	3.5
8	30.0	29.0	28.0	28.0	29.0						28.8	0.75	30.0	28.0	2.0
9	36.0	41.0	40.0	40.0	38.0						39.0	1.79	41.0	36.0	5.0
10	25.0	25.0	26.0	25.0	25.0						25.2	0.40	26.0	25.0	1.0
11	34.0	37.0	32.0	32.0	34.0						33.8	1.83	37.0	32.0	5.0
12	27.0	30.0	30.0	28.0	27.0						28.4	1.36	30.0	27.0	3.0
13	35.0	35.0	34.0	32.0	33.0						33.8	1.17	35.0	32.0	3.0
14	30.0	32.0	30.0	32.0	32.0						31.2	0.98	32.0	30.0	2.0
15	27.0	30.0	31.0	27.0	28.0						28.6	1.62	31.0	27.0	4.0
16	35.0	30.0	31.0	31.0	31.0						31.6	1.74	35.0	30.0	5.0
17	30.0	30.0	33.0	32.0	30.0						31.0	1.26	33.0	30.0	3.0
18	32.0	29.0	31.0	29.0	28.0						29.8	1.47	32.0	28.0	4.0
19	32.0	31.0	32.0	31.0	32.0						31.6	0.49	32.0	31.0	1.0
20	33.0	32.0	30.0	32.0	33.0						32.0	1.10	33.0	30.0	3.0
21	31.0	35.0	32.0	33.0	34.0						33.0	1.41	35.0	31.0	4.0
MOISTURE EVALUATION DATA 15 Minutes															
1	27.0	28.0	27.0	30.0	28.0						28.0	1.10	30.0	27.0	3.0
2	30.0	28.0	28.0	31.0	30.0						29.4	1.20	31.0	28.0	3.0
3	27.0	27.0	29.0	27.0	27.0						27.4	0.80	29.0	27.0	2.0
4	31.0	35.0	32.0	33.0	34.0						33.0	1.41	35.0	31.0	4.0
EQUIPMENT EVALUATION DATA 10 Minutes															
1	17.0	15.5	17.5	19.1	18.0						17.4	1.19	19.1	15.5	3.6
2	23.0	25.0	25.0	25.0	22.5						24.1	1.11	25.0	22.5	2.5
3	21.2	22.0	21.3								21.5	0.36	22.0	21.2	0.8
4	25.0	24.0	22.5	24.0	25.0	25.0	25.0	25.0	24.0	22.0	24.2	1.05	25.0	22.0	3.0

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	39.0	33.0	24.2
min	25.2	27.4	17.4
range	13.8	5.6	6.7

TABLE 4-11. RDF-5 SIZE DIFFERENCE BETWEEN AS-PRODUCED AND MECHANICALLY-TUMBLED PELLETS (initial size/final size/mm)

COMPOSITION EVALUATION DATA											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	6.0	11.0	11.0	9.0	11.0						9.6	1.96	11.0	6.0	5.0
2	7.0	7.0	9.0	10.0	9.0						8.4	1.20	10.0	7.0	3.0
3	4.5	7.0	5.5	7.0	7.0						6.2	1.03	7.0	4.5	2.5
4	6.0	9.0	8.0	8.0	3.0						6.8	2.14	9.0	3.0	6.0
5	2.0	6.0	8.0	8.0	9.0						6.6	2.50	9.0	2.0	7.0
6	7.0	7.0	9.0	6.0	10.0						7.8	1.47	10.0	6.0	4.0
7	12.0	11.0	6.0	9.5	6.0						8.9	2.50	12.0	6.0	6.0
8	7.0	6.0	6.0	9.0	6.0						6.8	1.17	9.0	6.0	3.0
9	10.0	7.0	7.0	6.0	6.0						7.2	1.47	10.0	6.0	4.0
10	5.0	5.0	6.0	7.5	7.5						6.2	1.12	7.5	5.0	2.5
11	8.0	10.0	10.0	10.0	10.0						9.6	0.80	10.0	8.0	2.0
12	5.0	7.0	6.0	7.0	9.0						6.8	1.33	9.0	5.0	4.0
13	9.0	7.0	6.0	5.0	7.0						6.8	1.33	9.0	5.0	4.0
14	9.0	10.0	10.0	8.0	6.0						8.6	1.50	10.0	6.0	4.0
15	9.0	5.0	6.0	8.0	7.0						7.0	1.41	9.0	5.0	4.0
16	4.0	6.0	8.0	7.0	7.0						6.4	1.36	8.0	4.0	4.0
17	7.0	7.0	7.0	7.0	7.0						7.0	0.00	7.0	7.0	0.0
18	6.0	7.0	6.0	7.0	11.0						7.4	1.85	11.0	6.0	5.0
19	7.0	9.0	5.0	11.0	8.0						8.0	2.00	11.0	5.0	6.0
20	10.0	9.0	9.0	12.0	9.0						9.8	1.17	12.0	9.0	3.0
21	7.0	7.0	10.0	6.0	8.0						7.6	1.36	10.0	6.0	4.0
MOISTURE EVALUATION DATA															
1	7.0	6.0	10.0	5.0	8.0						7.2	1.72	10.0	5.0	5.0
2	6.0	7.0	5.0	5.0	5.0						5.6	0.80	7.0	5.0	2.0
3	5.0	5.0	6.0	7.0	6.0						5.8	0.75	7.0	5.0	2.0
4	7.0	7.0	10.0	6.0	8.0						7.6	1.36	10.0	6.0	4.0
EQUIPMENT EVALUATION DATA															
1	5.5	2.5	4.5	1.4	4.0						3.6	1.46	5.5	1.4	4.1
2	4.5	2.5	5.0	7.5	5.0						4.9	1.59	7.5	2.5	5.0
3	1.3	1.0	1.7								1.3	0.29	1.7	1.0	0.7
4	7.0	3.5	5.5	8.5	5.0	6.0	3.0	5.0	2.0	4.0	5.0	1.84	8.5	2.0	6.5

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	9.8	7.6	5.0
min	6.2	5.6	1.3
range	3.6	2.0	3.6

TABLE 4-12. RDF-5 SIZE STABILITY FUNCTION (final size ÷ initial size * 100)

COMPOSITION EVALUATION DATA 15 Minutes											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	84.2	73.8	73.8	77.5	72.5						76.4	4.26	84.2	72.5	11.7
2	81.1	80.6	75.7	74.4	76.9						77.7	2.66	81.1	74.4	6.7
3	87.8	81.1	85.5	81.1	81.1						83.3	2.84	87.8	81.1	6.8
4	86.0	80.9	82.2	81.4	92.5						84.6	4.35	92.5	80.9	11.6
5	95.0	84.6	81.4	80.0	78.0						83.8	5.99	95.0	78.0	17.0
6	81.1	81.1	75.0	83.8	75.0						79.2	3.56	83.8	75.0	8.8
7	73.3	75.6	85.0	77.4	85.7						79.4	5.04	85.7	73.3	12.4
8	81.1	82.9	82.4	75.7	82.9						81.0	2.72	82.9	75.7	7.2
9	78.3	85.4	85.1	87.0	86.4						84.4	3.15	87.0	78.3	8.7
10	83.3	83.3	81.3	76.9	76.9						80.4	2.90	83.3	76.9	6.4
11	81.0	78.7	76.2	76.2	77.3						77.9	1.80	81.0	76.2	4.8
12	84.4	81.1	83.3	80.0	75.0						80.8	3.27	84.4	75.0	9.4
13	79.5	83.3	85.0	86.5	82.5						83.4	2.36	86.5	79.5	6.9
14	76.9	76.2	75.0	80.0	84.2						78.5	3.31	84.2	75.0	9.2
15	75.0	85.7	83.8	77.1	80.0						80.3	3.99	85.7	75.0	10.7
16	89.7	83.3	79.5	81.6	81.6						83.1	3.52	89.7	79.5	10.3
17	81.1	81.1	82.5	82.1	81.1						81.6	0.60	82.5	81.1	1.4
18	84.2	80.6	83.8	80.6	71.8						80.2	4.47	84.2	71.8	12.4
19	82.1	77.5	86.5	73.8	80.0						80.0	4.26	86.5	73.8	12.7
20	76.7	78.0	76.9	72.7	78.6						76.6	2.05	78.6	72.7	5.8
21	81.6	83.3	76.2	84.6	81.0						81.3	2.88	84.6	76.2	8.4
MOISTURE EVALUATION DATA 15 Minutes															
1	79.4	82.4	73.0	85.7	77.8						79.6	4.29	85.7	73.0	12.7
2	83.3	80.0	84.8	86.1	85.7						84.0	2.22	86.1	80.0	6.1
3	84.4	84.4	82.9	79.4	81.8						82.6	1.85	84.4	79.4	5.0
4	81.6	83.3	76.2	84.6	81.0						81.3	2.88	84.6	76.2	8.4
EQUIPMENT EVALUATION DATA 10 Minutes															
1	75.6	86.1	79.5	93.2	81.8						83.2	6.03	93.2	75.6	17.6
2	83.6	90.9	83.3	76.9	81.8						83.3	4.49	90.9	76.9	14.0
3	94.2	95.7	92.6								94.2	1.24	95.7	92.6	3.0
4	78.1	87.3	80.4	73.8	83.3	80.6	89.3	83.3	92.3	84.6	83.3	5.16	92.3	73.8	18.5

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	84.6	84.0	94.2
min	76.4	79.6	83.2
range	8.2	4.4	10.9

TABLE 4-13. RDF-5 FINES CONTENT ANALYSIS RESULTS FOR AS-PRODUCED PELLETS (initial fines/percent by weight)

COMPOSITION EVALUATION DATA											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	0.3	0.3	0.2	0.2	0.3						0.3	0.05	0.3	0.2	0.1
2	0.6	0.5	0.5	0.5	0.5						0.5	0.04	0.6	0.5	0.1
3	0.9	0.7	0.7	1.0	1.0						0.9	0.14	1.0	0.7	0.3
4	0.3	0.4	0.3	0.4	0.4						0.4	0.05	0.4	0.3	0.1
5	0.7	0.7	0.6	0.6	0.6						0.6	0.05	0.7	0.6	0.1
6	0.6	0.2	0.3	0.3	0.3						0.3	0.14	0.6	0.2	0.4
7	0.4	0.4	0.4	0.5	0.5						0.4	0.05	0.5	0.4	0.1
8	0.7	0.6	0.6	0.6	0.7						0.6	0.05	0.7	0.6	0.1
9	0.2	0.2	0.4	0.3	0.3						0.3	0.07	0.4	0.2	0.2
10	0.7	0.9	0.9	0.8	0.7						0.8	0.09	0.9	0.7	0.2
11	0.3	0.2	0.3	0.3	0.3						0.3	0.04	0.3	0.2	0.1
12	0.3	0.3	0.4	0.4	0.4						0.4	0.05	0.4	0.3	0.1
13	0.5	0.8	0.5	0.8	0.6						0.6	0.14	0.8	0.5	0.3
14	0.8	0.2	0.6	0.4	0.7						0.5	0.22	0.8	0.2	0.6
15	0.9	0.7	0.8	1.0	0.6						0.8	0.14	1.0	0.6	0.4
16	0.7	0.7	0.6	0.7	0.7						0.7	0.04	0.7	0.6	0.1
17	0.3	0.4	0.3	0.4	0.4						0.4	0.05	0.4	0.3	0.1
18	0.4	0.4	0.4	0.5	0.6						0.5	0.08	0.6	0.4	0.2
19	0.8	0.5	0.5	0.6	0.6						0.6	0.11	0.8	0.5	0.3
20	0.7	0.8	0.6	0.3	0.7						0.6	0.17	0.8	0.3	0.5
21	0.4	0.6	0.4	0.7	0.6						0.5	0.12	0.7	0.4	0.3
MOISTURE EVALUATION DATA															
1	0.2	0.3	0.5	0.3	0.4						0.3	0.10	0.5	0.2	0.3
2	0.6	0.5	0.5	0.4	0.5						0.5	0.06	0.6	0.4	0.2
3	0.8	0.9	0.6	0.9	0.7						0.8	0.12	0.9	0.6	0.3
4	0.4	0.6	0.4	0.7	0.6						0.5	0.12	0.7	0.4	0.3
EQUIPMENT EVALUATION DATA															
1	0.8	0.8	0.7	0.8	0.5						0.7	0.12	0.8	0.5	0.3
2	1.1	1.3	0.6	0.6	1.1						0.9	0.29	1.3	0.6	0.7
3	2.5	2.0	2.5								2.3	0.24	2.5	2.0	0.5
4	0.1	0.6	1.0	0.5	0.5	0.4	0.5	0.2	0.5	1.0	0.5	0.28	1.0	0.1	0.9

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	0.9	0.8	2.3
min	0.3	0.3	0.5
range	0.6	0.4	1.8

TABLE 4-14. RDF-5 FINES CONTENT ANALYSIS RESULTS FOR MECHANICALLY-TUMBLED PELLETS (final fines/15-minute tumble)

RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
COMPOSITION EVALUATION DATA															
1	1.4	1.4	1.3	1.4	1.4						1.4	0.04	1.4	1.3	0.1
2	1.6	1.5	1.6	1.5	1.4						1.5	0.07	1.6	1.4	0.2
3	2.2	2.0	1.9	2.2	2.2						2.1	0.13	2.2	1.9	0.3
4	1.1	1.1	1.1	1.3	1.1						1.1	0.08	1.3	1.1	0.2
5	1.6	1.5	1.4	1.5	1.5						1.5	0.06	1.6	1.4	0.2
6	1.1	1.1	1.2	1.5	1.2						1.2	0.15	1.5	1.1	0.4
7	1.2	1.2	1.3	1.7	1.3						1.3	0.19	1.7	1.2	0.5
8	1.7	1.6	1.6	1.8	1.8						1.7	0.09	1.8	1.6	0.2
9	1.1	1.0	0.7	1.2	1.1						1.0	0.17	1.2	0.7	0.5
10	2.3	1.7	1.9	1.8	1.9						1.9	0.20	2.3	1.7	0.6
11	0.9	1.1	1.1	1.2	1.0						1.1	0.10	1.2	0.9	0.3
12	1.3	1.3	1.4	1.4	1.5						1.4	0.07	1.5	1.3	0.2
13	1.4	1.5	1.3	1.8	1.5						1.5	0.17	1.8	1.3	0.5
14	1.9	1.0	2.0	1.3	1.8						1.6	0.38	2.0	1.0	1.0
15	2.3	2.2	2.3	2.6	2.0						2.3	0.19	2.6	2.0	0.6
16	2.2	2.2	1.9	1.8	2.3						2.1	0.19	2.3	1.8	0.5
17	1.2	1.4	1.0	1.3	1.3						1.2	0.14	1.4	1.0	0.4
18	1.3	1.4	1.4	1.5	1.1						1.3	0.14	1.5	1.1	0.4
19	1.6	1.3	1.5	1.6	1.5						1.5	0.11	1.6	1.3	0.3
20	1.5	1.7	1.7	1.7	1.6						1.6	0.08	1.7	1.5	0.2
21	1.2	1.6	1.7	1.9	1.7						1.6	0.23	1.9	1.2	0.7
MOISTURE EVALUATION DATA															
1	1.3	1.3	1.4	1.4	1.5						1.4	0.07	1.5	1.3	0.2
2	1.4	1.6	1.4	1.3	1.5						1.4	0.10	1.6	1.3	0.3
3	2.0	2.2	2.0	2.0	2.0						2.0	0.08	2.2	2.0	0.2
4	1.2	1.6	1.7	1.9	1.7						1.6	0.23	1.9	1.2	0.7
EQUIPMENT EVALUATION DATA															
1	2.5	2.6	2.1	2.5	2.3						2.4	0.18	2.6	2.1	0.5
2	2.6	2.7	1.5	1.6	2.0						2.1	0.50	2.7	1.5	1.2
3	5.5	4.3	5.0								4.9	0.49	5.5	4.3	1.2
4	0.7	1.3	1.6	1.1	1.2	1.1	1.2	0.8	1.2	1.8	1.2	0.31	1.8	0.7	1.1

ANALYTICAL REPLICATE STATISTICS: mean, std, max, min, range

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	2.3	2.0	4.9
min	1.0	1.4	1.2
range	1.3	0.7	3.7

TABLE 4-15. RDF-5 FINES CONTENT DIFFERENCE BETWEEN AS-PRODUCED AND MECHANICALLY-TUMBLED PELLETS (final fines/initial fines/percent weight)

RUN #	ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
COMPOSITION EVALUATION DATA															
1	1.1	1.1	1.1	1.2	1.1						1.1	0.04	1.2	1.1	0.1
2	1.0	1.0	1.1	1.0	0.9						1.0	0.06	1.1	0.9	0.2
3	1.3	1.3	1.2	1.2	1.2						1.2	0.05	1.3	1.2	0.1
4	0.8	0.7	0.8	0.9	0.7						0.8	0.07	0.9	0.7	0.2
5	0.9	0.8	0.8	0.9	0.9						0.9	0.05	0.9	0.8	0.1
6	0.5	0.9	0.9	1.2	0.9						0.9	0.22	1.2	0.5	0.7
7	0.8	0.8	0.9	1.2	0.8						0.9	0.15	1.2	0.8	0.4
8	1.0	1.0	1.0	1.2	1.1						1.1	0.08	1.2	1.0	0.2
9	0.9	0.8	0.3	0.9	0.8						0.7	0.22	0.9	0.3	0.6
10	1.6	0.8	1.0	1.0	1.2						1.1	0.27	1.6	0.8	0.8
11	0.6	0.9	0.8	0.9	0.7						0.8	0.12	0.9	0.6	0.3
12	1.0	1.0	1.0	1.0	1.1						1.0	0.04	1.1	1.0	0.1
13	0.9	0.7	0.8	1.0	0.9						0.9	0.10	1.0	0.7	0.3
14	1.1	0.8	1.4	0.9	1.1						1.1	0.21	1.4	0.8	0.6
15	1.4	1.5	1.5	1.6	1.4						1.5	0.07	1.6	1.4	0.2
16	1.5	1.5	1.3	1.1	1.6						1.4	0.18	1.6	1.1	0.5
17	0.9	1.0	0.7	0.9	0.9						0.9	0.10	1.0	0.7	0.3
18	0.9	1.0	1.0	1.0	0.5						0.9	0.19	1.0	0.5	0.5
19	0.8	0.8	1.0	1.0	0.9						0.9	0.09	1.0	0.8	0.2
20	0.8	0.9	1.1	1.4	0.9						1.0	0.21	1.4	0.8	0.6
21	0.8	1.0	1.3	1.2	1.1						1.1	0.17	1.3	0.8	0.5
MOISTURE EVALUATION DATA															
1	1.1	1.0	0.9	1.1	1.1						1.0	0.08	1.1	0.9	0.2
2	0.8	1.1	0.9	0.9	1.0						0.9	0.10	1.1	0.8	0.3
3	1.2	1.3	1.4	1.1	1.3						1.3	0.10	1.4	1.1	0.3
4	0.8	1.0	1.3	1.2	1.1						1.1	0.17	1.3	0.8	0.5
EQUIPMENT EVALUATION DATA															
1	1.7	1.8	1.4	1.7	1.8						1.7	0.15	1.8	1.4	0.4
2	1.5	1.4	0.9	1.0	0.9						1.1	0.26	1.5	0.9	0.6
3	3.0	2.3	2.5								2.6	0.29	3.0	2.3	0.7
4	0.6	0.7	0.6	0.6	0.7	0.7	0.7	0.6	0.7	0.8	0.7	0.06	0.8	0.6	0.2

SUMMARY STATISTICS FOR EACH EVALUATION

	COMPOSITION	MOISTURE	EQUIPMENT
max	1.5	1.3	2.6
min	0.7	0.9	0.7
range	0.7	0.3	1.9

TABLE 4-16. RDF-5 SIZE ANALYSIS RESULTS FROM DROP SHATTER DURABILITY EVALUATION (mm)

RDF-5 INITIAL SIZE (mm)

EQUIPMENT EVALUATION DATA RUN #	10 Drops ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
1	21	20	21	20	23						21	0.9	23	20	3
2	28	29	31	30	33						30	1.6	33	28	5
3	23	23	24								23	0.7	24	23	2
4	30	29	29	31	28	27	28	31	26	30	29	1.6	31	26	5

RDF-5 FINAL SIZE (mm)

EQUIPMENT EVALUATION DATA RUN #	10 Drops ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
1	18	19	19	18	19						18	0	19	18	1
2	23	25	26	25	28						25	1	28	23	5
3	21	20	22								21	1	22	20	3
4	25	24	26	28	23	23	23	26	23	26	25	2	28	23	5

