MANUFACTURER OF DENSIFIED-REFUSE DERIVED FUEL (d-RDF) PELLETS AND METHODS FOR THE DETERMINATION OF d-RDF PELLET DENSITIES

THESIS

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Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

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There are 150 milion tons of Municipal Solid Waste (MSW) annually produced in the United States, which is approximately equivalent to 150 million barrels of oil. MSW production is inexhaustible, and is increasing on an annual per capita basis of approximately three per cent.

After controlling the moisture and adding a binder, the combustible portion of MSW was converted to pellets. The objects of this project were to

1) evaluate the binder,
2) prepare the pellets, and
3) evaluate the pellets with regard to density.

The manufacture of pellets was conducted at the Naval Air Station, Jacksonville, Florida. The evaluation of the binders and the pellets was done at North Texas State University (NTSU). There were three procedures for measuring the density. The first, using water displacement, was from the American Society for Testing and Material (ASTM). The second, using wax coating, was also from ASTM. The third, using sharply-cut cylinderical pellets, was developed at NTSU.

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CHAPTER I

MUNICIPAL SOLID WASTE

Introduction

Garbage, or Municipal Solid Waste (MSW), is one of the least used by-product resources in the United States. Each of us disposes an average four pounds of garbage each day, or about one hundred and fifty million tons per year (7). A city with a population of approximately fifty thousand, such as Denton, Texas, landfills about sixty thousand tons of MSW annually. The density of this material ranges from two to five pounds per cubic foot (6).

Each ton of municipal solid waste is equivalent to one barrel of oil (6). Therefore, the 150 million tons of MSW annually produced in the United States is an energy equivalent to 150 million barrels of oil. This is roughly seven percent of the oil imported annually into the United States (6). Besides, the supply of MSW is inexhaustible (7).

Cities are running out of space for landfill. People are becoming increasingly cautious of residing near landfill sites (6). There are many regulatory and environmental difficulties in siting new landfills. There has been a rapid increase in the cost of solid waste disposal (2). These and other factors have resulted in an examination of alternatives in order to reduce the volume of MSW and to make more efficent use of MSW and landfill sites (1). As MSW can be a source of energy, cities are beginning to consider utilizing MSW (7).

Practical Reasons

There are several attractive and practical reasons for working with MSW (5):

a. MSW is a practical energy recovery source.

b. About 75% of MSW is combustible.

c. By-products such as ferrous metals, aluminum, glass, cardboard, ash, and aggregate can be recovered.

d. MSW is not only an inexhaustible source, but it is increasing on an annual per capita basis of approximately three per cent (6).

e. Burning MSW reduces its volume by 80-95%. The remaining 5-20% ash is more environmentally acceptable than MSW.

f. The combustible portion of MSW has 6000 to 7000 Btu's per pound in its dry state, the energy equivalent of a good grade of lignite coal.

g. The combustible portion of MSW has a lower sulfur content than most coals. Thus, the sulfur oxide emission from MSW (0.3 percent) is normally less than from coal

(1 to 3 percent).

h. When MSW is heated, it volatilizes such usable gases as methane and ethane.

There are several ways to obtain energy from MSW. One is through the direct burning of MSW (6). Another method is to convert it into liquid or gaseous fuel by means of pyrolysis, bioconversion, or by hydrogenation (8).

Contents of MSW

Approximately eighty-three percent of MSW is combustible. This combustible portion is known as refuse derived fuel (RDF). Seventeen percent is non-combustible (4).

Of the total volume of MSW, the combustible portion is composed of:

52%	paper
14%	plastic
5%	wood
4%	garden waste
3%	food waste
3%	textile
1%	rubber
1%	leather

The non-combustible portion contains:

6%	glass/ceramic/stone

6% ferrous compounds

2% aluminum

2% industrial/commercial

1% residential/dirt.

To produce RDF, the MSW can be separated by a variety of methods, including air-classification and screening techniques (8). The moisture content of MSW varies from season to season. In the Denton, Texas, area the average moisture content is 17 percent, with a range of 3 to 30 per cent (4). In wetter areas, such as Madison, Wisconsin, the moisture content of MSW may reach as high as 60 percent (6).

Disposal of MSW

MSW is traditionally disposed of by landfilling, ocean dumping or incineration (2). There are many problems caused by burning and landfilling of MSW such as pollution. Burying MSW is not economical and requires a lot of space (2). The cost of disposal ranges between $15 and $50 per ton, and it will probably increase (6).

This research project undertaken for this thesis involves several steps:

1) evaluation of binders.

2) preperation of pellets.

3) evaluation of pellets with regard to density.

CHAPTER II

REFUSE DERIVED FUEL

Refuse derived fuel (RDF), refers to a heterogeneous mixture of combustible materials (8). It contains mostly paper and plastic obtained from municipal solid waste. RDF can be derived by combination of such mechanical processes as air-classification or sieving and shredding, or by chemical processes which separate the ferrous and aluminum metal compounds (7).

Objectives

The objective of processing MSW to RDF is to prepare a fuel to meet the buyer's specifications. The specifications needed are obvious: maximization of calorific content and minimization of ash, moisture, or anything that cause problems to the user (2). RDF is a useful, adequate fuel and proper preparation and attention to specifications will change its reputation for use as a supplement to coal or as the sole fuel in appropriate furnaces (7).