RDF-5 SIZE DIFFERENCE (Si-Sf) (mm)

EQUIPMENT EVALUATION DATA RUN #	10 Drops ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
1	3.3	1.5	2.2	2	4						2.6	0.91	4.0	1.5	2.5
2	5	3.8	5	5	5						4.8	0.48	5.0	3.8	1.2
3	2	3	2								2.3	0.47	3.0	2.0	1.0
4	5	5	3	3.5	5	4	5	5	3.5		4.3	0.78	5.0	3.0	2.0

TABLE 4-17. RDF-5 FINES CONTENT ANALYSIS RESULTS FOR DROP SHATTER DURABILITY EVALUATION (percent by weight as produced)

RDF-5 INITIAL FINES (% BY WEIGHT AS PRODUCED)

EQUIPMENT EVALUATION DATA RUN #	ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
1	0.6	1.0	0.8	0.7	0.7						0.8	0.1	1.0	0.6	0.4
2	0.8	1.0	0.7	0.8	0.8						0.8	0.1	1.0	0.7	0.3
3	2.4	2.2	1.7								2.1	0.3	2.4	1.7	0.7
4	0.4	0.8	0.7	0.4	0.5	0.8	1.0	0.2	0.7	0.4	0.6	0.2	1.0	0.2	0.8

RDF-5 FINAL FINES 10 Drops

EQUIPMENT EVALUATION DATA RUN #	ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
1	1.0	1.5	1.3	1.2	1.2						1.2	0.2	1.5	1.0	0.5
2	1.2	1.4	1.2	1.1	1.1						1.2	0.1	1.4	1.1	0.3
3	3.6	3.5	2.8								3.3	0.4	3.6	2.8	0.8
4	0.6	1.1	0.9	0.6	0.7	1.0	1.3	0.4	1.0	0.5	0.8	0.3	1.3	0.4	0.9

RDF-5 FINES DIFFERENCE (% WT, Ff-Fi)

EQUIPMENT EVALUATION DATA 10 Drops RUN #	ANALYTICAL REPLICATES										ANALYTICAL REPLICATE STATISTICS mean	std	max	min	range
1	0.4	0.5	0.5	0.5	0.5						0.5	0.04	0.5	0.4	0.1
2	0.4	0.4	0.5	0.3	0.3						0.4	0.07	0.5	0.3	0.2
3	1.2	1.3	1.1								1.2	0.08	1.3	1.1	0.2
4	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.1	0.2	0.06	0.3	0.1	0.2

TABLE 4-18. RDF-5 FUNNEL ANGLE ANALYSIS RESULTS
(angle of repose after flow)

EQUIPMENT EVALUATION DATA											ANALYTICAL REPLICATE STATISTICS				
RUN #	ANALYTICAL REPLICATES										mean	std	max	min	range
1	49.5	52.9	51.4	50.3	53.8	56.3	52.2	52.5	54.1	54.7	52.7	1.94	56.3	49.5	6.8
2	52.0	51.0	50.0	48.5	51.0	48.5	51.0	53.0	49.0	48.0	50.2	1.58	53.0	48.0	5.0
3	50.0	50.5	51.0	49.5	51.0						50.4	0.58	51.0	49.5	1.5
4	48.0	50.9	50.7	50.9	51.7	51.3	48.5	51.9	49.4	49.8	50.3	1.27	51.9	48.0	3.9

TABLE 4-19. PELLET QUALITY RANKING AS A RESULT OF EQUIPMENT VARIATIONS

Pellet quality rank	Equipment parameters		Pellet density (g/cc)	Water absorption (%)	Fines generation (%)
	Grid (in.)	Die (in.)			
1	1.5 × 2.0	0.5	1.27	19.2	0.7
2	1.0 × 2.0	0.5	1.20*	23.6	1.1
3	1.0 × 2.0	0.75	1.18*	35.9	1.7
4	1.5 × 2.0	0.75	1.13	15.1	2.6

*Mean values are not statistically different.

4.2.2 Results of Moisture Evaluation

During preliminary shakedown processing runs, observations were made which indicated that feedstock moisture contents below 10 percent and above 30 percent created severe operational problems. Low moisture contents created overheating and smoking and charring problems, while excessively high moisture content materials were prone to plug the pellet mill. These operational constraints served to define practical end limits of moisture content. The feedstock moisture levels that were evaluated in more detail (see Section 3.2) are presented in the second data block of Table 4-2.

A one-tailed Student's t test was used to determine which of the dependent variables changed significantly in response to the independent variable. Of all the physical characteristics measured, only the characteristics of bulk density (Figure 4-1) and water absorption (Figure 4-2) showed a significant response to changes in feedstock moisture content. Pellet density (Figure 4-3) indicated a significant increase for the lowest moisture value, but the other three moisture levels were determined to be statistically indistinguishable from each other. Furthermore, it was concluded that in the range of 14 to 18 percent, the feedstock moisture level did not have a significant impact on other RDF characteristics.

4.2.3 Results of Composition Evaluations

In this evaluation, refuse composition was the independent variable. RDF was produced from 21 different refuse compositions. The controlled (constant) variables were moisture and system operating parameters. Throughout the composition evaluation, RDF moisture averaged 10.5 percent (Table 4-5), and the system was operated with the 2- × 1.5-in. hammermill grid and the 0.5-in. pellet mill die ring.

The field data and sample statistics for the RDF physical characteristics are presented in Tables 4-2 to 4-15, and the chemical characteristics are presented in Table 4-20. The sample statistics derived from the field data were then subjected to further analyses to determine relationships between

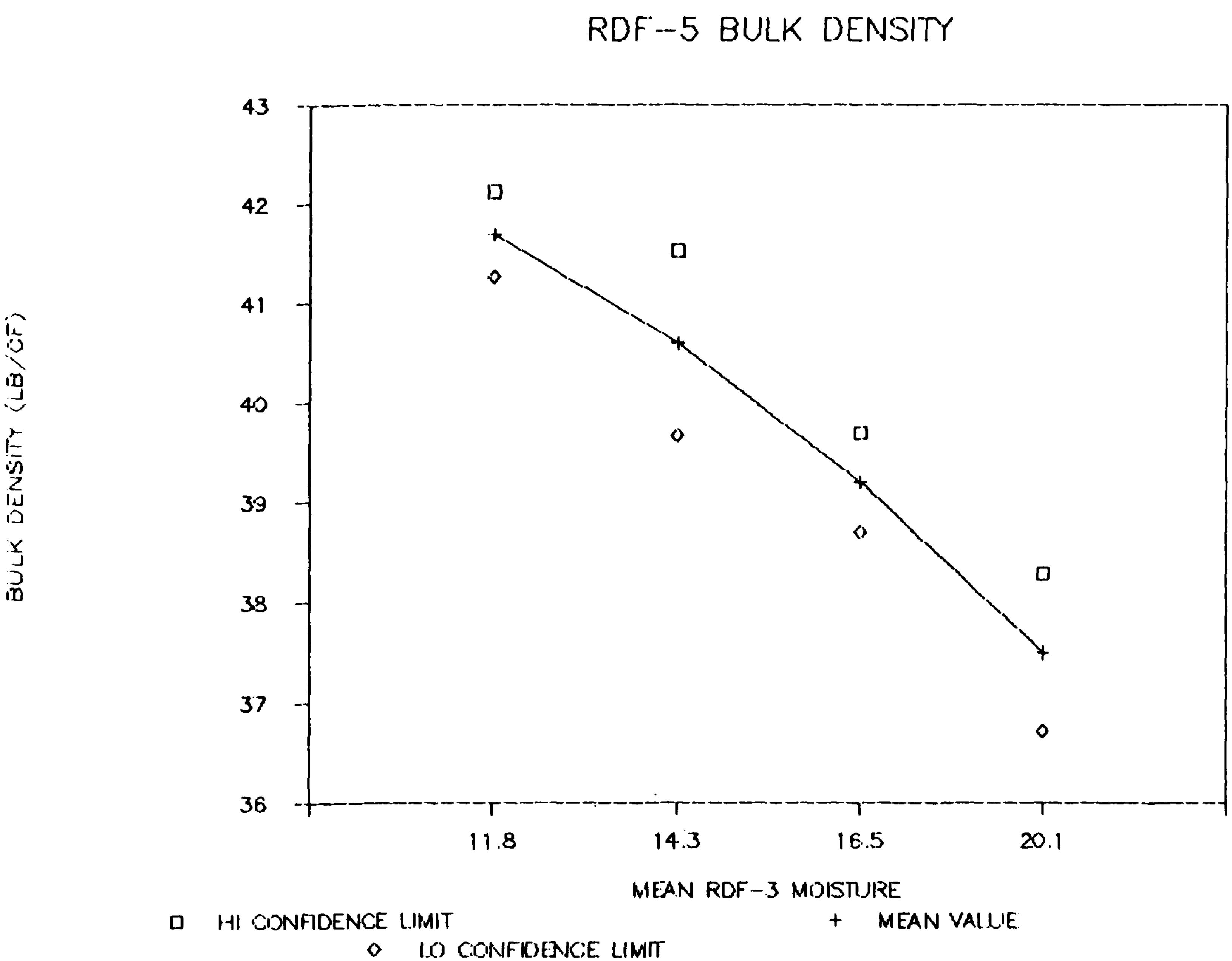

Figure 4-1. RDF-5 bulk density: RDF-3 moisture graph.

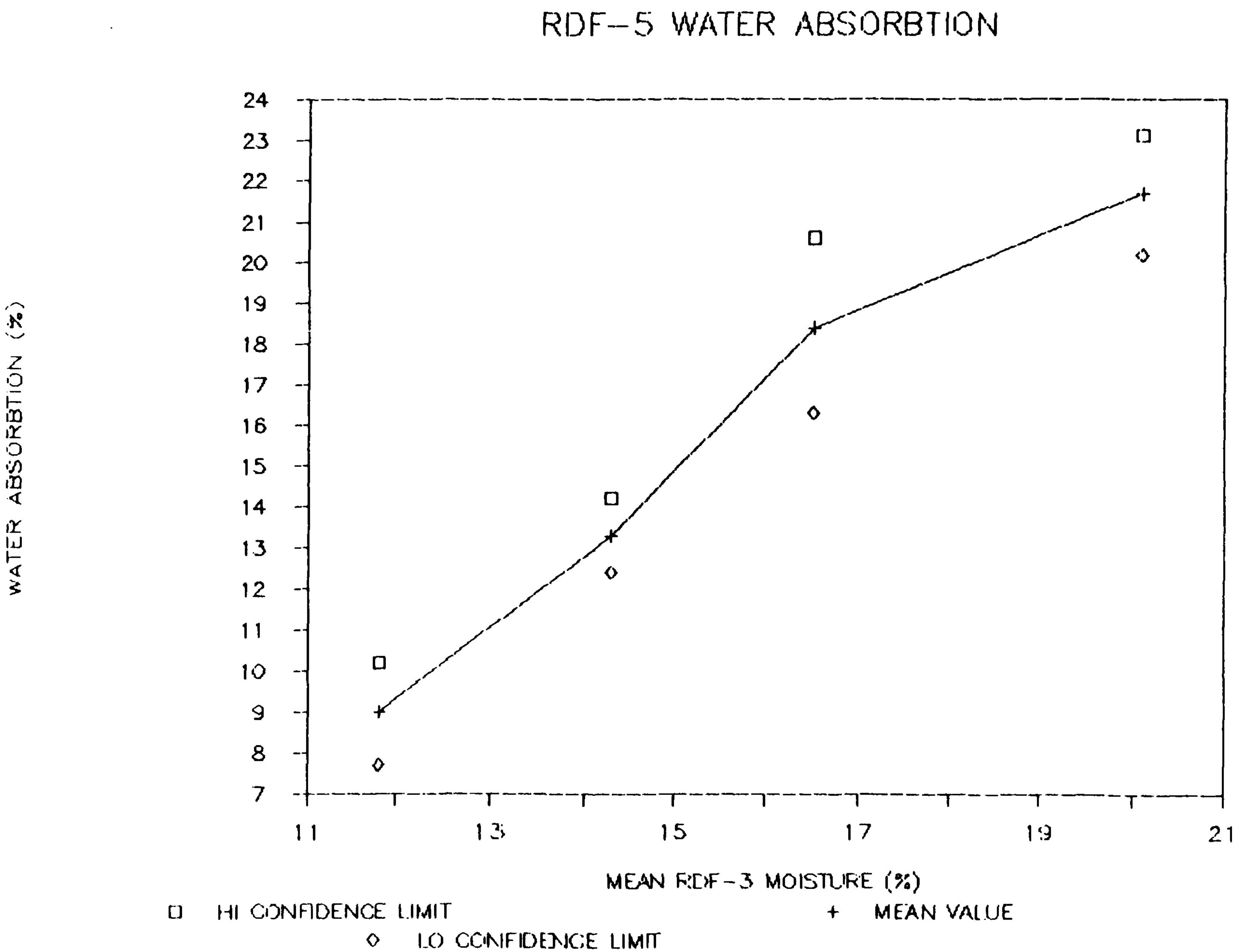

Figure 4-2. RDF-5 water absorption: RDF-3 moisture graph.

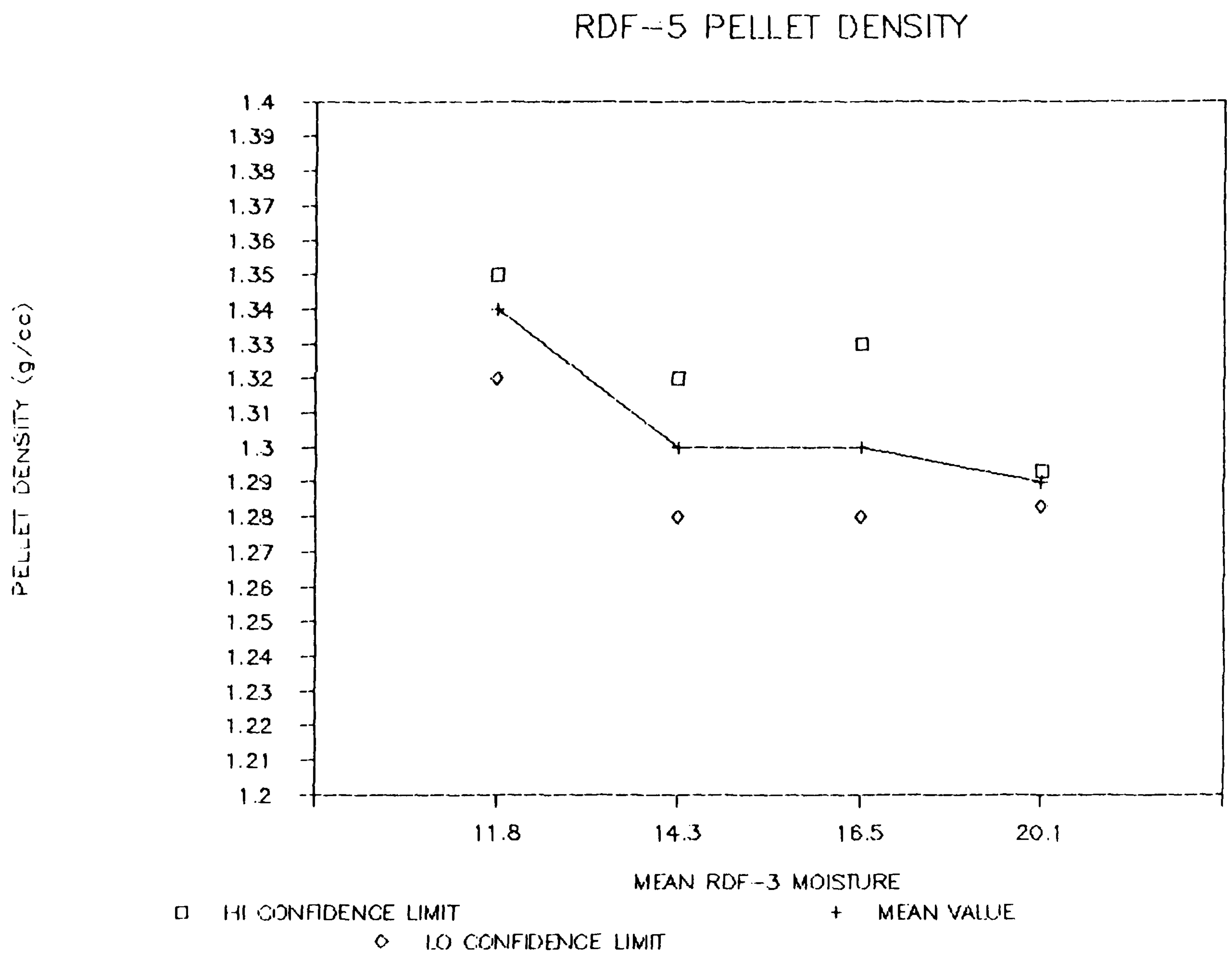

Figure 4-3. RDF-5 pellet density: RDF-3 moisture graph.

TABLE 4-20. RDF-5 CHEMICAL ANALYSIS RESULTS REPORTED ON DRY BASIS

	PROXIMATE ANALYSIS					ULTIMATE ANALYSIS						ASH FUSION TEMPERATURES*			
	HHV Btu/lb	H2O %	VOL %	F.CARB %	ASH %	C %	H %	N %	S %	Cl %	O %	I.D.	SOFT.	HEMI.	FLUID
RUN #												degrees fahrenheit			
1	7310	7.7	80.0	9.0	11.0	43.1	5.05	0.12	0.12	0.07	40.5	2380	2400	2420	2540
2	7970	7.8	80.6	10.0	9.4	46.6	5.55	0.17	0.10	0.11	38.0	2280	2300	2320	2360
3	7790	8.0	76.5	7.9	15.6	49.5	6.17	0.24	0.10	0.08	28.3	2080	2120	2140	2400
4	7960	7.5	82.0	9.1	8.8	46.6	5.67	0.20	0.08	0.08	38.6	2370	2430	2470	2800
5	6710	7.3	73.4	11.9	14.7	40.5	4.80	0.10	0.05	0.08	39.8	2320	2340	2360	2380
6	6850	6.4	75.3	8.2	16.4	38.9	4.59	0.11	0.05	0.07	39.8	2280	2300	2320	2340
7	7660	5.6	77.5	8.4	14.1	43.9	5.56	0.17	0.06	0.09	36.0	2580	2600	2620	2640
8	7240	6.7	76.0	8.4	15.6	41.5	4.69	0.26	0.12	0.11	37.7	2260	2280	2300	2360
9	7600	7.7	82.4	9.2	8.4	43.9	5.05	0.19	0.10	0.13	42.3	2420	2430	2440	2460
10	7760	6.5	73.6	11.4	15.0	43.7	5.32	0.15	0.10	0.06	35.7	2260	2280	2300	2340
11	7680	7.4	79.4	10.1	10.3	43.9	4.96	0.25	0.11	0.10	40.3	2340	2400	2420	2440
12	8040	6.5	82.0	10.7	7.3	45.4	5.41	0.23	0.10	0.11	41.4	2380	2400	2420	2440
13	7210	6.8	78.2	8.9	12.9	42.9	4.96	0.15	0.06	0.14	38.9	2280	2320	2340	2380
14	8100	8.3	81.3	10.3	8.4	44.6	4.95	0.23	0.06	0.10	41.6	2360	2380	2400	2420
15	6940	7.2	74.6	7.4	17.9	42.5	5.12	0.18	0.05	0.09	34.1	2320	2340	2360	2380
16	7750	7.0	81.9	9.7	8.4	45.0	5.34	0.15	0.09	0.13	40.9	2480	2800	2800	2800
17	7480	7.1	82.4	10.0	7.5	43.4	4.97	0.12	0.09	0.13	43.8	2400	2420	2440	2500
18	7370	7.0	75.4	9.1	15.4	40.9	4.75	0.18	0.11	0.06	38.5	2220	2260	2280	2300
19	7390	7.4	73.7	10.2	16.1	40.9	4.50	0.23	0.11	0.06	38.0	2260	2280	2300	2320
20	7720	6.2	82.4	7.6	10.1	43.1	5.01	0.23	0.12	0.11	41.4	2800	2800	2800	2800
max	8100	8.3	82.4	11.9	17.9	49.5	6.17	0.26	0.12	0.14	43.8	2800	2800	2800	2800
min	6710	5.6	73.4	7.4	7.3	38.9	4.50	0.10	0.05	0.06	28.3	2080	2120	2140	2300
range	1390	2.8	9.0	4.5	10.6	10.6	1.67	0.16	0.07	0.08	15.5	720	680	660	500

*I.D.: Initial deformation
Soft: Softening
Hemi: Hemispherical

characteristics and to determine the interactive effects of the refuse components on each dependent variable. These analyses were the correlation analyses and the regression analyses.

4.2.3.1 Correlation analyses results--

Correlation analyses were done to determine the relative strength of association among the dependent variables (on a one-to-one basis) and between the dependent variables and each individual refuse component. The correlation coefficient can be either positive or negative. It is not a predictive value, rather it indicates relative trends (Reference 6). The primary objective of this analysis was to determine if there was a strong enough relationship between any of the dependent variables so that one measurement could be used to indicate the expected value of another. For example, if it was determined that a strong positive relationship (i.e., if one is high, so is the other) existed between pellet density and fines generation, and if both qualities were deemed important for the particular process application, only one characteristic would need to be specified and measured because the other could be assumed to have an associated value.

Table 4-21 presents the full matrix of all correlation coefficients (r values). Table 4-22 is screened, presenting only those correlation coefficients with an absolute value above 0.7. To determine what degree of variability in one value is explained by the other value, the r value is squared. Therefore, r=0.7 was chosen as a cutoff, because at that level less than 50 percent of a variability is explained by the correlation. Table 4-23 presents correlation coeefficients of refuse components to each dependent variable, with an absolute r value of greater than 0.7. These correlations are discussed in Section 5.0.

4.2.3.2 Regression analysis results--

The desired end point of the regression analysis was to develop models (predictive equations) which could be used to predict RDF characteristics when refuse composition is known. Output was obtained for both the linear and second order fits for all RDF characteristics measured. To determine if the second order model, Equation 2-3, was more appropriate than the linear, Equation 2-2, the hypothesis

$$H_0: B_{ij} = 0 \text{ for all } i \text{ and } j$$

versus

$$H_1: B_{ij} \neq 0 \text{ for some } i \text{ and } j$$

was tested. The test statistic for this hypothesis is a ratio of variance as given by:

$$F_{10,\,6} = \frac{SSR_{linear} - SSR_{quadratic}\ /10}{SSR_{quadratic}/6}$$

TABLE 4-22. CORRELATIONS BETWEEN RDF CHARACTERISTIC VALUES WITH ABSOLUTE R-VALUES GREATER THAN 0.7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
RDF CHARACTERISTICS	ID.TEMP	S.TEMP	H.TEMP	F.TEMP	HHV	VOLATIL	ASH	CHLORIN	P.DENS.	WAT.ABS	5-H2O	BULKDEN	FINES	SIZE,I.	SIZE,F.	SIZE,D.	SIZE,S.	F.CARB	CARBON	HYD	OXY	3-SIZE	3-BDEN
1 ASH, INITIAL DEFORMATION	1.00																						
2 ASH, SOFTENING TEMP.	0.93	1.00																					
3 ASH, HEMISPHERICAL TEMP.	0.93	1.00	1.00																				
4 ASH, FLUID TEMP.	0.80	0.88	0.89	1.00																			
5 HIGHER HEATING VALUE					1.00																		
6 VOLATILES						1.00																	
7 ASH						-0.94	1.00																
8 CHLORINE								1.00															
9 PELLET DENSITY					-0.84				1.00														
10 WATER ABSORBTION										1.00													
11 RDF-5 MOISTURE											1.00												
12 RDF-5 BULK DENSITY									0.74			1.00											
13 FINES, FINAL													1.00										
14 SIZE, INITIAL														1.00									
15 SIZE, FINAL														0.96	1.00								
16 SIZE, DIFFERENCE																1.00							
17 SIZE, STABILITY																-0.81	1.00						
18 FIXED CARBON																		1.00					
19 CARBON					0.77														1.00				
20 HYDROGEN																			0.90	1.00			
21 OXYGEN																					1.00		
22 RDF-3 SIZE																						1.00	
23 RDF-3 BULK DENSITY																							1.00

TABLE 4-23. CORRELATIONS BETWEEN REFUSE COMPONENTS AND RDF CHARACTERISTICS WITH ABSOLUTE R-VALUES GREATER THAN 0.70

CHARACTERISTIC	PAPER	PLASTIC	ORGANIC	GLASS	INERTS
PAPER	1.00				
PLASTIC		1.00			
ORGANIC	-0.79		1.00		
GLASS				1.00	
INERTS					1.00
ASH, INITIAL DEFORMATION TEMP.					
ASH, SOFTENING TEMP.					
ASH, HEMISPHERICAL TEMP.					
ASH, FLUID TEMP.					
HIGHER HEATING VALUE					
VOLATILES				-0.87	
ASH				0.87	
CHLORINE					
PELLET DENSITY					
WATER ABSORBTION					
RDF-5 MOISTURE					
RDF-5 BULK DENSITY		-0.81			
FINES, FINAL					
SIZE, INITIAL					0.74
SIZE, FINAL					
SIZE, DIFFERENCE					
SIZE, STABILITY					
FIXED CARBON					
CARBON					
HYDROGEN					
OXYGEN					
3-SIZE					
3-B. DENSITY					

where SSR is the sum of the squares of the residuals (deviations) from the linear or quadratic models and the values 10 and 6 represent degrees of freedom. For every RDF characteristic, H_o was accepted. This indicated that the quadratic terms did not significantly improve the prediction of the estimation equation. Further, a test of the coefficients of the linear model indicated that each of the RDF characteristics was not constant over the range of proportions of the pellets. That is, the hypothesis that there is no linear effect due to composition

$$H_o:B_1 = B_2 = \ldots B_5$$

was always rejected. Therefore, it was determined that on the basis of the data obtained during the experiment, RDF characteristics are linear functions of the proportions of the refuse components that comprise the pellets.

The regression analysis takes into account the interactive effects of the five refuse components on each of the RDF characteristics. As indicated by the low levels for the one-to-one correlations, RDF characteristics are generally not dependent on any single refuse component. These results suggest that there are interactive effects. Therefore, the multiple regression analysis provides a more appropriate mechanism for estimating RDF characteristics from refuse composition information by accounting for interactive effects.

The output of the regression analysis (Table 4-24) was used to develop a series of 21 predictive equations (Table 4-25). To interpret the results and precision of the regression analysis, the standard error of the estimate (SEE) can be referred to as the key measure of the uncertainty in the experiment. It is used to estimate the variability in the predictive equation results. Small values of the SEE compared to the standard deviation (SD) of the observed values would indicate the predicted values have less associated variability than the observed values. Actual comparison of that ratio indicates that the predictive equations are lessening the variability to some extent. However, a significant reduction in variability would be indicated by a ratio value of 1:10 or less; the greatest improvements for this experiment were only 4:10 for bulk density and ash. This indicates that the predictive equation results have essentially the equivalent variability of the physical measurements. This suggests that there are other factors which contribute to the variability in RDF characteristics which were not identified in this research program. There is something other than composition that is causing variation in the dependent variable; or, the composition may have to be further defined (i.e., more categories).

Although the best application of the predictive equations are in situations when conditions match those of the experiment, they can be used in other cases to roughly estimate RDF characteristics. If the equations are used in cases that do not match the experimental conditions, the precision of the resultant estimate would be undefined.

TABLE 4-24. MULTIPLE REGRESSION COEFFICIENTS

CHARACTERISTIC	PAPER	PLASTIC	ORGANIC	GLASS	INERT	SEE
ASH, INITIAL DEFORMATION	2626	2184	2091	397	2967	140.6
ASH, SOFTENING TEMP.	2716	2262	2048	188	2551	140.7
ASH, HEMISPHERICAL TEMP.	2727	2311	2066	240	2545	133.4
ASH, FLUID TEMP.	2776	2834	1909	335	2358	112.7
HIGHER HEATING VALUE	7099	11964	7964	1895	8520	178.8
VOLATILES	82.0	79.2	84.7	20.6	51.1	1.7
ASH	8.3	11.1	5.6	73.1	47.4	1.5
CHLORINE	0.1	0.01	0.17	-0.13	-0.20	0.02
PELLET DENSITY	1.4	1.0	1.3	1.7	1.7	0.02
WATER ABSORBTION	16.1	27.7	29.5	12.3	-17.0	3.7
RDF-5 BULK DENSITY	47.3	13.1	37.4	47.6	45.5	0.8
FINES, FINAL	1.1	1.2	3.5	-0.8	2.9	0.3
SIZE, INITIAL	36.6	60.6	24.0	80.6	44.3	2.5
SIZE, FINAL	28.4	56.2	19.8	62.5	32.3	2.5
SIZE, DIFFERENCE	8.2	4.4	4.2	18.1	12.0	1.1
SIZE, STABILITY	0.8	1.0	0.8	0.7	0.7	0.02
FIXED CARBON	9.7	10.1	9.6	6.5	1.3	1.3
CARBON	41.5	62.1	45.3	20.7	53.1	2.1
HYDROGEN	4.8	8.3	4.7	2.7	7.8	0.4
OXYGEN	45.2	17.4	43.7	3.5	-8.6	2.4
RDF-3 SIZE	14.6	21.5	14.6	5.5	9.9	3.2
RDF-3 BULK DENSITY	2.9	3.7	4.0	6.4	4.7	0.9

TABLE 4-25. PREDICTIVE EQUATIONS FOR DETERMINING RDF CHARACTERISTICS WHEN PROCESSED FEEDSTOCK COMPOSITION IS KNOWN OR ASSUMED

CHARACTERISTIC		EQUATION					SEE	SD	SEE/SD
Y	=	B1 (X1)+	B2 (X2)+	B3 (X3)+	B4 (X4) +	B5 (X5)			
ASH, INITIAL DEFORMATION	=	2626 (PA)+	2184 (PL)+	2091 (OR)+	397 (GL) +	2967 (IN)	140.6	173.0	0.8
ASH, SOFTENING TEMP.	=	2716 (PA)+	2262 (PL)+	2048 (OR)+	188 (GL) +	2551 (IN)	140.7	186.0	0.8
ASH, HEMISPHERICAL TEMP.	=	2727 (PA)+	2311 (PL)+	2066 (OR)+	240 (GL) +	2545 (IN)	133.4	180 0	0.7
ASH, FLUID TEMP.	=	2776 (PA)+	2834 (PL)+	1909 (OR)+	335 (GL) +	2358 (IN)	112.7	174.0	0.6
HIGHER HEATING VALUE	=	7099 (PA)+	11964 (PL)+	7964 (OR)+	1895 (GL) +	8520 (IN)	178.8	387.0	0.5
VOLATILES	=	82.0 (PA)+	79.2 (PL)+	84.7 (OR)+	20.6 (GL) +	51.1 (IN)	1.7	3.4	0.5
ASH	=	8.3 (PA)+	11.1 (PL)+	5.6 (OR)+	73.1 (GL) +	47.4 (IN)	1.5	3.5	0.4
CHLORINE	=	0.1 (PA)+	0.01 (PL)+	0.17 (OR)+	-0.13 (GL) +	-0.20 (IN)	0.02	0.02	1.1
PELLET DENSITY	=	1.4 (PA)+	1.0 (PL)+	1.3 (OR)+	1.7 (GL) +	1.7 (IN)	0.02	0.04	0.5
WATER ABSORBTION	=	16.1 (PA)+	27.7 (PL)+	29.5 (OR)+	12.3 (GL) +	-17.0 (IN)	3.7	3.7	1.0
RDF-5 BULK DENSITY	=	47.3 (PA)+	13.1 (PL)+	37.4 (OR)+	47.6 (GL) +	45.5 (IN)	0.8	2.0	0.4
FINES, FINAL	=	1.1 (PA)+	1.2 (PL)+	3.5 (OR)+	-0.8 (GL) +	2.9 (IN)	0.3	0.3	0.9
SIZE, INITIAL	=	36.6 (PA)+	60.6 (PL)+	24.0 (OR)+	80.6 (GL) +	44.3 (IN)	2.5	3.5	0.7
SIZE, FINAL	=	28.4 (PA)+	56.2 (PL)+	19.8 (OR)+	62.5 (GL) +	32.3 (IN)	2.5	3.1	0.8
SIZE, DIFFERENCE	=	8.2 (PA)+	4.4 (PL)+	4.2 (OR)+	18.1 (GL) +	12.0 (IN)	1.1	1.1	1.0
SIZE, STABILITY	=	0.8 (PA)+	1.0 (PL)+	0.8 (OR)+	0.7 (GL) +	0.7 (IN)	0.02	0.02	1.2
FIXED CARBON	=	9.7 (PA)+	10.1 (PL)+	9.6 (OR)+	6.5 (GL) +	1.3 (IN)	1.3	1.2	1.1
CARBON	=	41.5 (PA)+	62.1 (PL)+	45.3 (OR)+	20.7 (GL) +	53.1 (IN)	2.1	2.4	0.9
HYDROGEN	=	4.8 (PA)+	8.3 (PL)+	4.7 (OR)+	2.7 (GL) +	7.8 (IN)	0.4	0.4	0.9
OXYGEN	=	45.2 (PA)+	17.4 (PL)+	43.7 (OR)+	3.5 (GL) +	-8.6 (IN)	2.4	3.4	0.7
RDF-3 SIZE	=	14.6 (PA)+	21.5 (PL)+	14.6 (OR)+	5.5 (GL) +	9.9 (IN)	3.2	3.5	0.9
RDF-3 BULK DENSITY	=	2.9 (PA)+	3.7 (PL)+	4.0 (OR)+	6.4 (GL) +	4.7 (IN)	0.9	0.8	1.0

WHERE:

PA = FRACTIONAL PAPER CONTENT OF PROCESSED WASTE
PL = FRACTIONAL PLACTIC CONTENT OF PROCESSED WASTE
OR = FRACTIONAL ORGANIC CONTENT OF PROCESSED WASTE
GL = FRACTIONAL GLASS CONTENT OF PROCESSED WASTE
IN = FRACTIONAL INERTS CONTENT OF PROCESSED WASTE
SEE = STANDARD ERROR OF THE REGRESSION ESTIMATE
SD = STANDARD DEVIATION OF THE ANALYTICAL MEASUREMENT

NOTE, FOR THE SEE TO BE VALID, THE FOLLOWING CONDITIONS MUST BE MET:

PA + PL + GL + OR + IN = 1.0
MOISTURE CONTENT MUST BE BETWEEN 12 AND 20 PERCENT
PROCESSING EQUIPMENT MUST BE SIMILIAR TO NAS JACKSONVILLE TEST FACILITY

SECTION 5.0
CONCLUSIONS

5.1 INTRODUCTION

The product of this investigation can be utilized by the Navy to develop guidance criteria for implementing materials and energy recovery systems. Information has been developed which describes how RDF characteristics are affected by variables such as system operating parameters, refuse feedstock moisture, and refuse feedstock composition. The range of values obtained as a result of these three evaluations should be representative of RDF characteristics which can be achieved on a full production scale. Specifications for purchase of a reasonably exceptable quality RDF could be developed based on these observed ranges once combustion properties have been determined. The particular fuel characteristics selected for specification and their chosen values will, however, be highly dependent upon the site-specific fuel requirements and design limitations of the intended facility.

Furthermore, predictive equations have been developed which can be used to estimate 21 RDF characteristics, provided refuse feedstock composition is known. These equations could be helpful in determining whether or not it is possible to produce a desired RDF characteristic from a known composition waste stream.

5.2 INDEPENDENT VARIABLE EVALUATIONS

Throughout the test program, three independent variable test evaluations (equipment, moisture, and composition) and 11 RDF characteristics (dependent variables, Table 5-1) were consistently measured. By comparing the range of values obtained for these characteristics, inferences can be made as to which independent variables probably have the greater effect on any particular characteristic.

Changes in system operating parameters (pellet mill dies and hammermill grates) resulted in a broader range of values for each RDF physical characteristic, with the exception of initial and final size. These two characteristics showed the greatest range as a result of changing refuse composition. RDF-5 bulk density, pellet density, and RDF-3 size exhibited similar ranges as a result of RDF equipment changes and refuse composition changes. It is most interesting to note that refuse composition exhibited as much effect on RDF-3 size (a range of 3.8 mm) as did changes in the hammermill grates (a range of 4.0 mm); equipment operating parameters yielded a greater range of values for RDF-5 water absorption (range of 31 percent) than did refuse feedstock moisture (range of 17.4 percent).

TABLE 5-1. RANGE OF VALUES: COMPARISON BETWEEN TEST EVALUATIONS

Characteristic	Composition	Moisture	Equipment
RDF 3 size	12.7 - 16.5	13.6 - 14.2	14.2 - 18.2
RDF 5 B. density	38.5 - 45.9	37.5 - 41.7	32.3 - 39.9
Pellet density	1.29- 1.42	1.29- 1.34	1.13- 1.27
Water absorption	9.0 - 26.4	9.0 - 21.7	19.2 - 51.1
Initial size	31.4 - 46.2	33.2 - 40.6	21.0 - 29.1
Final size	25.2 - 39.0	27.4 - 33.0	17.4 - 24.2
Size difference	6.2 - 9.8	5.6 - 7.6	1.3 - 5.0
Size stability	76.4 - 84.6	79.6 - 84.0	83.2 - 94.2
Initial fines	0.3 - 0.9	0.3 - 0.8	0.5 - 2.3
Final fines	1.0 - 2.3	1.4 - 2.0	1.2 - 4.9
Fines Difference	0.7 - 1.5	0.9 - 1.3	0.7 - 2.6

5.2.1 Equipment Configuration

The prevailing general theory regarding the matching of feedstock particle size to pellet mill die diameter indicates that the optimum combination is to have the feedstock average particle size less than half the diameter of the pellet mill die. With this combination, the hammermill does most of the mechanical size reduction (as it is designed to do), and minimal size reduction would be done in the pellet mill. This would reduce pellet mill die wear and power consumption.

The results of this study indicate that better quality pellets are produced when the particle size of the feedstock is larger than the pellet mill die opening. This quality advantage is probably at the cost of increased die wear and increased power consumption in the pellet mill.

Only pellet density (Table 4-7), water absorption (Table 4-8), and fines generation (Table 4-15) showed a significant response to changes in equipment operating parameters. All other characteristics were unaffected. Table 4-19 ranks these three characteristics and indicates that the equipment-operating parameters, consisting of the 2- × 1.5-in. hammermill grid and the 0.5 in. pellet mill die, produce the best overall quality pellets. This set of equipment-operating parameters was used in all subsequent testing as being system optimum.

As was anticipated, the 0.5-in. diameter die, which has a performance ratio specified by the manufacturer (length:diameter) of 9.0, consistently produced higher-quality pellets than did the 0.75-in. die, which has a manufacturers' specified performance ratio of 5.3.

5.2.2 Moisture Evaluation

Feedstock moisture contents below 10 percent and above 30 percent created severe operational problems and should be avoided. In the range of 14 to 18 percent, moisture level did not have a significant impact on RDF characteristics.

A one-tailed Student's t test was used to determine which of the dependent RDF characteristics changed significantly in response to the varying moisture conditions. Of all the physical characteristics measured, only the characteristics of bulk density (Table 4-6 and Figure 4-1) and water absorption (Table 4-8 and Figure 4-2) showed a significant response to changes in feedstock moisture content. Pellet density (Table 4-7 and Figure 4-3) exhibited a significant increase for the lowest moisture value, but the pellet densities at the other three moisture levels were not statistically distinguishable.

5.2.3 Composition Evaluation

5.2.3.1 Correlation Analysis--

The correlations among ash fusion temperatures and between ash:volatiles, final size:initial size, and carbon:hydrogen are at significant levels

($r > 0.9$). The remaining results indicated that high levels of significance were not identified, and that one value could not be used to reliably estimate the value of another.

However, the following observations can be made concerning the correlations that were observed above 0.5 (absolute). These correlations do add some insight to the relationships between characteristics and individual refuse components, and may aid in the development of specifications or in planning future research programs.

5.2.3.1.1 Correlations between refuse components and RDF characteristics--

- Plastic:Bulk density, R = -0.81. When RDF is extruded in pellet form, sheets of plastic tend to form separation planes in the pellets. These fracture planes are where the pellets are most likely to break. The shorter pellets with irregular ends tend to cause a lower bulk density. The result, while not surprising, is none the less a positive statistical confirmation of what has long been suspected.

- Inerts:Initial size, R =0.74. In this program, the inerts catagory was composed entirely of aluminum (glass was a separate catagory); and due to the constraints of experimental design, only had two values, 0 and 5 percent. It is probable that aluminum pieces form good binding structures within each pellet.

- Paper:Bulk density, R = 0.68. This relationship is the inverse of the relationship between plastic and bulk density (R = -0.81) and is logical, because on a compositional basis, paper displaces plastic in the feedstock. This does point out that paper and plastic constituents have the most impact upon bulk density--higher paper content yielding higher bulk density values--while higher plastic content yields lower values. The R^2 value indicates that only 46 percent of the variability in the bulk density is directly attributable to the effects of paper.

- Glass:Ash, R = 0.87. Glass is obviously a contributor to the ash content of RDF. The square of the correlation coefficient (R^2) indicates that 77 percent of the variability in the ash data can be attributed to the effects of varying glass content in the feedstock. This is, of course, not surprising and essentially serves as an internal check of the analysis.

- Glass:Volatiles, R = -0.87. This correlation indicates that 75 percent (R^2) of the variability in the volatiles data can be attributed to changes in the glass content of the feedstock. Again, the glass component can be expected to displace volatile matter to yield this result.

- Paper:Organics, R = -0.79. In this test program, paper and organics were the major refuse components and therefore had the most influence on one another from a simple displacement effect.

• Paper:Ash fusion temperature, R = 0.64; and, Glass:Ash fusion temperatures R = -0.67, -0.66, -0.65, -0.61. These relationships point out that ash fusion temperatures, characteristics that are important to operations, are primarily controlled by the glass and paper content of the feedstock. It is known that glass has a low ash fusion temperature and is a major contributor to furnace slagging. In this experiment, paper and glass often displaced one another as the composition changed. Thus, the ash content of the paper fraction, which is primarily clay (high ash fusion temperatures), displaces the low ash fusion temperature glass fraction. The R^2 values show that only about 40 percent of the variability of the ash fusion temperatures can be attributed to either glass or paper independently of one another.

5.2.3.1.2 Correlations between RDF characteristics--

• Ash:Volatiles, R = -0.94. This strong inverse relationship in which ash displaces volatile materials is therefore logical and expected.

• Pellet density:Higher heating value, R = -0.84. It is interesting to note that these seemingly dissimilar characteristics are so strongly related to one another. The R^2 value indicates that 71 percent of the variability in the higher heating value data can be associated with changes in the pellet density and vice versa.

• Final size:Initial size, R = 0.96. The relatively strong correlation between characteristic size of the pellets before and after tumbling in the durability test device indicates that the tumbling of pellets to determine their size stability is probably not necessary. In that 93 percent of the variability in the final size data can be attributed to the initial size of the pellets, there will be strong confidence in estimating the relative value of the final size by measuring the as-produced initial size.

• Size difference:Size stability, R = 0.81. Correlation of these two characteristics is obvious since both are calculated from the initial and final size of the pellets, and are, therefore, mathematically associated.

• Carbon:Hydrogen, R = 0.90. The ratios of these two elements have a relatively narrow range in papers and plastics. Therefore, a high correlation can be expected.

• Bulk density:Pellet density, R = 0.74. Only 55 percent of the variability in the bulk density data can be attributed to variations in pellet density. This is perhaps a lower level relationship than one might have anticipated due to the physical similarity of the measurements. Other researchers (Reference 7) have found that pellet durability and fines generation are more strongly correlated to pellet density. Such a correlation would indicate that the more dense the pellet, the stronger it is and the fewer fine particles and dust it will generate during handling. Although this observation was not verified over the range of pellet densities studied in this program, specifying appropriate pellet densities may also avoid dusting problems commonly associated with the use of RDF-5.

5.2.4 Regression Analysis

There were only two instances in which the regression analysis equations reduced the variability in the estimated value of a characteristic. Those two characteristics are bulk density and ash, which have a standard error:standard deviation ratio of 4:10. A significant reduction would be indicated by a ratio of 1:10 or less. These relatively high ratios indicate that the results of the predictive equations have a variability essentially equivalent to the physical measurement. This suggests that there are factors other than composition that contribute to the variability in RDF characteristics or that the composition may have to be further defined (i.e., more categories).

SECTION 6.0
RECOMMENDATIONS

6.1 SPECIFICATION GUIDANCE

The information presented in this report represents the first effort to isolate and quantify the individual effects of refuse moisture, refuse composition, and system operating parameters on RDF characteristics. To use the information of this report for RDF specifications, the following is recommended:

Table 6-1 lists the physical and chemical characteristics that were measured in these evaluations, their specification utility, and the range of values obtained. The list is not prioritized and is subject to change, depending upon site-specific requirements. Based on this information, specifications for purchase of an appropriate quality RDF can be estimated. The particular fuel characteristics selected for specification and their chosen values will be completely dependent upon the site-specific fuel requirements and use limitations of the intended facility. The responsible facility operators must determine from the equipment manufacturers and the experience of other RDF users what combination of characteristics and values are required for their given or proposed facility to successfully utilize RDF.

In general, the more similar the RDF-5 is to coal, the fewer the number of adjustments that will need to be made from normal coal operation. The unavoidable corollary to this statement is that obtaining RDF characteristics that are near that of coal takes more mechanical processing and electrical energy, resulting in a more expensive RDF. Economic tradeoffs must be made between ease of operations, equipment modifications, and the cost of premium quality RDF. Again, specific RDF costs, as well as specific RDF quality requirements are tied directly to site-specific conditions.

6.2 FURTHER RESEARCH REQUIREMENTS

While this research program has quantified many aspects of RDF production and fuel characteristics, it has also identified the need to continue the research in order to fully understand the complex interactions that occur in the production and utilization of RDF. While the information presented herein provides a means for estimating RDF specifications from waste composition, completion of the following suggested research could yield more specific and, therefore, more universally applicable specification data.

1. Develop an interactive RDF/boiler classification system based on the achievable RDF characteristics and the fuel requirements and limitations of the various types of boilers in use by the Navy.

TABLE 6-1. RANKING AND RANGE OF RDF CHARACTERISTIC VALUES

Characteristic	Specification utility	Range of values over entire test
Final fines	Storage/handling	1.0 - 4.9%
RDF-3 bulk density	Storage/handling	2.5 - 3.9 lb/cf
RDF-5 bulk density	Storage/handling	38.5 - 45.9 lb/cf
Water absorption	Storage/handling	9.0 - 51.1%
RDF-3 size	Storage/handling	12.7 - 18.2 mm
Moisture	Storage/handling	*
RDF-5 initial size	Storage/handling	31.4 - 46.2 mm
RDF-5 final size	Storage/handling	17.4 - 39.0 mm
RDF-5 size stability	Storage/handling	76.4 - 94.2%
		Range due to changes in composition
Final fines	Combustion	1.0 - 4.9%
Pellet density	Combustion	1.13 - 1.42 gr/cc
(the following characteristics are on a dry basis)		
Ash fusion temperatures	Combustion	2080 - 2800°C
Heating value	Combustion	6710 - 8100 Btu/lb
Ash	Combustion	7.3 - 17.9%
Volatiles	Combustion	73.4 - 82.4%
Chlorine	Combustion	0.06 - 0.14%
Carbon	Combustion	38.9 - 49.5%
Fixed carbon	Combustion	7.4 - 11.9%
Hydrogen	Combustion	4.5 - 6.17%
Oxygen	Combustion	28.3 - 43.8%

* Controlled - range not valid.

2. Perform combustion tests (both laboratory and full scale) using RDF produced under carefully controlled conditions in order to determine and quantify what relationships may exist between RDF physical and chemical characteristics and RDF combustion characteristics.

3. Produce and run combustion tests on RDF prepared from actual municipal or military solid waste. Such an experiment would provide the opportunity to observe the actual range of values for RDF physical, chemical, and combustion characteristics. The combustion tests would provide the opportunity to evaluate which characteristics and which associated values may be critical to facility operations and the economic performance of the RDF.

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APPENDIX A

PROCESSING EQUIPMENT, MODIFICATIONS, AND CURRENT STATUS

A.1 SYSTEM STATUS OVERVIEW

In order to meet the RDF research objectives of this program, it was first necessary to determine the operational status of the NAS JAX refuse preprocessing and RDF processing subsystems. Furthermore, equipment rehabilitation, maintenance, and modifications had to be effected in order to make the facility suitable for research testing. Because the HRI subsystem had failed to meet performance guarantees, the preprocessing subsystem had been taken out of operation by NAS JAX in 1982. The NCEL-installed RDF subsystem had gone through only a brief shakedown in 1983, at which time all the components were operated under no-load conditions. In 1983 an unsuccessful attempt was made to process peat into pellets with the RDF system. Unfortunately, problematic peat residues were left in the system that had to be cleaned out before refuse processing could be started. Furthermore, during the winter of 1983-1984 severe cold weather caused a waterline to freeze and break, resulting in water damage to several of the electrical components. Preliminary site inspections also indicated that errors in the system electrical wiring were present and would require correction to enable operation of the facility.

A.1.1 Brief Refuse/RDF Processing Line Overview

The refuse preprocessing system used in this project (see Figure A-1) starts at the tipping floor with a subfloor pan conveyor leading to a shear shredder used for primary size reduction. The material is then conveyed over a magnetic separator and through a trommel to a 340-cubic yard storage bin which was bypassed for the majority of the test work. The RDF processing line begins with a hammermill equipped with a pneumatic pickup system that discharges via a cyclone and rotary airlock into a 250-cubic foot surge bin. The surge bin is equipped with vertical and horizontal augers and feeds the centrifeeder of the Sprout Waldren pellet mill, which is followed by a pellet cooler. All of the above major components are connected by numerous sections of fast moving, steeply inclined conveyors.

A.2 REFUSE PREPROCESSING SUBCOMPONENTS

A.2.1 Primary Size Reduction

A Southern Engineering flail mill and a Kleco shear shredder were available for primary size reduction. NAS JAX public works personnel have reported that the flail mill is operational and has a processing capacity of approximately 1.5 TPH. Operation of this unit generates significant quantities of dust, which then creates a potentially explosive environment.

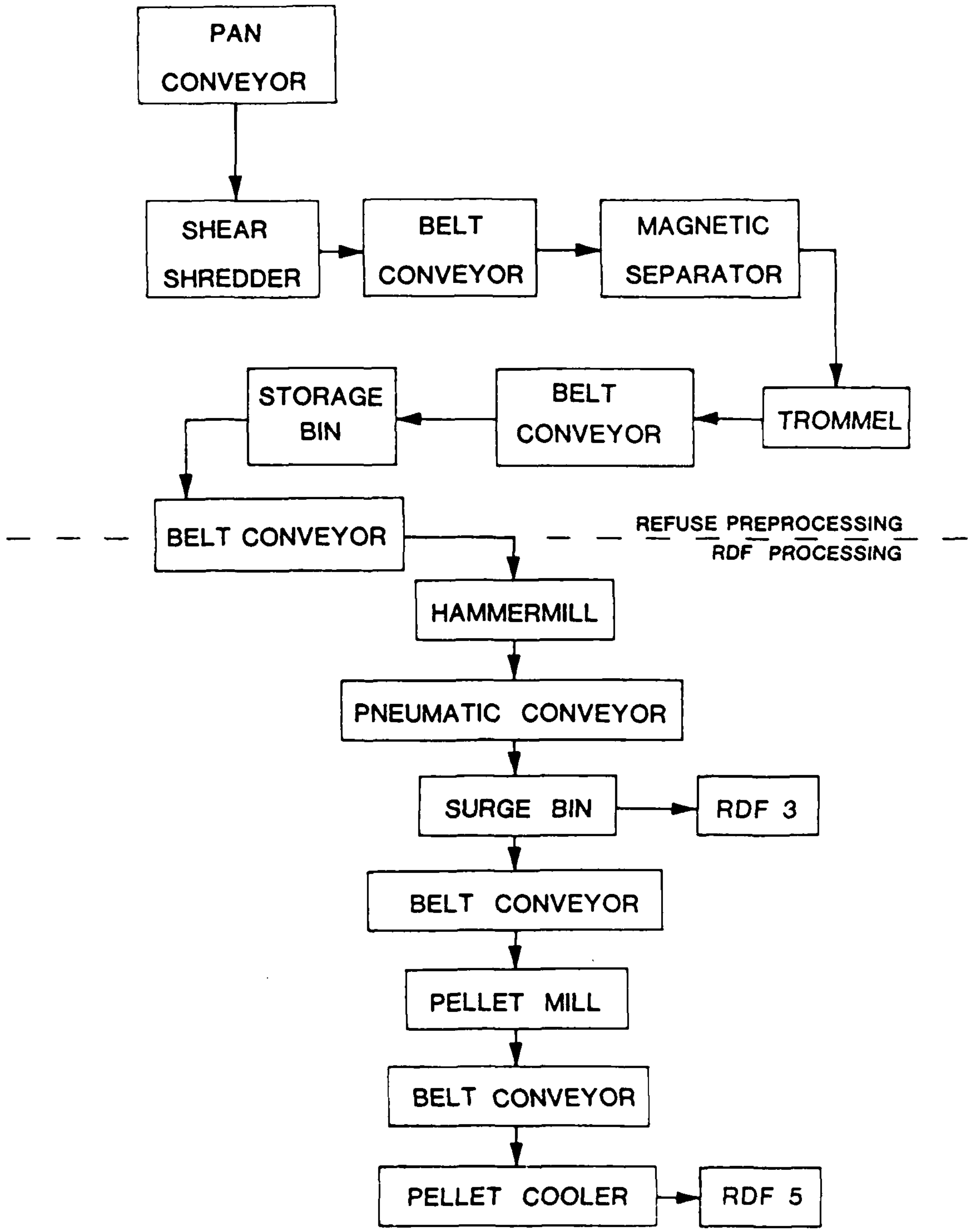


Figure A-1. Refuse preprocessing and NCEL RDF processing line.

Preliminary reports indicated that the shear shredder was not operational and that operational status would be attained only through the installation of new rotors at a cost of approximately $10,000. However, upon initiation of this project, NAS JAX public works personnel claimed the shear shredder did work and proceeded to demonstrate its capability by shredding scrap lumber. The shear shredder continued to operate very reliably. It provides adequate size reduction (approximately 6 to 8 in. nominal), is relatively quiet, and does not generate dust. Because its operation entails considerably lower explosion risk than the flail mill, the shear shredder was used throughout the research program. It was observed frequently that when the shear shredder drive motor would reverse itself because of resistant materials, the main preprocessing 600-amp circuit breaker would trip. Considerable manpower was expended troubleshooting the suspected problematic circuit breaker, only to find out that the shredder had been installed with undersized wiring. This resulted in an erroneous overload signal to the breaker. The only significant consequence of this wiring error was downtime. Other than general lubrication, no maintenance was required on the shear shredder or its associated conveyors.

The shear shredder capacity is highly dependent upon the type of material processed or, more specifically, on the number of times the shredder must reverse itself to process resistant materials. As an example, it might take an hour to shred 1000 lb of old phone books, but only 10 min to shred 1000 lb of loose newspaper. In timed runs of 1000-lb lots of mixed, loose waste material, throughput rates of 2 to 2.5 TPH were readily achievable.

A.2.2 Magnetic Separator

This component consists of an Eriez Magnetics three-stage electro/permanent magnet. Although this research program utilized synthetic trash that was specifically composited and, by recipe, did not contain any ferrous metals, the magnetic separator was nonetheless utilized as a safety precaution in the event that tramp metals were unknowingly introduced into the system. For example, some degree of contamination in the aluminum category was observed; and hand separation, although employed, was not totally effective. There were also numerous paper clips and metal fasteners present in the paper. Therefore, the magnetic separator provided a backup for the elimination of unwanted and potentially damaging materials.

Over time, the conveyor roller at the discharge end of the electro magnet became permanently magnetized. Magnetic material is attracted to the roller as it is discharged by the electro magnet. This material accumulates around the roller, and as a result, both roller and belt are accelerated.

While processing, the conveyor-drive motor would shut off after a brief (2- to 4-min) time period. This was corrected by adjusting the speed-sensor control. No other operational problems occurred.

A.2.3 Trommel

The trommel consists of a 4-ft diameter, 8-ft long inclined cylinder. It is designed to screen waste by rotating at 12 revolutions per minute (RPM) and discharging fine material through 1/2-in. diameter holes. Since this research program was designed to utilize a synthetic waste stream, such a separation function was not appropriate. Therefore, the trommel was blinded by covering the screen with old conveyor belt material. The trommel now functions simply as a rotary mixer/conveyor.

The trommel fines discharge conveyor was not operational. Under normal operation, this conveyor would carry away the material that fell through the 1/2-in. holes. Since there are no plans to use the trommel as a screen, no attempts were made to repair this conveyor.

A.2.4 Storage Bin

The storage bin consists of a 340-cubic yard steel bin (~19 ft × 33 ft × 14 ft) and is equipped with two discharge augers, an auger-traversing mechanism, and a reversible discharge conveyor. The augers were operational, but the traversing mechanism was not. During initial operation, the augers and traversing mechanism were locked out, and the RDF was manually transferred from the bin to the discharge conveyor. Manual removal ensured that no material was left in the bin, thus ensuring the integrity of the desired waste composition. During processing runs of 1000 lb or less, manual removal was not overly burdensome; however, a bypass chute was installed to eliminate manual handling. This consisted of a tarp stretched on a slope from the end of the storage bin feed conveyor to the discharge conveyor. The tarp was later replaced with a plywood structure. With the bypass chute in place, RDF processing was continuous from the shear shredder to the live-center surge bin. The bypass chute was very effective in that it reduced manpower requirements and provided a steady, even feed to the hammermill.

Other maintenance and repair items included reinstallation of the ladder that provides access to the top of the bin and to the feed conveyor and general lubrication of all components. New drive belts were installed on the storage bin discharge conveyor motor. It was also necessary to adjust the belt-drive gear reducer to keep the belts from slipping off.

A.3 RDF PROCESSING SUBCOMPONENTS

A.3.1 Secondary Size Reduction

This component consists of a corrugated-wall feed conveyor and a hammermill manufactured by Williams Patent Crusher and Pulverizer Company. Before the hammermill motor could be operated, a control transformer in the breaker panel required replacement and the circuit breaker had to be adjusted. There were several operational problems with the hammermill due to miswiring, water damage, and peat residue build up. The explosion suppression system was not operational and had to be bypassed. The limited quantities of material processed, coupled with the highly controlled waste stream, significantly reduced any risk of explosion.

The shredder also has an overload controller to stop the feed conveyor when the shredder motor amperage exceeds a preset level. The original wiring of this system prevented the conveyors from functioning at any time. Although several attempts were made to correct the system, proper operation was never obtained. As a result, the overload contacts had to be bypassed. Potential overload conditions were monitored by the operator, and the feed conveyors were stopped manually if the amperage exceeded the load limit.

During initial trial runs, it was noted that overload conditions occurred frequently and that it took 5 to 10 min for the shredder to clear after the last material was fed into it. During the last trial run, large chunks of black material were observed passing through the pneumatic transport system. To identify the source of this material, the ductwork downstream from the hammermill was taken apart. Large quantities of peat residue were found to be occluding the shredder grates and the ductwork directly underneath the shredder. This material had apparently been left in the processing line following a brief peat study in 1983. After the peat was removed, the shredder operation improved considerably, with little or no overloading and minimal time required for the shredder to clear itself.

The 3-hp feed conveyor motor burned out during the composition evalation tests. No specific problem was identified as the cause, and the motor was replaced.

Timed rate tests on the hammermill indicated that rates of 1.5 to 2 TPH were achievable. With the smaller 1-in. grates, the hammermill processed 3000 lb/hr operating at near maximum load capacity. When equipped with the 1 1/2-in. grates, the hammermill processed 3500 lb/hr without difficulty.

A.3.2 Pneumatic System

The pneumatic transport system consists of a material handling fan, a deentrainment cyclone with a rotary airlock, return ducting, a pulse-jet baghouse with a rotary airlock, and an air compressor system.

The wiper seals on the cyclone rotary airlock were essentially absent and had to be replaced before any refuse processing occurred. Old conveyor belting material was used for the replacement seals. These seals may need to be replaced in the future because the amount of dust escaping from the airlock has progressively increased. The switches in the hand-off-automatic (h-o-a) control box had to be replaced due to water damage.

No operational problems have occurred with the baghouse pulse-jet cleaning system. The motor on the rotary airlock is not operational, but the airlock can be operated by turning the valve manually. Only minute quantities of dust were collected by the baghouse system. The overall effectiveness of the subsystem is suspect.

A.3.3 Live-Center Surge Bin

The surge bin component consists of a feed conveyor and a 250-cubic yd capacity Sprout-Waldron live-center, surge bin. Four vertical augers are used to distribute and agitate the material inside the bin, while two horizontal augers at the bottom are used to move the material out of the bin. The horizontal augers are on a Reeves variable-speed drive system.

Loading the surge bin to capacity was hampered by a shroud above the surge bin feed conveyor. The bottom extension of this shroud forced the RDF to drop and fill the side of the bin directly below the conveyor, causing an overflow before the bin was actually full. To correct this, the bottom portion of the shroud was cut away. This increased the capacity of the bin from about 800 lb to approximately 1000 lb of RDF-3.

The right horizontal auger speed adjustment crank handle was repaired, and because of water damage, all the vertical auger h-o-a switches were replaced.

During a regular process run, the right horizontal auger stopped turning even though the gear drive was still running. The auger gear was removed, revealing that the auger shaft key was missing. Apparently the auger was running on only a friction fit. A new key was installed, the chain sprockets were realigned, and the chain tension was adjusted. There were no further problems with this unit.

The delivery rate of the RDF-3 from the bin is controlled primarily by the variable-speed drive system on the horizontal augers, but can also be controlled in part by the use or non-use of one or more of the vertical augers. Timed deliveries into 55-gal drums indicated that the maximum achievable rate was 2.0 TPH which is approximately three times the maximum pellet mill throughput rate.

A.3.4 Pellet Mill

This component consists of a corrugated-wall feed conveyor belt and a Sprout-Waldron pellet mill, driven by a 250-hp motor. A 5-hp motor drives a centrifeeder which distributes material uniformly across the pellet mill die ring.

There are two die rings for the pellet mill (3/4 in. and 1/2 in.). Peat had been left in the 3/4-in. die, and this material had to be removed manually prior to RDF processing. Attempts to clear the die holes by mechanically processing the peat out (making peat pellets) with other processed material failed. Ultimately, the die had to be cleaned with a pneumatic chisel. When the 3/4-in. die ring was later removed and the 1/2-in. die ring installed, it was noticed that the 3/4-in. die ring still had considerable amounts of peat residue in the die holes. These residual deposits were suspected of interfering with proper pellet formation. This residual peat was removed with steel brushes. A significant amount of pitting and corrosion was evident in the 3/4-in. die as a result of storing the die with peat in it.

During one of the preliminary trial runs, the centrifeeder was overloaded and the centrifeeder motor burned out. While the motor was being replaced, it was discovered that the motor overload protectors in the breaker panel were installed backwards, making them inoperative. The protectors were reinstalled properly and no further overload-control problems were encountered.

The two primary operational difficulties with the pellet mills related to bridging of loose RDF-3 in the funnel-shaped hopper above the centrifeeder and bridging of compacted RDF-3 between the plows in front of the compaction wheels. As the RDF-3 falls from the feed conveyor, it must free fall through a necked-down sheet metal hopper before entering the centrifeeder. This hopper has a cross section of approximately 2 ft by 1 1/2 ft near the top. The bottom opening at the mouth of the centrifeeder is approximately 8 in. × 10 in. This necked-down restriction at the mouth of the centrifeeder was observed to be the single most limiting feature of the pellet mill and consequently the entire processing line. Timed rate tests indicated that flows of 0.7 TPH were achievable, but attempts to exceed that rate consistently resulted in bridging in the hopper. While feeding at lower rates, it was observed that surges in the feed rate (slug feeding) often had the same result.

The second and most common operational problem was bridging of the material across the plows which direct the RDF-3 towards and under the compaction wheels. RDF would tend to hang up on the arms which support the plows or the leading edge of the plow. It was noted that strings of textile material significantly aggravated this problem. Slugs of accumulated material large enough to span the gap (4 to 6 in.) between the plows would apparently become dislodged and fall across the gap forming a bridge. As additional materials were delivered by the centrifeeder, the bridged material would become compacted and reinforced and no subsequent materials could reach the compaction wheel. If this condition went undetected, one-third and eventually the entire pellet-mill processing chamber would become filled with densely compacted RDF. Subsequent manual removal of plugged materials required up to 30 min. To avoid this consequence, the output of the pellet mill was monitored closely, and routine (every 5 to 10 min.) preventative maintenance checks were made to remove any textile or RDF accumulations. There was little evidence that this plugging phenomenon was feed rate dependant.

The roller assembly, which pushes the RDF into the dies, was rotated 180 degrees. The three rollers form a triangular assembly. The original roller position located the base of the triangle at the top of the mill. This configuration provided a ledge on which loose material could accumulate. Eventually, this loose material would build up and create a plug. By inverting the assembly, there is no longer a natural location for material to accumulate. While this has not completely eliminated plugging problems, it significantly reduced them.

During a special 12-hr process run, the pellet mill shut down automatically even though the process was running smoothly. The cause was found to be the oil pressure set-switch. Although the operating manual indicates the pressure should not go below 20 pounds per square inch (psi), the switch was set at a minimum oil pressure of 30 psi. When the mill began automatically shutting down, it had been operating for the longest continuous time to date. This caused the oil temperature to increase, therefore, lowering its viscosity. The set point was reduced to 23 psi and no further problems were encountered.

The pellet mill feed conveyor is driven by a 3-hp motor at a constant speed of 300 ft/min over a distance of 10 ft. This high speed made it difficult to feed the pellet mill at a smooth, even rate and caused considerable material spillage. The speed of this conveyor was therefore reduced approximately 30 to 40 percent by changing the sheaves on the motor and gear drive. This significantly reduced material spillage and provided a more controlled feed to the mill.

A.3.5 Pellet Cooler

This component consists of a corrugated-wall feed conveyor belt and a 20-ft long × 5-ft wide Sprout-Waldron pellet cooler. Air is drawn by a 42-in. fan through the perforated steel conveyor of the cooler, thus cooling and drying the pellets. A PARAJUST motor provides two conveyor speeds, each of which are adjustable over a wide range.

Water from frozen water pipes damaged the circuit boards in the PARAJUST controller, and these had to be replaced before the unit could be operated. No other problems were encountered with this component.

The pellet-cooler feed conveyor belt is driven by a 3-hp motor at a constant speed of 200 ft/min over a distance of less than 10 ft and at a very steep incline. The high speed made it difficult to visually monitor pellet production and also created a great deal of pellet fallback and spillage. To correct these problems, the conveyor speed was reduced by approximately 30 to 40 percent by changing the sheaves on the motor and gear drive.

Observations regarding the capacity of the pellet cooler were restricted by the output of the pellet mill. It is probable, however, that the cooler has sufficient volume to handle at least three times the output of the mill. Pellets enter the cooler at approximately 190°F and exit at 5° to 10°F above ambient temperature. The set retention time in the cooler is 15 minutes.

A.3.6 Other Components

A.3.6.1 Pellet Mill Cooling System--

During the 12-hr process run, the transmission oil of the pellet mill did not reach the set point which engages the cooling system. Therefore, although believed to be operational, no verification was made. Oil temperature was monitored throughout all processing runs to ensure that it never exceeded recommended levels.

A.3.6.2 Overload Feed Control System--

The pellet mill also has an overload feed control system, similar to that of the hammermill. This system is designed to stop the feed conveyor if the pellet mill motor amperage exceeds a certain set point. Although the motor amperage did exceed the recommended operating maximum on several occasions (for brief periods of time), the conveyor never automatically stopped. Therefore, this system is suspected of being nonoperational. As with the hammermill, the pellet mill amperage was closely monitored during operation and the feed conveyor was manually turned on and off as required.

A.3.6.3 Overhead Crane--

The 5-ton overhead crane in the RDF processing area required minor repairs and adjustments to bring it into operational status. The trolley shoe above the hoist had pulled loose. This occurred because movement of the crane caused the contacts to be pulled at a downward angle, thus loosening them. To correct this problem, a pulling arm was installed that allowed the trolley shoe to pull parallel to the track, thus eliminating the stress on the contacts. A fuse in the hoist motor starter was replaced, the connector was tightened, and the trolley linkage was adjusted. The crane is currently in reliable operating condition. However, it has been yellow tagged (operate with caution) by base inspectors because it is "possible" to run the main carriage of the crane into certain fixtures and sections of duct work.

APPENDIX B

RDF ANALYTICAL METHODS EVALUATION

B.1 OBJECTIVES

The objective of this phase of the test program was to obtain information on the precision of RDF analytical methods for physical characteristics and, where necessary, to modify existing or proposed methods so as to make them more precise and/or more cost effective to execute. The results of this methods evaluation phase were used to:

1. Establish which measurements most accurately and efficiently characterize RDF.

2. Establish the number of replicates required to estimate, within an acceptable level of precision, a given RDF characteristic.

3. To test and evaluate proposed methods with regards to precision, accuracy, cost effectiveness, and ease of execution.

Final versions of all RDF analytical procedures discussed in this section are presented in Appendices C through L. It is important to note that the methods, specific levels of precision, and numbers of replicates described herein are applicable only to RDF-3 and RDF-5 produced and sampled at the NCEL test facility.

Other forms of densified RDF (i.e., briquettes, cubes, etc.) may require significantly different analytical procedures, sample sizes, and numbers of replicates to obtain the same level of precision.

B.2 TECHNICAL APPROACH

B.2.2 Sampling and Sample Preparation

In sample analysis, the method of sample acquisition is very important. One must be confident that the sample is representative of the lot (that it is not biased) and that it has been handled and stored properly prior to analysis. To ensure the integrity of the samples, ASTM standard or draft procedures for sampling, sample handling, and sample preparation were followed whenever practical. When not economically possible to execute the procedures in detail, every attempt was made to observe the fundamental principles of the methods.

The following comments summarize some of the fundamental aspects of sample collection and preparation that were applied to this program.

- All increments of the gross samples were obtained only during steady-state operation. That is, the first and last quarters (approximately 250 lb each) of the production run were not included in the gross sample.
- All gross samples were divided into analytical samples by utilizing a Gilson Sample Splitter. The sample splitter provides even, unbiased division, which allows the fine materials to be distributed proportionately among the splits. In general, there was approximately a 10 to 1 ratio of gross sample to final analytical sample.
- All moisture analysis samples were stored in airtight containers prior to analysis.
- All other samples were stored in appropriate containers and allowed to air-dry overnight. This is a proposed ASTM procedure (E38.08-3.1) and helps to ensure that the mass of the analytical sample does not change (due to moisture loss or gain) during the analysis.
- All RDF-5 increment samples were collected as they fell from the discharge end of the pellet cooler. All RDF-3 increment samples were collected as grab samples from the output section of the surge bin.

B.2.3 Technical Approach

The data for evaluating the analytical methodology were derived while testing RDF produced during the equipment evaluation phase of work. Two pellet mill dies and two hammer mill grid sets were available. This equipment is therefore capable of four configurations, specifically:

1. 1-in. grid, 3/4-in. die.
2. 1-in. grid, 1/2-in. die.
3. 1 1/2-in. grid, 3/4-in. die.
4. 1 1/2-in. grid, 1/2-in. die.

Data utilized for evaluating the methods were obtained from RDF produced from each of the four possible equipment configurations. The refuse moisture content and the refuse composition were controlled variables.

B.3 DATA ANALYSIS

For all data on methods validation, the following sample statistics are presented: mean, standard deviation, and confidence interval of the mean. The confidence interval defines the range in which the actual population mean should lie. In all cases, the confidence interval was calculated at the 95 percent reliability level.

For each method, the combination of the desired level of precision and the observed standard deviation provides a method for determining the number of replicates required to confidently estimate the mean value in subsequent applications. Precision varies with the particular type of measurement. There is a trade-off between the desired level of precision (or the maximum tolerable error) and the number of samples required to obtain that precision level. Sometimes the number of replicates and precision are balanced such that the characteristic can be adequately described without exorbitant analytical investment. The following equation was used to establish the balance between the number of replicates (sample size) and the allowable maximum error.[1]

$$n = \frac{\sigma^2 \cdot Z^2_{\alpha/2}}{d^2}$$

where

d = desired precision (or maximum error)

$Z^2_{\alpha/2}$ = critical normal deviate for specified realiablity $1 - \alpha$

σ = assumed population standard deviation

B.3.1 RDF-3 Total Moisture (see Appendix C)

The moisture content of municipal or military solid waste varies widely on a temporal (daily, seasonally) as well as geographic basis. It has been observed qualitatively that the moisture content of RDF-3 has an impact on RDF-5 production. The ability to measure RDF-3 moisture and accurately quantify its effect on resultant pellet quality may be a critical factor in the evaluation and control of the pelletizing process.

The moisture content of RDF-3 was determined by placing a representative sample of as-produced RDF-3 into a drying oven set at a temperature of 107°C ± 3°C until it reaches a stable dry weight. Proposed "Test Method for Total Moisture in Refuse-Derived Fuel Samples" (ASTM E38.01-EDS-6) was followed with the exception of the use of a dessicator prior to weighing. A dessicator was not required because the samples were not out of the oven long enough for any appreciable change in mass to occur due to moisture loss or gain from the atmosphere; and thermal air currents and eddies had no impact on the relatively large sample mass. Composite samples were obtained by filling two 5-gal buckets with grab samples obtained throughout each processing run. Each analytical replicate was 250 grams, obtained from the composited samples. The ASTM proposed method does not specify a sample size. The results of analyzing seven different production lots of RDF-3 are presented in Table B-1. The average standard deviation (approximately 2 percent of the mean) of the individual analyses will allow estimation of the mean moisture content with a maximum error less than ± 5 percent with

[1] Probability and Statistics for Modern Engineering. Lawrence L. Lapin. Brooks/Cole Publishing Co. Monterey, California. 1983. Pg. 270.

one analytical sample. By analyzing four replicates, the maximum error (at 95 percent confidence) can be lowered to ± 0.25 percent. This precision (± 0.25 percent) should provide an adequate measure of RDF-3 moisture level.

TABLE B-1. RDF-3 MOISTURE ANALYSIS

Production date	Grid size (inches)	Number of replicates	Mean % moisture	Standard deviation	Confidence interval
09/27/84	1	11	6.4	0.3	6.2 - 6.6
10/01/84	1	4	11.8	0.3	11.3 - 12.3
10/03/84	1 1/2	4	13.6	0.4	13.0 - 14.2
10/09/84	1 1/2	4	14.9	0.1	14.7 - 15.1
10/15/84	1 1/2	3	16.3	0.4	15.3 - 17.3
10/17/84	1 1/2	3	13.4	0.2	12.9 - 13.9
11/09/84	1	10	17.8	0.2	17.7 - 17.9

B.3.2 RDF-3 Size Analysis (see Appendix D)

The characteristic size and the particle size distribution of RDF-3 are useful in evaluating the performance characteristics of size reduction equipment (ASTM E959-83, "Characterizing the Performance of Refuse Size-Reduction Equipment") and may be useful in predicting the behavior of a particular lot of RDF-3 with densification equipment or combustion systems. The size distribution is determined by mechanically or manually sieving an air-dried sample of RDF-3 into sized fractions, which are determined by the size of the sieve openings. The masses of these sized fractions are then plotted on Weibull probability graph paper and the characteristic size (36.79 percent retained) and slope of the distribution (or distribution coefficient) are determined from the plot.

ASTM Standard Method E828-81, "Designating the Size of RDF-3 From Its Sieve Analysis," recommends an analytical sample of approximately 2 Kg be sieved in increments that are small enough that they do not form mats and blind the individual sieves. A 2-Kg sample, with a bulk density of about 2 lb/ft^3, has a volume of approximately 2 ft^3, or almost half of the total volume of the entire sieve shaker cabinet. It was determined empirically that a 50-gram increment was the largest increment that would consistently pass all sieves without hanging up in mats and requiring manual redistribution. To sieve one 2-Kg analytical sample in 50-gram increments would require in excess of one man day of labor. The data presented in Table B-2 indicate that by treating each 50-gram increment as an independent

TABLE B-2. RDF-3 SIZE ANALYSIS

Production date	Grid size (inches)	Number of replicates	Mean characteristic particle size* (mm)	Standard deviation	95% Confidence interval	Mean Distribution coefficient†	Standard deviation	95% Confidence interval
09/26/84	1	5	13.6	0.5	12.9 - 14.3	1.61	0.11	1.51 - 1.71
10/16/84	1 1/2	5	18.2	1.3	16.6 - 20.2	1.25	0.11	1.15 - 1.35
11/09/84	1	5	14.2	0.4	13.7 - 14.7	1.50	0.10	1.40 - 1.60

* 36.79 percent retained from Weibull plot.
† Slope of line from Weibull plot.

analytical sample, the mean characteristic size can be estimated to within ± 2mm by averaging the individual results of five 50-gram replicates. The total time required for this treatment is approximately 2 manhours.

A review of ASTM E828-81 and other sources indicate that there are at least a half dozen reporting schemes that may be useful in specific applications. On the present program, the characteristic size and the slope of the plotted line completely describe the size distribution and will allow the other forms of information to be generated, if required.

As with other RDF analyses, it must be stressed that obtaining a truly representative 50-gram sample of a lot of RDF-3 requires a considerable amount of planning and attention to detail. Although the analytical method has adequate precision, it would be very easy to obtain precise but inaccurate data from an improperly acquired, biased sample.

B.3.3 RDF-3 Loose Bulk Density (see Appendix E)

The loose bulk density of RDF-3 is useful to design engineers in specifying material handling systems for RDF-3. The loose bulk density is determined by measuring the net weight of uncompacted RDF-3 contained in a level, full 55-gal drum of known weight and volume. (This procedure is a variation on proposed ASTM method E38.08-6.4, "Determining the Bulk Density of Solid Waste Fractions.") It was discovered, during evaluation of this procedure, that a significant improvement in precision is obtained by filling the drum in a controlled manner. The drum is filled by passing the RDF-3 through a sieve with square openings approximately 3 to 5 times the characteristic particle size. This allows the RDF-3 (that may have been compacted during storage) to be uniformly fluffed and to fall in a reproducible manner onto other RDF-3 already in the drum.

The data presented in Table B-3 represent multiple bulk density determinations made on two lots of RDF-3 produced with different hammermill grids. The low standard deviations (less than 5 percent of the mean) indicate that the method is very reproducible and with four replicates can estimate the mean to within ± 0.2 lb/ft^3 at the 95 percent confidence level. To estimate the mean with a maximum error of 0.5 lb/ft^3 requires only one analysis.

TABLE B-3. RDF-3 LOOSE BULK DENSITY

Production date	Grid size (inches)	Number of replicates	Mean bulk density (lb/ft^3)	Standard deviation	Confidence interval
09/27/84	1	4	2.1	0.1	1.9 - 2.3
10/17/84	1 1/2	5	2.2	0.0	2.2

B.3.4 RDF-3 Compacted Bulk Density

The compacted bulk density of RDF-3 is useful to design engineers in specifying storage facilities or transportation vehicles for RDF-3. A method for determining the compacted bulk density of RDF-3 was developed during this program by observing the amount of volume reduction that results from applying a controlled load to a known mass and volume of loose RDF-3 in a 55-gal drum. The drum is filled with RDF-3, as in the loose bulk density procedure; and a heavy cardboard baffle, which is slightly smaller than the diameter of the drum is placed on top of the RDF-3. A 100-lb total load is then centered and gently lowered onto the baffle compressing the RDF-3. The change in volume of RDF-3 is determined, and the resultant compressed bulk density is calculated for that load. Other loading factors could be specified, as required, for specialized applications.

The data presented in Table B-4 indicate that the method has a low standard deviation (approximately 2 percent of the mean). With this degree of reproducibility, only one replicate is required to estimate the compacted bulk density to ± 0.5 lb/ft^3 at the 95 percent confidence level.

TABLE B-4. COMPACTED BULK DENSITY RDF-3

Production date	Grid size (inches)	Number of replicates	Mean bulk density (lb/ft^3)	Standard deviation	95% Confidence interval
09/27/84	1	2	5.8	0.1	4.9 to 6.7
10/17/84	1 1/2	4	4.9	0.1	4.7 to 5.1

B.3.5 Air-Drying RDF

In the air-drying procedure, the moisture content of a laboratory sample of RDF is simply allowed to equilibrate with the ambient relative humidity conditions under which it will be handled during subsequent evaluations. The equilibration ensures that there will be minimal weight changes due to moisture loss or gain that may interfere with the results of gravimetric-based analyses such as sizing, durability, or density. The "Proposed Standard Method of Air-Drying RDF-5 for Further Analysis" (ASTM E38.08-3.1) indicates that there is no numerical quantity reported from this procedure and that is merely a sample preparation procedure. To establish the rate of the air-drying moisture loss and therefore the potential impact on other analytical procedures, the initial weights of several 1-Kg laboratory samples exposed to two relative humidity conditions were compared to their final weights after 24 hr. With those data, the 24-hr air drying moisture losses were calculated. These data, presented in Table B-5, indicate that even under the lower relative humidity condition, the 24-hr weight loss was only about 1 percent. Therefore, the anticipated moisture losses during, for example, a 1-hr durability test would be negligible under normal Florida relative humidity conditions (lower relative humidity climates could result in more significant losses).

TABLE B-5. RDF-5 AIR-DRYING

% Relative humidity	Production date	Number of replicates	Mean % weight loss (24 hr)	Standard deviation	95% Confidence interval
72 - 90	10/09/84	12	0.3	0.14	0.2 - 0.4
66	10/09/84	4	1.1	0.17	0.8 - 1.4

B.3.6 <u>RDF-5 Bulk Density (see Appendix F)</u>

The bulk density of RDF-5 is useful to design engineers in specifying materials handling, storage, and transportation systems. Since the bulk density procedure is both rapid and sensitive, it also may be useful as a means of monitoring the output of the densification system and evaluating the effects of production variables on a real-time basis. The bulk density is determined by measuring the net weight of RDF-5 contained in a level, full 5-gal bucket of known tare weight and volume. The ASTM "Proposed Standard Method for Measuring Bulk Density of RDF-5" (E38.08-3.6) calls for the use of a 1.0 ft^3 plywood box. However, the bucket eliminates the corner voids and, as indicated by the data presented in Table B-6, the bucket has a better standard deviation than the box. By averaging ten replicates using either container, the mean bulk density can be estimated to within ± 0.3 lb/ft^3 with a 95 percent confidence level.

B.3.7 <u>RDF-5 Pellet Density (see Appendix G)</u>

The density of the individual pellets is a measure of the effectiveness of the densification process and may be used as a production quality control monitor. The "Proposed Standard Method for Measuring Density of RDF-5" (ASTM E38.08-3.3) presents a methodology in which ten representative pellets are weighed and then double coated in hot wax to waterproof them. The volume of each pellet is then determined individually by water displacement and the average density calculated. This procedure is time-consuming and has results that are highly dependent upon the representativeness of the ten selected pellets. It is also reported in the ASTM draft procedure that this method gives results that are only good to 0.1 gr/cc. Past RDF sampling and analytical experience indicates that the high variability in small RDF samples, the high probability of bias in choosing ten representative pellets, and the added complications of working with hot wax tend to make this procedure have a very low probability of producing acceptable results. Therefore, the ASTM proposed procedure was not evaluated on the present program.

TABLE B-6. *RDF-5 BULK DENSITY*

Analytical method	Production date	Production Conditions Grid size (inches)	Die size (inches)	Number of replicates	Mean bulk density (lb/ft^3)	Standard deviation	Confidence interval
1.0 cf box	10/09/84	1 1/2	1/2	10	38.7	0.44	38.4 - 39.1
0.7 cf bucket	10/09/84	1 1/2	1/2	10	39.0	0.37	38.7 - 39.3

The alternative procedure used to measure pellet density involves the evaluation of a representative 250-gram sample with the fines (less than 1/2 in. in diameter) removed by sieving. The remaining sample is then weighed and emptied into a 1-liter graduate cylinder containing a measured volume of water. The sample volume in then determined immediately by water displacement. The method is very rapid, uncomplicated, bias free, and, as indicated by the data in Table B-7, very reproducible. The 95 percent confidence interval of the mean is most commonly ± 0.02 gram/cc, with the worst case measurement (October 3, 1984) being ± 0.03 gram/cc. In general, it is possible to estimate the mean density with a maximum error of ± 0.02 gram/cc by analyzing four replicate samples. To reduce this maximum error to ± 0.01 gram/cc would require the analysis of 16 samples.

TABLE B-7. PELLET DENSITY

Production date	Production Conditions		Number of replicates	Mean pellet density (g/cc)	Standard deviation	95% Confidence interval
	Grid size (inches)	Die size (inches)				
10/03/84	1 1/2	3/4	10	1.16	0.04	1.13 - 1.19
10/09/84	1 1/2	1/2	10	1.27	0.02	1.26 - 1.28
10/17/84	1 1/2	3/4	5	1.13	0.02	1.11 - 1.15
11/09/84	1	1/2	5	1.20	0.01	1.18 - 1.22
11/13/84	1	3/4	5	1.18	0.02	1.16 - 1.20

B.3.8 RDF-5 Size Analysis (see Appendix H)

The characteristic size and fines content of RDF-5 are used as primary reference points in evaluating the RDF-5 production process and the resultant product durability. The characteristic size is also important in assessing the appropriateness of the fuel for a particular fuel feed mechanism or combustion system. The fines content is a good indicator of the general physical condition of an as-received fuel and is useful in predicting fuel handling and storage characteristics.

Proposed ASTM E38.08-3.4 "Standard Method for Measuring Particle Size Distribution" requires a 1-Kg analytical sample of pellets to be initially divided by length into groups by multiples of 1 centimeter. Where the mass of any one group is more than 25 percent of the total sample mass, the size distribution is not considered to be adequately described, and the group is then subdivided into smaller (0.5 cm) and smaller (0.25 cm) groups until no more than 25 percent of the sample mass is contained in any one size grouping. Preliminary use of the proposed method showed that when most pellets are very nearly the same size (which is a desirable attribute for materials handling and combustion), one must resolve rather small (i.e., 0.25 cm) differences in in pellet length. While this approach may be correct in a theory, it is tedious and does not provide a particularly precise estimation of the characteristic size. Since RDF-5 in pellet form may be produced having nominal diameters anywhere from 1/4 in. to 4 in., defining the size groupings as multiples of the pellet length to diameter ratios promotes fewer but adequate numbers of size classes. Several modifications were accordingly made in this procedure and are summarized in the following paragraphs.

The characteristic size of RDF-5 is determined graphically in similar fashion to that of RDF-3, using a Weibull probability graph of the RDF-5 particle size distribution. The size distribution is determined by manually separating a 1-Kg air-dried sample of pellets into size groups defined by multiples of the pellet length/diameter ratios. The weight of each group is then determined and plotted along with the weight of the fines on Weibull probability graph paper. No restriction is placed upon the percentage of the sample that may be reported for a specific size group.

To determine the fines content of a production lot of RDF-5, a 1-Kg air-dried sample is sieved on a standard wire sieve with openings equal to one half the nominal diameter of the pellets. The weight percent of the material passing the sieve is considered the fines content. Previously, fines were defined as materials passing through a 3/8-in. sieve, but it logically follows that what is "fine" material when working with 1/2-in. pellets should be different from what is considered "fine" when working with 1-in. or 4-in. pellets.

Data were also collected on the size distribution (slope of the Weibull probability curve). However, these data were found to be highly variable and a clear interpretation of the results was not obvious.

Data on size analysis (initial and final size and fines content) is presented in Tables B-8 and B-9 as initial size along with tumble and drop shatter durability test results. The analysis of the 1/2-in. pellets had a higher standard deviation than the 3/4 in. due primarily to the presence or absence of a few long pellets (greater than 5 diameters) in the analytical sample. Two or three long pellets have a considerable mass and tend to have a significant impact on the resultant characteristic size. Even in this worst case situation, the average standard deviation is only about 7 percent of the average mean characteristic size, and the mean can be estimated with a maximum error of ± 2 mm at a 95 percent confidence level by analyzing five replicates.

B.3.9 <u>RDF-5 Tumble and Drop Shatter Durability Tests (see Appendix I)</u>

Two test procedures were evaluated to determine the durability of RDF-5 pellets. In both tests, the initial characteristic size and fines content of a 1-Kg, air-dried sample are determined; the sample is subjected to physical abuse, and the resultant characteristic size and fines content determined and compared to the initial values.

TABLE B-8. TUMBLER DURABILITY TEST: CHARACTERISTIC SIZE

		Production Conditions			Initial			Final				
Tumble time (min)	Production date	Grid size (inches)	Die size (inches)	Number of replicates	Mean characteristic size (mm)	Standard deviation	95% Confidence interval	Mean characteristic size (mm)	Standard deviation	95% Confidence interval	Reduction in characteristic size (mm)	Size stability factor* (%)
10	11/09/84	1	1/2	5	29.0	2.2	26.3 - 31.7	24.1	1.2	22.6 - 25.6	4.9	83
20	11/09/84	1	1/2	3	28.2	1.6	24.2 - 32.2	22.5	0.0	22.5	5.7	80
30	11/09/84	1	1/2	3	28.5	2.2	23.0 - 34.0	20.8	1.4	17.3 - 24.3	7.7	73
10	11/13/84	1	3/4	5	21.0	1.8	18.8 - 23.2	17.4	1.3	15.8 - 19.0	3.6	83
20	11/13/84	1	3/4	3	19.8	0.8	17.8 - 21.8	16.7	1.5	13.0 - 20.4	3.1	84
30	11/13/84	1	3/4	3	20.9	0.4	19.9 - 21.9	18.0	0.0	18	2.9	86

* Size stability factor = final size ÷ initial size × 100.

TABLE B-9. TUMBLE DURABILITY TEST: FINES GENERATION

Tumble time (minutes)	Production date	Production Conditions: Grid size (inches)	Production Conditions: Die size (inches)	Number of replicates	Initial: Mean percent fines	Initial: Standard deviation	Initial: 95% Confidence interval	Final: Mean percent fines	Final: Standard deviation	Final: 95% Confidence interval	Increase in fines percent
10	11/09/84	1	1/2	5	0.9	0.3	0.5 - 1.3	2.1	0.6	1.4 - 2.8	1.2
20	11/09/84	1	1/2	3	1.1	0.3	0.4 - 1.9	2.5	0.3	1.8 - 3.3	1.4
30	11/09/84	1	1/2	3	1.3	0.2	0.8 - 1.6	3.0	0.4	2.0 - 4.0	1.7
10	11/13/84	1	3/4	5	0.7	0.1	0.6 - 0.8	2.4	0.2	2.2 - 2.7	1.7
20	11/13/84	1	3/4	3	1.0	0.2	0.5 - 1.5	3.2	0.0	3.2	2.2
30	11/13/84	1	3/4	3	0.8	0.2	0.3 - 1.3	3.5	0.2	3.0 - 4.0	2.7

In the tumbler test, (ASTM Proposed Standard Method for Measuring Durability of RDF-5, E38.08-3.8) the 1-Kg size sample is placed in a 1-ft square × 4-in. closed box; and the box is rotated on an axle, tumbling the pellets against the inside of the box and each other for a specified period of time. Tables B-8 and B-9 present data on the reduction in characteristic size and increase in fines content resulting from tumbling two lots of pellets for 10, 20, and 30 minutes each.

The drop test evaluated for possible application on this project was modeled on the principles of the ASTM, "Drop Shatter Test for Coal" (D440-49), which is specifically designed to measure the size stability of coal. The drop test involves dropping a sized, 1-Kg sample through a 6-ft length of 6-in. PVC pipe onto a steel plate that is fastened to the end of the pipe. The pellets hit the plate and each other with an impact velocity of approximately 20 ft/second. After multiple drops, the pellets are again sized to determine the resultant decrease in characteristic size and increase in fines content. Tables B-10 and B-11 present the results of dropping two lots of pellets 10, 20, and 30 times each.

It was initially predicted that the drop shatter test would be more effective than the tumble test in reducing the characteristic size. Examination of test results for the 1/2-in. pellets in Tables B-8 and B-10 indicates that the reductions in characteristic size from the drop test and the tumble test are essentially the same. It can also be observed that both tests exhibit similar size reduction responses to extended tumble times or multiple drops. The apparently incongruous results of the 3/4-in. tumble test (pellets appear to get longer with extended tumble times) are not real. The high degree of overlap in the confidence intervals in the before and after sizes obscure the fact that they are really members of the same population and, thus, do not show a statistically significant size change during tumbling. This phenomenon results from the physical shape of the pellets (they are as long as the diameter) and the fact that the size distribution was very closely centered on the mean characteristic size.

Examination of the fines generating potential of the two tests on Tables B-9 and B-11 indicates that the tumble test produces more fines than the drop test and is therefore a more severe and more challenging test. The response of the samples to extended tumble times is also more consistent than for multiple drops.

Given that the tumble test is superior to the drop test in fines generation and that the two tests are equally effective in reducing the characteristic size and in challenging the pellet integrity, only the tumble test was considered in further evaluations.

Table B-12 presents the results of analyzing the tumble test durability of 1/2-in. pellets based on ten replicates. On the average, the characteristic length was reduced by 5 mm with a standard deviation of 1.9. This translates to a 95 percent confidence interval of 5.0 ± 1.3 mm. A minimum of four replicates are required in order to determine the mean reduction in characteristic length with 95 percent confidence in a maximum error of ± 2 mm.

TABLE B-10. DROP SHATTER DURABILITY TEST: CHARACTERISTIC SIZE

		Production Conditions			Initial			Final				
Number of drops	Production date	Grid size (inches)	Die size (inches)	Number of replicates	Mean characteristic size (mm)	Standard deviation	95% Confidence interval	Mean characteristic size (mm)	Standard deviation	95% Confidence interval	Reduction in characteristic size (mm)	Size stability factor* (%)
10	11/09/84	1	1/2	5	30.1	1.8	27.9 - 32.3	25.3	1.6	23.3 - 27.3	4.8	84
20	11/09/84	1	1/2	3	34.5	1.8	30.0 - 39.0	29.0	1.0	26.5 - 31.5	5.5	84
30	11/09/84	1	1/2	2	35.0	3.5	4.0 - 66.5	27.3	0.4	23.7 - 30.9	7.7	78

* Size stability factor = final size ÷ initial size × 100.

TABLE B-11. DROP SHATTER DURABILITY TEST: FINES GENERATION

Number of drops	Production date	Production Conditions		Number of replicates	Initial			Final			Increase in fines percent
		Grid size (inches)	Die size (inches)		Mean percent fines	Standard deviation	95% Confidence interval	Mean percent fines	Standard deviation	95% Confidence interval	
10	11/09/84	1	1/2	5	0.8	0.1	0.7 - 0.9	1.2	0.1	1.1 - 1.3	0.4
20	11/09/84	1	1/2	3	0.7	0.2	0.2 - 1.2	1.1	0.2	0.6 - 1.6	0.4
30	11/09/84	1	1/2	2	0.7	0.1	0.0 - 1.6	1.4	0.1	0.5 - 2.3	0.7

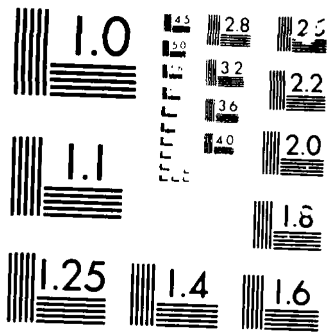
TABLE B-12. RDF-5 DURABILITY, TUMBLE TEST, 10 MINUTES
(October 9, 1984, 1 1/2-in. grid, 1/2-in. die)

Replicate	Initial characteristic size (mm)	Final characteristic size (mm)	Difference in characteristic size (mm)	Size stability factor* (%)	Initial fines content (%)	Final fines content (%)	Difference in fines content (%)
1	32	25	7.0	78.1	0.1	0.7	0.6
2	27.5	24	3.5	87.3	0.6	1.3	0.7
3	28	22.5	5.5	80.4	1.0	1.6	0.6
4	32.5	24	8.5	73.8	0.5	1.1	0.6
5	30	25	5.0	83.3	0.5	1.2	0.7
6	31	25	6.0	80.6	0.4	1.1	0.7
7	28	25	3.0	89.3	0.5	1.2	0.7
8	30	25	5.0	83.3	0.2	0.8	0.6
9	26	24	2.0	92.3	0.5	1.2	0.7
10	26	22	4.0	84.6	1.0	0.3	0.8
Mean	29.1	24.2	5.0	83.3	0.5	1.2	0.7
Standard deviation	2.3	1.1	1.9	5.5	0.3	0.3	0.1
95% confidence interval	27.5 - 30.7	23.4.- 25.0	3.7 - 6.3	79.4 - 87.2	0.3 - 0.7	1.0 - 1.4	0.6 - 0.8

* Size stability factor = final size ÷ initial size × 100.

AD-A168 906 OPERATIONAL TEST REPORT: EFFECTS OF MOISTURE AND COMPOSITION ON DENSIFIED..(U) SYSTECH CORP XENIA OH G SMITH ET AL. APR 86 NCEL-CR-86.010 N00123-83-D-0149 2/2

UNCLASSIFIED F/G 21/4 NL



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Another way of presenting the same data is to calculate the size stability factor (final size divided by initial size times 100). On the average, the pellets retained 83.3 percent of their original size with a standard deviation of 5.5 percent, which yields a confidence interval of 83.3 ± 3.9 percent. At least three replicate analyses are required in order to determine the size stability with a maximum error less than 5 percent.

The fines generation values (percent of the mass of the sample that turned into sievable fines at less than 1/4 in.) for ten replicate analyses averaged 0.7 percent with a standard deviation of 0.1. This information yields a confidence interval of 0.7 ± 0.1 percent. To estimate the fines generation with a maximum error of ± 0.1 percent, requires at least four replicate analyses.

B.3.10 RDF-5 Funnel Angle (see Appendix J)

When pellets are allowed to flow freely through a gate in the bottom of a storage bin or hopper, a funnel-shaped hole is formed in the stored mass around the discharge aperture. The angle of the sides of that hole is referred to as the funnel angle. It has been observed that RDF-5 (especially with a large percentage of fines) will frequently form very steep funnel angles. This results in the need for mechanically-assisted or manual emptying of the bin contents. The funnel angle may thus be useful to design engineers in developing appropriate RDF-5 storage facilities and may also allow for the specification of a flow property that will avoid fuel storage and handling problems with specific lots of RDF-5.

Using a technique developed at SYSTECH, the funnel angle is determined experimentally by filling a box (18 in. × 14 in. × 12 in.) with RDF-5 and allowing the pellets to exit through a trapdoor centrally located in the bottom of the box. The angle formed by the surface of the pellets remaining in the box with the horizontal (see Figure J-1) is measured with a large protractor and reported as the funnel angle.

The results of determining the funnel angle on several production lots of pellets is presented in Table B-13. Though the funnel angle can be determined with a precision of the mean of ±1.3 degrees, there was no difference in the results for the various lots. This result is as expected since previous studies performed by SYSTECH (U.S. Army Contract No. CERL-ES-074, "Effects of Physical Properties of Densified Refuse-Derived Fuel on Flow Characteristics") have indicated that at higher levels of fines (>10 percent) a strong correlation between fines content and funnel angle exists. All production lots evaluated in this work had fines content of less than 5 percent.

B.3.12 Water Absorption (see Appendix G)

It can be readily observed that when RDF-5 comes into contact with water, it swells to three to five times its original pellet size and upon subsequent handling rapidly disintegrates to an unconsolidated pulpy mass. This type of hydrophilic deterioration is often observed as the result of less than ideal storage conditions (i.e., yard storage) and gives rise to a multitude of material handling and combustion problems. The ability to resist moisture absorption is considered a desirable RDF-5 characteristic. The "Proposed Standard Method for Measuring Hydrophilia of RDF-5," ASTM E38.08.37, presents a procedure for determining how much water can be absorbed by RDF-5 in a rigidly controlled, simulated rainfall situation. The proposed method requires an accurately timed series of ten wetting and draining cycles with a total elapsed time of approximately 3 hours. This proposed method was not evaluated because of excessive manpower requirements.

TABLE B-13. RDF-5 FUNNEL ANGLE

	Production Conditions					
Production date	Grid size (inches)	Die size (inches)	Number of replicates	Mean funnel angle (degrees)	Standard deviation	95% Confidence interval
10/01/84	1	3/4	20	51.5	2.9	51.1 - 52.9
10/03/84	1 1/2	3/4	20	49.9	2.4	48.8 - 51.0
10/09/84	1 1/2	1/2	20	50.3	3.0	48.9 - 51.7
10/17/84	1 1/2	3/4	10	50.0	1.8	48.7 - 51.3
11/09/84	1	1/2	20	50.2	2.4	49.1 - 51.3
11/13/84	1	3/4	20	52.7	2.6	51.5 - 53.9

The water absorption procedure developed and evaluated in this program is performed in conjunction with the pellet density procedure and takes only a few additional minutes. Although the resultant standard deviations are significantly larger than those reported for the ASTM method, the resultant precision is adequate to distinguish significant differences in the hydrophilic tendencies of the pellets produced.

During the density procedure, as the 250-gram sample of pellets is submerged in the graduated cylinder to determine its volume, a stop watch is started and the elapsed time that the pellets are submerged is controlled. It was determined empirically that being submerged for 2 minutes results in significant water weight gain without totally saturating the pellets and thus gives a measure of resistance to moisture absorbency rather than total water capacity. At the end of 2 m.nutes, the pellets are transferred onto an 8-in. diameter sieve whose openings are approximately one fourth the diameter of the pellets (one half the size of a fines sieve) and the excess water is rapidly shaken off by rapping the sieve and pellets sharply on a counter top or other solid surface several times. The pellets are then reweighed to determine their water weight gain.

The water absorption data resulting from the evaluation of seven lots of pellets is presented in Table B-14. On the average, for all pellets, the 95 percent confidence interval was approximately the mean percent weight gain ± 3.5 percent. It is readily observed that the 1/2-in. pellets were much more consistent (lower standard deviation) on the average than the 3/4-in. pellets. Analysis of 1/2-in. pellets in the future will require only three replicates to estimate the mean weight gain with a maximum error of ± 2.0 percent. To lower this maximum error to ± 1 percent would require approximately nine replicates. For the analysis of 3/4-in. pellets, 16 replicate analyses would be required to be 95 percent confident in a maximum error of ± 2.0 percent, but if a maximum error of 5 percent were tolerable, only 3 replicates would be required.

TABLE B-14. RDF-5 WATER ABSORPTION

	Production Conditions					
Production date	Grid size (inches)	Die size (inches)	Number of replicates	Mean weight gain (%)	Standard deviation	95% Confidence interval
10/03/84	1 1/2	3/4	10	60.9	5.3	57.1 - 64
10/09/84	1 1/2	1/2	10	19.2	1.6	18.1 - 20
10/17/84	1 1/2	3/4	5	51.1	4.2	45.9 - 56
11/09/84	1	1/2	5	23.6	1.4	21.9 - 25
11/13/84	1	3/4	5	35.8	1.2	34.3 - 37

APPENDIX C

ASTM PROPOSED TEST METHOD FOR TOTAL MOISTURE (SINGLE STAGE) IN RDF-3 SAMPLES

1.0 SCOPE

1.1 This method covers the measurement of total moisture in refuse-derived fuel (RDF) RDF-3 as it exists at the site, at the time, and under the conditions it is sampled.

1.2 Emphasis must be placed on the proper collection of a gross sample that is representative of the lot to be analyzed. Care must be taken to assure that the moisture conditions of all samples are preserved between the time of original sampling and laboratory analysis of the sample.

2.0 APPLICABLE DOCUMENTS--ASTM STANDARDS

E829-81 Standard Method of Preparing RDF-3 Samples for Laboratory Analysis.

Proposed Standard Sampling Procedure for RDF-3 Collection and Division of a Gross Sample.

3.0 SUMMARY OF METHOD

A RDF-3 laboratory sample is dried under specified conditions to determine total moisture.

4.0 DEFINITIONS

4.1 Analysis Sample

A representative 250-gram portion of the laboratory sample.

4.2 Lot

A large designated quantity of RDF-3, usually a shipment or production period.

4.3 Gross Sample

A sample representing a lot of RDF-3 and composed of a number of increments on which neither reduction nor division has been performed.

4.4 Laboratory Sample

A representative portion of the gross sample delivered to the laboratory for further analysis.

4.5 Precision

A term used to indicate the capability of a person, of an instrument, or a method to obtain reproducible results; specifically a measure of the chance error as expressed by the variance, the standard error of a multiple of the standard error (see Recommended Practice E177).

4.6 Representative Sample

A sample collected in such a manner that it has characteristics equivalent to the lot sampled.

4.7 Sample Division

The process whereby a sample is reduced in weight without change in particle size or other characteristics.

4.8 Bias (Systematic Error)

An error that is consistently negative or consistently positive. The mean of errors resulting from a series of observations that does not tend towards zero.

5.0 APPARATUS

5.1 Drying Oven

A large chamber, mechanical draft oven capable of maintaining a controlled temperature between the limits of 100° and 110°C may be used. One air change per minute should be satisfactory. Air flow should be baffled to prevent any sample loss due to air currents.

5.2 Drying Pan

A noncorroding pan or fine mesh basket to be used for holding the sample during the drying process. Pan size will vary with the size of the sample dried. If a fine mesh pan is used, care should be exercised that the mesh does not allow any sample to fall through.

5.3 Balance (Laboratory Sample)

A balance of sufficient capacity to weigh the sample and container with a sensitivity of 0.1 gram in 1000 gram.

6.0 PRECAUTIONS

6.1 Due to the origins of RDF municipal waste, common sense dictates that some precautions should be observed when conducting tests on the samples. Recommended hygienic practices include use of gloves when handling RDF, wearing NIOSH approved type dust masks (especially while shredding RDF samples), conducting tests under a negative pressure hood when possible, and washing hands before eating or smoking.

6.2 Prior to moisture analysis, RDF samples should be protected from moisture change due to exposure to rain, snow, wind, and sun or contact with absorbent materials. It may be desirable that samples be kept refrigerated until analyzed.

7.0 SAMPLING

7.1 The gross sample should be collected in accordance with the Proposed Sampling Procedure for RDF-3 Collection and Division of a Gross Sample.

7.2 The laboratory sample should be taken from the gross sample by division.

7.3 The analytical sample mass should be 250 gram ± 5 percent.

7.4 The sample must be stored in an airtight container prior to analysis.

8.0 PROCEDURE

8.1 The tare weight of a clean, empty drying pan is obtained to an accuracy of 0.1 gram.

8.2 The 250-gram sample of RDF-3 is placed in the drying pan. A maximum sample depth of 5 to 10 cm is recommended. The pan and sample are weighed to 0.1 gram.

NOTE 1: If a mesh-type pan is used, a clean sheet of aluminum foil should be placed under the pan to check for any sample "fall through." If any occurs, a smaller mesh drying pan is required.

NOTE 2: Due to difficulty in the division of RDF-3 laboratory samples to obtain representative sample splits, it is recommended that the gross RDF sample be divided such that it is possible to use the entire RDF laboratory sample for the moisture test.

8.3 Place the pan and sample in the drying oven at 107° ± 3°C for a minimum of 2 hours.

NOTE 3: Sample should be observed periodically to make certain that the sample does not decompose or ignite at this temperature.

8.4 After no less than a 2-hr drying time, the pan and sample are removed from the oven and quickly weighed to the nearest 0.1 gram.

8.5 The sample and pan are placed in the oven for at least 1 additional hour at 107° ± 3°C.

8.6 The sample and pan are again removed and weighed to the nearest 0.1 gram. If the sample weight loss was less than .1 percent per hour of the original sample weight, the determination is complete; if not, Section 8.5 and 8.6 should be repeated.

NOTE 4: At this point, the dried sample can be used for further analysis, if desired.

9.0 CALCULATIONS

$$M_{ss} = \frac{W_I - W_F}{W_I} \times 100$$

M_{ss} = Total moisture (single-stage method).

W_I = Initial net weight of sample before drying.

W_I = Final net weight of sample after drying.

10.0 PRECISION

To be determined.

APPENDIX D

MODIFIED ASTM E828-81
NEW STANDARD METHOD OF DESIGNATING THE SIZE OF RDF-3 FROM ITS SIEVE ANALYSIS

1.0 SCOPE

1.1 RDF is defined as a shredded refuse fuel, supplementing fuel burned in utility or industrial boilers that have ash handling capabilities. Using a front-end separation system, metal, glass, and other inorganics are first removed. The remaining organic fraction, processed to relatively uniform size particles, is RDF. It can be transported to the site of existing boilers.

RDF is a form of fuel derived from the communities' waste and may be subclassified as follows:

RDF-1 - Wastes used as a fuel in its as-discarded form.
RDF-2 - As-discarded wastes processed to coarse particle size with or without ferrous metal separation.
RDF-3 - Combustible waste fraction processed to particle sizes--95 percent passing 2-in. square screening.
RDF-4 - Combustible waste fraction processed into powder form--95 percent passing No. 10 mesh screening.
RDF-5 - Combustible waste fraction densified (compressed) into the form of pellets, slugs, cubettes, or briquettes.
RDF-6 - Combustible waste fraction processed into liquid fuel.
RDF-7 - Combustible waste fraction processed into gaseous fuel.

1.2 This method of designating the size of RDF from its sieve analysis is applicable to the classified light fraction (RDF-3) of shredded municipal or industrial waste materials less than 0.15 meter (6 in.) in size.

2.0 APPLICABLE DOCUMENTS--ASTM STANDARDS

E177 Recommended Practice for Use of the Terms Precision and Accuracy as applied to Measurement of a Property of Material.

E11-70 Standard Specification for Wire-cloth Sieves for Testing Purposes.

D2234-72 Standard Methods for Collection of a Gross Sample of Coal.

3.0 SUMMARY OF METHOD

This method covers the separation of an RDF sample into defined size fractions and expressing said fractions as a weight percent of an air-dried sample.

4.0 SIGNIFICANCE AND USE

The purpose of this standard is to provide a method for the size classification of RDF-3 for use by consumers and producers of RDF-3.

5.0 DEFINITIONS

5.1 Air-Drying

A process of partial drying of RDF-3 to bring its moisture content near to equilibrium with the atmosphere in the room in which the sieving is to take place.

5.2 Representative Sample

A sample collected in such a manner that it has characteristics equivalent to the material being sampled.

5.3 Sample Division

The process of extracting a smaller sample from a gross sample wherein the representative properties of the large sample are retained.

5.4 Gross Sample

A sample representing a lot of RDF and composed of a number of increments on which neither reduction nor division has been performed.

5.5 Lot

A large designated quantity of RDF-3.

5.6 Laboratory Sample

A representative portion of the gross sample delivered to the laboratory for further analysis.

6.0 APPARATUS

6.1 Sieves

6.1.1 Drying oven, forced-draft type, capable of maintaining a temperature of 107 ± 3°C and so constructed that fresh air is introduced to all parts of the oven to ensure the removal of moisture-laden air.

6.1.2 Use sieves conforming to ASTM specification E11-70 for wire cloth for testing purposes. For recommended sizes, see Addendum I.

6.1.3 For RDF-3 and larger than 50-mm (2-in.) screens having rectangular frames 0.6 to 0.7 meter^2 (6 to 8 ft^2) sieve area are satisfactory.

For RDF-3, 50-mm (2-in.) or smaller, rectangular frames having 0.2 to 0.4 meter^2 (2- to 4-ft^2) sieve area are satisfactory.

For RDF-3 smaller than 0.01 meter (0.5 in.) circular sieves, 0.3 meter (12 in.), or 0.2-meter (8-in.) in diameter are satisfactory.

6.2 Sieving Devices (Addendum II)

6.2.1 Hand sieving is permissible.

6.2.2 Sieving machines which provide the necessary agitation and tumbling action may be used.

(1) Gilson testing screen Model TS-1 having six screens and a pan, 0.46 meter by 0.66 meter (18 × 26 in.), has been found to be satisfactory for RDF-3 under .05 meter (2 in.) when equipped with a special low-amplitude drive shaft.

(2) Rainhart Rotary Pan Sieve using 300 mm (12 in.) or 200 mm (8 in.) circular sieves has been found to be satisfactory for RDF-3 under 12.5 mm (0.5 in.) in size.

(3) A Ro-tap screening machine with 200 mm (8 in.) circular sieve has been found to be satisfactory for RDF-3 under 12.5 mm (0.5 in.) in size.

6.3 Balance (Laboratory Sample)

A balance having sufficient capacity to weigh the sample and container with a sensitivity of 0.1 gram in 1000 gram.

7.0 PRECAUTIONS

Due to the origins of RDF-3 in municipal waste, common sense dictates that some precautions be observed when conducting tests on the samples. Recommended hygienic practices include use of gloves when handling RDF-3, wearing NIOSH-approved type masks (especially while shredding RDF-3 samples), conducting tests under a negative pressure hood when possible, and washing hands before eating or smoking.

8.0 SAMPLING

8.1 Collect increments, regularly and systematically, so that the entire quantity of RDF sampled will be proportionately representative in the gross sample, and with such frequency that a gross sample of the required amount shall be collected. No sampling procedure shall be used which alters the particle size distribution.

The sampling procedures to be used, the number and size of samples required to obtain a representative sample, and the method of division of the gross sample into the laboratory sample shall be established in accordance with an agreement between purchaser and supplier.

The number and size of samples required may be determined by Standard Method D 2234; a method for determining the random variance and segregation variance caused by nonrandom distribution of the ash content in the lot. This method involves the collection of two sets of 30 samples from a stopped conveyor. The first set includes 30 very small samples to furnish data for the random variance; the second set includes 30 large samples to furnish data for the segregation variance. Since one of the important components of variance is that due to segregation, it is essential that the 30 large samples be so distributed with respect to time that coverage of all fractions of RDF are represented.

Division of the gross sample into the laboratory sample may be done by coning and quartering or by use of a mechanical sample splitter.

8.2 The sample shall be approximately 50 gram in weight.

8.3 The sample shall be air dried.

9.0 PROCEDURE

9.1 Weigh the air-dried sample.

9.2 Machine sieving.

(1) When sieving machines are used, their thoroughness of sieving shall be tested by comparison with hand methods.

(2) Stack the sieves progressively starting with the smallest aperture size above the pan to the largest aperture size at the top.

(3) Introduce the air-dried sample above the largest screen in small enough increments such that matting of the material does not occur to an extent that prevents the under-size materials from reaching and passing the screen.

The amount of RDF-3 added to the top screen in any increment must not exceed one-third of the volume of the screen, in order to prevent matting or blinding.

(4) After adding each increment, assemble the pans or trays in the machine and turn on agitation for 10 minutes or up to 15 minutes, if necessary, to complete screening.

Inspect each screen for evidence of matting. If a screen is mostly or entirely covered with a mat, decrease the size of the initial increments such that no mat forms on any sieve, and repeat the tests.

(5) When sieving of each increment is complete, the weight of material remaining on each screen shall be promptly determined to the nearest 0.1 gram.

If more than one increment is sieved to pass the entire sample, add the incremental weights remaining on each sieve.

If the sum of the weights shows a loss of 2 percent or more, reject the analysis and make another test using a second sample.

NOTE 1: The sand and glass contained in a sample of RDF-3 has a strong tendency to segregate from the light fraction. For this reason, great care must be taken to include the entire sample in the sieve analysis. When a sample is divided, the sand will probably not divide equally into the sample portions.

Samples may be divided for convenience in feeding the sieving apparatus, but the weights of all portions of the sample must be properly summed so that the entire sample has been included in the sieve analysis.

NOTE 2: Some abrasion and physical degradation of the sample by the screen can occur during the sieving operation. The analyst shall monitor and report his observations of any sample degradation.

10.0 REPORT

10.1 Report the weights of the size fractions as a percentage of the weight of the air-dried laboratory sample of RDF-3. Calculate to the nearest 0.5 percent the percentages of the size fractions remaining on each sieve and the percentage passing through the smallest aperture sieve.

A suitable report form is given in Addendum III.

10.2 Record the results starting with the larger aperture size. If desirable, the percentage can also be reported on a cumulative basis as "cumulative percentage greater than size" or "cumulative percentage less than size" where size refers to sieve aperture size or mesh number.

10.3 The graphical form is suitable for recording the sieve analysis data for determining the percentage retained, for the cumulative percentage, and for plotting the cumulative percentage on the Rosin-Rammler graph.

The characteristics of the size distribution can be determined from the plotted cumulative percentage, resulting in a distribution coefficient "n"; and an absolute constant, or mean particle size "x"; in accordance with the techniques of Rosin-Rammler analysis.

The procedure for determining these coefficients is as follows:

1. Plot "percent cumulative greater than size" against size on the graphical form.

2. Draw a straight line through the plotted points.

3. Read the size at 36.79 percent. This is the characteristic size.

4. Select two points, "A", one screen size less than and "B", one size greater than the characteristic size, lying on a straight line drawn through the plotted points.

Measure the horizontal distance of points A and B from the left axis in mm (or inches) and enter them in the table "characteristics" along with the percentage retained. Take the difference between x and y.

The distribution coefficient, "n", is the slope of the line.

Measure the horizontal distance, "x", of points A and B from the left vertical axis and record in the table "characteristics."

Measure the vertical distance, "y", of points A and B from the bottom axis. Record in the table and subtract the x and y measurements to obtain the differences.

11.0 PRECISION AND ACCURANCY

To be determined.

APPENDIX E

SYSTECH DRAFT METHOD, RDF-3, BULK DENSITY

1.0 SCOPE

This method covers the determination of the minimum bulk density of RDF-3 at the time and place of sampling and as influenced by its current state of storage.

2.0 SUMMARY OF METHOD

A container with known volume, such as a 55-gal drum, is filled with RDF-3 in a controlled manner and weighed in order to determine the weight per unit volume of the loose, uncompacted RFD-3.

3.0 SIGNIFICANCE AND USE

The bulk density of RDF-3 may be of use to engineers in designing or specifying storage facilities, transportation, and materials handling equipment for RDF-3 production, transportation, or utilization systems. Due to the highly compressible nature of RDF-3 when under load (such as when in a deep bin or high pile), and its rather limited elastic rebound properties, the results of this procedure must be considered as a relative guide to the original as-produced, fully-fluffed bulk density of the material. A statement as to the storage conditions or production status of the material is helpful in the interpretation and application of the resultant measurement data.

4.0 APPARATUS

4.1 Container with known volume, at least 7 ft^3 (e.g., 55-gal drum). Container volume may be calibrated by filling with water and obtaining the weight of the water.

4.2 Scale capable of weighing the sample and container to within 1 lb.

5.0 PROCEDURE--LOOSE BULK DENSITY

5.1 Record the weight of the empty container to within 1 lb.

5.2 Fill container by passing the RDF-3 through a screen with openings of 3 to 5 times the nominal particle size such that it is level with the top edge of the container. The screen is used to break up any material matts and to provide a mechanism for evenly filling the container. Do not shake the container or compact the sample.

5.3 Record the weight of the sample and container to within 1 lb.

6.0 CALCULATIONS

Bulk density is calculated as:

$$B = \frac{W_{S/C} - W_C}{V_C}$$

Where:

B = Bulk density, lb/ft^3.

$W_{S/C}$ = Gross weight sample and container.

W_C = Net container weight.

V_C = Volume of container (ft^3).

7.0 REPORTING

Report bulk density in lb/ft^3, specified as loose bulk density. Describe the conditions under which the RDF-3 was acquired; i.e., as produced, from bin storage, from transfer trailer, from pneumatic system, etc.

8.0 PRECISION

To be determined.

9.0 ACCURANCY

To be determined.

APPENDIX F

SYSTECH PROPOSED STANDARD METHOD FOR MEASURING BULK DENSITY OF RDF-5

1.0 SCOPE

1.1 This method determines the bulk density of RDF-5. Bulk density is determined by weighing a known volume of sample.

1.2 Bulk density may be determined for as-produced, as-received, or air-dried RDF-5.

2.0 APPLICABLE DOCUMENTS--PROPOSED ASTM STANDARDS

2.1 Collecting and Dividing a Gross Sample of RDF-5.

2.2 Air-Drying RDF-5 for Further Analysis.

3.0 SIGNIFICANCE AND USE

Bulk density characterizes the storage, handling, and transportation properties of RDF-5 and provides data which can be used by designers and plant engineers.

4.0 TERMINOLOGY

RDF-5 - solid fuel derived from municipal solid waste in which the processed combustible fraction is densified (compressed) into the form of pellets, cubettes, or briquettes.

5.0 APPARATUS

5.1 Any container whose volume can be accurately measured and is within the range of 1/2 to 2 ft^3. A plastic 5-gal (.7 ft^3) bucket is satisfactory.

5.2 Leveler - a straight-edge used to scrape off excess sample. The leveler should be longer than the container is wide.

5.3 Balance - a weight measuring device accurate to 0.5 lb (0.2 kg).

6.0 PROCEDURE

6.1 Record the mass of the empty container to within 0.5 lb (0.2 kg).

6.2 Slightly overfill the container with RDF-5. Bring the sample level with the top edge of the container by using the leveler to scrape off the excess sample.

6.3 Record the weight of the container and sample to within 0.5 lb (0.2 kg).

7.0 CALCULATIONS

The bulk density is calculated as follows:

$$B = \frac{W_{sb} - W_b}{V}$$

where:

B = Bulk density in lb/ft3 (kg/m3).

W_{sb} = Weight of sample and container in lb (kg).

W_b = Weight of container in lb (kg).

V = Volume of container ft^3 (m^3).

8.0 REPORT

8.1 Bulk density, B, shall be reported in units of lb/ft3 (kg/m3).

8.2 Bulk density shall be reported on an as-received or air-dried basis.

APPENDIX G

SYSTECH TEST METHOD FOR DETERMINING PELLET DENSITY AND WATER REPELLENCY OF RDF-5

1.0 SCOPE

1.1 This method determines two characteristics of RDF-5: the pellet density, or mass per unit volume; and the resistance of the pellets to absorbing water; i.e., their water repellency.

1.2 This method is most directly applicable to pellet and briquette forms of RDF-5 with densities greater than water (>1.0 gram/cc). Variations on the procedure may be agreed upon by the involved parties as being applicable to the characterization of larger forms of RDF-5 (cubettes and loggettes) or to the characterization of less dense forms of RDF-5 (<1.0 gram/cc).

2.0 APPLICABLE DOCUMENTS--ASTM STANDARDS

Air Drying RDF-5 Samples.
Determination of the Size Distribution of RDF-5.

3.0 SUMMARY OF METHOD

This method is first used to determine gravimetrically the mass of a representative sample of RDF-5. The volume of the weighed sample is then determined by water displacement and the mass per unit volume calculated. By weighing the wetted sample after the water displacement volume determination, the water weight gain of the sample is determined. The percent water weight gain is inversely proportional to the ability to resist absorbing water, the water repellency.

4.0 SIGNIFICANCE AND USE

4.1 The pellet density of RDF-5 is an indication of the effectiveness of the densification system and can be used to compare various densification processes. It is also useful in predicting the handling, storage, and combustion characteristics of the RDF and may therefore be used in as a purchase specification.

4.2 The water repellency of the pellets indicate their short-term tolerance to exposure to moisture under less than ideal storage, handling, and weather conditions. A favorable result for this characteristic does not however indicate a tolerance to long-term exposure to weather. All experience to date indicates that long-term exposure to weather results in significant particle deterioration. Water repellency may be used in a purchase specification.

5.0 PROCEDURE

5.1 Acquire a representative 1-kg laboratory sample from the gross sample by division.

5.2 Air dry the laboratory sample as per ASTM E38.08-3.1 air drying RDF-5 samples.

5.3 Split the sieved laboratory sample into four equal analytical samples of approximately 250 gram each by division.

5.4 Sieve the four laboratory samples to remove the fines content. The fines sieve is defined as having openings equal to one-half the diameter of the pellets or one-half the least dimension of the briquettes.

5.5 Determine the mass of the first analytical sample to the nearest 0.1 gram. Record the initial sample mass, M_i.

5.6 Place approximately 500 cc of room temperature water in a 1-liter clear plastic graduate cylinder and estimate the volume of water to the nearest ml. Record the initial volume, V_i.

5.7 Immediately after starting a stop watch or observing the start time, rapidly pour the entire sieved, weighed analytical sample into the graduate cylinder. During the next minute, dislodge as many of the air bubbles as possible by gently tapping the sides and bottom of the graduate cylinder against the edge and top of the work table. Do not stir the pellets or expect to be able to dislodge the smaller air bubbles.

5.8 Before the end of the first minute, observe the combined volume of the water and pellets in the cylinder to at least the nearest 5 cc. Record the final volume, V_f.

5.9 Allow the pellets to soak in the graduate cylinder for an additional 1 minute, giving a total submerged time of 2 minutes. Place the fines sieve over a sink or other water receptacle and at the end of 2 minutes, quickly dump the contents of the cylinder into the fines sieve allowing the majority of the water to drain off. For the next 15 seconds, dislodge from the pellets as much of the remaining water as possible by alternately shaking and then sharply rapping the sieve on a solid surface five to ten times.

5.10 Transfer the pellets from the sieve to a tared container and determine their wetted mass to the nearest 0.1 gram. Record the final mass, M_f.

5.11 Repeat the above Steps 5.5 through 5.10 for the remaining three analytical samples.

6.0 REPORT

Calculate the particle density and the water repellency of each of the four analytical samples as described below. Average the four values obtained and report the mean value for each characteristic.

6.1 Particle Density Calculation

Calculate the mass (grams) per unit volume (cubic centimeters) of the fuel particles as follows:

$$Dp = M_i/(V_f - V_i)$$

Where:

D_p = Particle density, gram/cc.
M_i = Initial net mass of the sample, gram.
V_f = Final volume of water and fuel particles, cc.
V_i = Initial volume of water, cc.

6.2 Water Repellency Calculation

Calculate the water repellency of the sample as follows:

$$R = 1 - ([W_f - W_i] / W_i) \times 100$$

Where:

R = Water repellency of the fuel particles, percent.
W_f = Final (wetted) net mass of the sample, gram.
W_i = Initial net mass of the sample, gram.

6.3 Reporting the Mean Values

Calculate and report the average values for density and water repellency from the results of the four analytical samples.

7.0 PRECISION

To be determined.

8.0 BIAS

NOTE: RDF-5 particles that have considerable surface texture, such as those that have been subjected to excessive moisture or long-term storage under less than ideal storage conditions (high humidity), tend to trap small air bubbles which exaggerate the apparent volume when using this procedure. Qualitative reports of the relative condition of the pellets are useful in the interpretation of the data.

APPENDIX H

SYSTECH DRAFT METHOD FOR MEASURING
PARTICLE SIZE DISTRIBUTION OF RDF-5

1.0 SCOPE

1.1 This method is used to determine the size distribution of a pelletized RDF-5 sample. Size is defined as the maximum length of the particle, where length is determined by the RDF-5 manufacturing process.

1.2 An air-dried RDF-5 sample is separated into categories of differing particle sizes. The size distribution is measured as the weight percentage of each size category. A graph of the cumulative weight fractions of the sample versus particle size is plotted. From this plot are taken values which describe the size distribution and the characteristic particle size.

1.3 This method of measuring size by hand allows accurate description of RDF-5 particle size distribution. Measurement by hand is superior to sieving techniques, wherein particles may be broken by the size separation technique itself. However, hand measurement is more time-consuming than sieving techniques.

2.0 APPLICABLE DOCUMENTS--PROPOSED ASTM STANDARDS

2.1 Collecting and Dividing a Gross Sample of RDF-5.

2.2 Air Drying RDF-5 for Further Analysis.

3.0 SIGNIFICANCE AND USE

3.1 The particle size distribution of RDF-5 strongly influences the combustion, storage, and handling characteristics of the fuel. Small particles tend to block the flow through storage bins and feed hoppers, although correct bin and hopper designs will alleviate this problem of blockage.

4.0 TERMINOLOGY

RDF-5 - solid fuel derived municipal solid waste in which the processed combustible fraction is densified (compressed) into the form of pellets, cubettes, or briquettes.

5.0 APPARATUS

5.1 Containers

Any suitably sized containers of appropriate materials to hold the particles which are separated according to size (pint-size plastic freezer containers are suitable). The tare weight of each container shall be recorded to the nearest 0.1 gram. These containers may be labelled according to size categories as defined in Section 6.0.

5.2 Balance

A device capable of weighing the sample and container with a precision of ± 0.1 gram.

5.3 Modified Ruler

A linear scale with increments marked in multiples of the pellet diameter.

6.0 PROCEDURE

6.1 The sample shall weigh 1.0 ± 0.1 kg (2.2 ± 0.2 lb) unless otherwise specified. Record the weight of the sample to the nearest 0.1 gram.

6.2 Beginning with the largest particles, separate the pellets into size groups that are defined by multiples of the pellet diameter, such as less than one diameter, one to less than two diameter, two diameter to less than three diameter, etc., and fines (the sievable fraction at less than one-half the diameter).

6.3 Record the weight of each size category to the nearest 0.1 gram.

6.4 Sum the weights of the size components. If this sum differs by more than one percent from the sample weight recorded initially, then reject the analysis and begin another test.

6.5 Use the sum of the separate size categories as the total weight to determine weight percentages of each size fraction.

7.0 CALCULATIONS

For each size category, calculate the cumulative percent less than the top size. Plot the cummulative percents versus top size on Rosin Rammler graph paper. Draw a straight line through all points, excluding fines. Read X_i, the characteristic size, as the value where the line crosses 36.79 percent oversized. Measure the slope of the line and report this as n, the distribution coefficient.

8.0 REPORT

Report the distribution coefficient, n (a dimensionless number); X_i, the characteristic size in millimeters; and the percent fines.

9.0 PRECISION

To be determined.

APPENDIX I

PROPOSED ASTM STANDARD METHOD FOR MEASURING TUMBLER DURABILITY OF RDF-5

1.0 SCOPE

1.1 This method covers the measurement of the relative durability of RDF-5 when subjected to impact and abrasion.

1.2 A sample of air-dried RDF-5 is tumbled in a rotating box at a specified rate of rotation and time. The size distributions determined before and after tumbling are used to derive D, the RDF-5 durability rating.

2.0 APPLICABLE DOCUMENTS--PROPOSED ASTM STANDARDS

2.1 Measuring Particle Size Distribution of RDF-5.

2.2 Collecting and Dividing a Gross Sample of RDF-5.

2.3 Air Drying RDF-5 for Further Analysis.

3.0 SIGNIFICANCE AND USE

3.1 The particle size distribution of RDF-5 strongly influences the storage and handling characteristics of the fuel. The formation of small particles tends to restrict flow through storage bins and feed hoppers.

3.2 This method of measuring the durability or resistance to breakage of RDF-5 allows prediction and comparison of relative size degradation due to impact and abrasion of various RDF-5 types. Durability may be used to rank different types of RDF-5 with regard to breakage during handling and storage.

4.0 TERMINOLOGY

RDF-5 - solid fuel derived from municipal solid waste in which the processed combustible fraction is densified (compressed) into the form of pellets, cubettes, or briquettes.

5.0 APPARATUS

5.1 Tumbler - the box pictured in Figure 1 is entirely closed and dust-proof. Projections, like rivets and screws, should be well-rounded and kept to a minimum. The axis of rotation extends through the box and a break plate is installed to randomize pellet tumbling action.

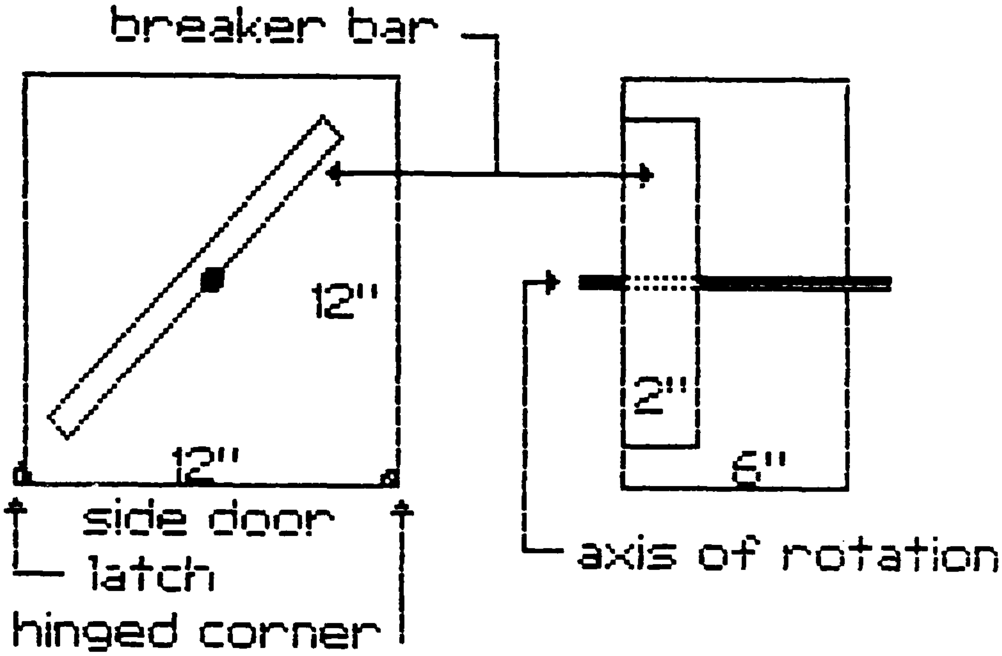

Figure I-1. Tumbler durability box.

6.0 PROCEDURE

6.1 Perform an initial size distribution analysis on an air-dried 1.0 kg laboratory sample of RDF-5 using the proposed standard method for Measuring Particle Size Distribution of RDF-5.

6.2 Place the sample in the tumbler box and secure the cover. Tumble at 50 RPM for 15 minutes.

6.3 Perform a size distribution analysis on the tumbled sample.

7.0 CALCULATIONS

Durability, D, is calculated as follows:

$$D = \frac{X_p}{X_f} 100$$

X_f = The characteristic particle size of the feed.

X_p = The characteristic particle size of the product.

8.0 REPORT

Durability shall be reported as D, percentage of characteristic particle size reduction.

APPENDIX J

SYSTECH DRAFT METHOD FOR DETERMINING THE FUNNEL ANGLE OF RDF-5

1.0 SCOPE

This method simulates the flow of RDF-5 through an opening in the bottom of a bin or hopper and allows measurement of the angle of the formed void, which is funnel shaped. Funnel angle is an important characteristic of flow through an orifice. If flow occurs, the funnel angle is the angle formed between the material that was freely flowing and the nonflowing material. It is measured from the junction of the orifice and the bottom of the container. A small funnel angle has a positive flow effect, while a large funnel angle has a negative flow effect.

2.0 SIGNIFICANCE AND USE

The funnel angle is an important indicator of potential material-handling problems regarding the storage and retrieval of RDF-5. Experience has shown that RDF-5, especially when it contains a large percentage (>10 percent) of fine material (<1/2 diameter), often bridges or forms pipes or rat holes when free-flowing material is removed from the bottom openings of bins, silos, or bunkers. This nonflowing condition results in a requirement for additional manpower or specialized equipment to retrieve the material and may also cause fuel interruptions or erratic flow of fuel to combustion systems. All of the above are undesirable conditions. The funnel angle may serve to forewarn operators or purchasers of the additional costs associated with usage of RDF-5 having an undesirable (high) funnel angle.

3.0 EQUIPMENT

3.1 Flow test box (Figure J-1). One side of the box is made of ®plexiglas to allow measurement of the funnel angle without disturbing the pellets remaining in the box.

3.2 A 2-ft^3 container.

3.3 Protractor.

4.0 PROCEDURE

4.1 Obtain representative samples from the gross sample. Each sample should be approximately 2 ft^3.

4.2 Place the sample in the box. The box should be checked with a carpenters bubble-level to assure that it is level.

4.3 Place the container underneath the orifice.

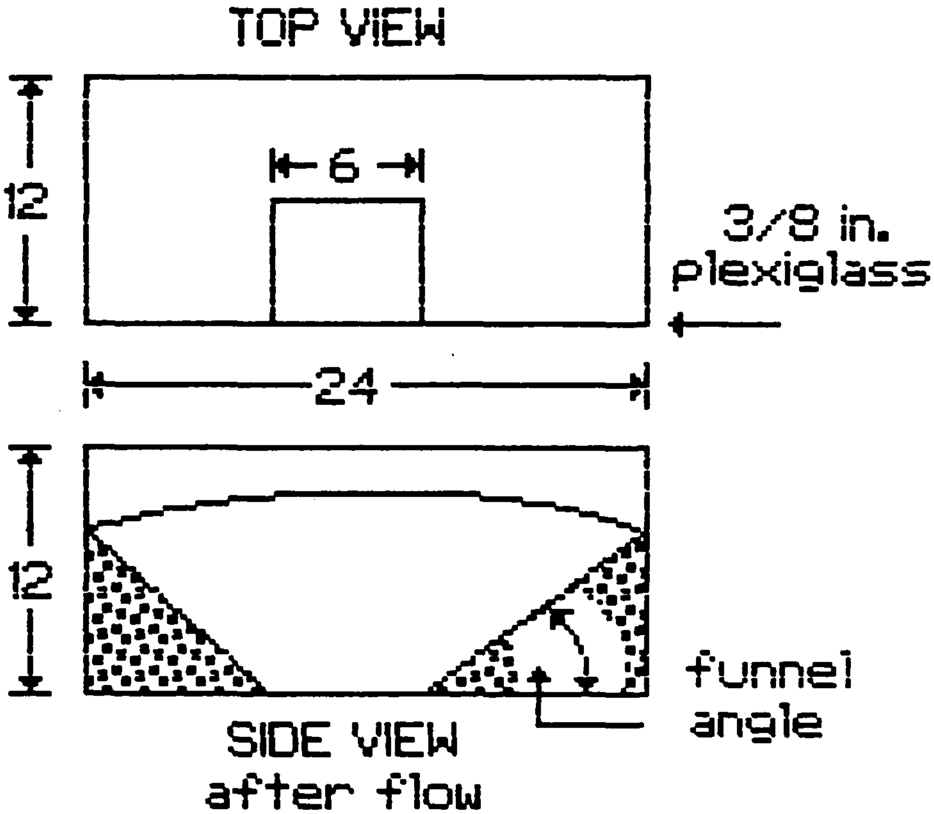

Figure J-1. Flow test box.

4.4 Open the hinged gate.

4.5 When flow stops, measure ana record the angle formed by the RDF-5 remaining in the box and the bottom of the box.

4.6 Repeat the above steps a minimum of five times.

5.0 REPORTING

The angle that the remaining RDF-5 forms with the horizontal level is the funnel angle. This angle is reported for each sample analyzed. An average angle and standard deviation is then reported.

6.0 PRECISION AND BIAS

To be determined.

APPENDIX K

ASTM-PROPOSED STANDARD METHOD FOR MEASURING TOTAL MOISTURE OF RDF-5

1.0 SCOPE

This method covers the one-step measurement of total moisture in RDF-5. The total moisture content is determined by establishing the weight loss of the RDF-5 laboratory sample when it is heated under controlled conditions.

2.0 APPLICABLE DOCUMENTS--PROPOSED ASTM STANDARDS

2.1 Collecting and Dividing a Gross Sample of RDF-5.

2.2 Air Drying RDF-5 for Further Analysis.

3.0 SIGNIFICANCE AND USE

Moisture content is an important factor determining the storage and handling characteristics of RDF-5. High moisture content is associated with RDF-5 particle expansion or "puffing" and size degradation. This method may be used to monitor fuel moisture content.

4.0 TERMINOLOGY

RDF-5 - solid fuel derived from municipal solid waste in which the processed combustible fraction is densified (compressed) into the form of pellets, cubettes, or briquettes.

5.0 APPARATUS

5.1 Drying Oven

The oven shall be either the mechanical draft or natural circulation type which is capable of constant uniform temperature within the specimen chamber regulated at 107 ± 3°C, (225 ± 5°F).

5.2 Drying pans

Clean, dry, noncorroding pans used to contain the sample during the drying process.

5.3 Balance

A device capable of weighing the sample and container with a sensitivity of 0.1 gram in 1000 gram.

6.0 PRECAUTIONS

6.1 All operations shall be done rapidly and in as few operations as possible because moisture loss depends on several factors other than total moisture content, such as atmospheric temperature and humidity.

6.2 At all times, RDF-5 samples should be protected from moisture change due to exposure to rain, snow, wind, sun, or contact with absorbant materials.

6.3 Samples should be transported to the laboratory and analyzed as soon as possible. If any sample-handling step involves an extended time period, the sample and container should be weighed before and after the process to determine any weight gain or loss. This weight gain or loss shall be included in the calculation of moisture content.

7.0 PROCEDURE

7.1 Determine the tare weight of clean, dry pans to an accuracy of 0.1 gram.

7.2 Place the 1.0 ± 0.1 kg (2.2 ± 0.2 lb) laboratory sample into the drying pan so that the sample depth does not exceed 10 cm (4 in.). More than one pan may be necessary. Weigh each pan and sample to 0.1 gram.

7.3 Place the pan and sample into the oven at 107 ± 3°C (225 ± 5°F) for at least 2 hours.

7.4 After at least 2 hours of drying time, remove the pan and sample and quickly obtain an initial dry weight to the nearest 0.1 gram.

7.5 Return the pan and sample to the oven at 107 ± 3°C (225 ± 5°F) for at least 1 additional hour.

7.6 Remove the pan and sample from the oven and weigh to the nearest 0.1 gram. If the sample weight loss is less than or equal to 0.1 percent per hour of the original sample weight, the determination is complete; if not, Steps 7.5 and 7.6 are repeated.

8.0 CALCULATIONS

Calculate the total moisture, M, as follows:

$$M = \frac{W_i - W_f}{W_i} \times 100$$

where:

W_i = Net weight of as-received laboratory sample.

W_f = Net weight of laboratory sample after drying.

9.0 PRECISION

To be determined.

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