Physical forms of RDF

There are several forms of RDF (2): RDF-1-waste used as fuel in its discarded form; RDF-2-waste processed to coarse particle size, with or without ferrous metal separation; RDF-3-shredded fuel, or waste that has been processed to remove metal, glass, and other inorganic material; RDF-4-combustible waste processed into powder form (2 mm size); RDF-5-combustible waste densified into pellets, slugs, cubettes, or briquets, called d-RDF; RDF-6-combustible waste processed into liquid fuel; RDF-7-combustible waste processed into gaseous fuel.

It is almost trite to point out that different sources of RDF, especially prepared from different sources of MSW, will vary in their fuel properties. The variability among any sample of RDF is perhaps best described in terms of the proximate fuel properties of calorific content, ash, and moisture (8).

CHAPTER III

DEVELOPING THE WORK AT NORTH TEXAS STATE UNIVERSITY

In the early 1970s many cities in the United States started using refuse derived fuel without any treatment other than drying. In Ames, Iowa; Madison, Wisconsin; and Miami, Florida, RDF was burned to produce electricity. In other areas it was tried as an energy source in the production of cement (4).

In the late 1970s an RDF project was begun in Denton, Texas, conducted by North Texas State University (NTSU). Samples of RDF were taken by hand from a Denton landfill and analyzed. The combustible portion of RDF was investigated as an energy source.

Goals

The NTSU project had several goals. The first was the successful use of RDF as fuel for industry, as coal is used. Secondly, the project was looking for higher bulk density, 25-30 pounds per cubic foot, and greater consistency than the raw material provides. Actual bulk density of RDF, after separation from MSW, leaves a combustible portion of 2-5 pounds per cubic foot (6). This is hard to transport and gives low per-volume heat. High density makes the material easily transportable, provides good storage properties, and produces more heat for less volume. A third goal was the development of a chemically and biologically stable product that would not lose heat content over time (3).

The Process

The project selected to work with RDF-5, or d-RDF, densified from a well prepared RDF-3 brought to North Texas State University from Ames, Iowa. This RDF-3 had been prepared from MSW by primary and secondary shredders with a hammer mill of -6 inch opening. After shredding, the material had been passed through an electromagnet to extract ferrous metals, and had gone through the air separator process. Finally, the RDF-3 had been passed through screens to achieve a 75-80% combustible sample.

When the RDF-3 arrived at NTSU the moisture content was optimized. To achieve this, RDF-3 was dried for 24 hours in an oven, at 120 F, for a zero moisture content. Then water was sprayed on the RDF-3 to achieve the specific moisture content necessary. After testing a variety of moisture percentages, it was decided that 15% was the best.

A higher quality RDF-5 can result with the addition of a chemical compound called a binder. This chemical compound binds the RDF for biological and chemical stability. The binder prevents the pellets from rotting and helps them retain their heat content (3).

Binding agents differ from each other according to the source. The many types of binding agents available can be used alone in varying percentages. The project had to determine the best chemical compound to be used as a binding agent. Expense and environmental and laboratory acceptability were the primary criteria for selection from among the most effective binding agents (6).

Approximately 150 binders were tested, evaluated, and graded. In grading the binding agents, 60 was the highest possible score for cost, and 40 was the highest environmental acceptability score.

In evaluating possible binders, it was found that the cost per pound varied widely. For example, Lime was \$0.05; Portland Cement, \$0.03 and Limestone, \$0.0025. Environmental acceptability was determined by considering SO_X, NO_X, and chloride emissions. The 150 binders were reduced by this procedure to sixty-eight. (See Appendix C). These binders were then evaluated by a laboratory acceptability protocol during a two-year period, between 1983-1985. (See Appendix A). The laboratory acceptability protocol considered the following characteristics: 1. durability - the ability of the pellet to maintain shape and integrity; 2. humidity - the effect of 100% humidity on the pellets; 3. water sorbability - the ability of the pellet to absorb water within one hour; 4. weatherability - the ability of the pellet to maintain effectiveness over time (4).

Btu content, ash content and ignition temperature were also examined. For evaluation purposes, hand densification by Carver press at 5000 psi was determined to be adequate for comparison of the pellets.

Results

The examination process was as follows (8):

screen + air classification =RDF-3
RDF-3 + densification = RDF-5
RDF-3 + moisture + binder + densification = RDF-5.

The top six binders, those with the lowest total cost and highest environmental acceptability scores, were selected for use in the project. They were limestone, calcium hydroxide, coal fines, kiln dust, carbon black, and fly ash. These binders all had the common traits of small particle size, high surface area, and calcium content (6).

CHAPTER IV

LARGE-SCALE PRODUCTION OF PELLETS AT THE NAVAL AIR STATION, JACKSONVILLE, FLORIDA

After selection of the best binders, it was decided to test the work on a wider scale by making a large amount of pellets. The Naval Air Station, in Jacksonville, Florida, (JAX-NAS) offered the use of the large equipment needed: magnetic separators, shredders, a hummer mill, and a Sprout-Waldron pelletizer.

The work began by leaving Denton, Texas, on July 20, 1985 to go to Jacksonville, Florida. Six and a half tons of RDF-3 from Ames, Iowa, and another half ton of RDF-3 from Pompano Beach, Florida, were taken to Jacksonville. The binders were taken from NTSU to JAX-NAS. The mixing and pelletizing processes were finished by August 31, 1985.

The cement mixtures were used for large-scale mixing of the RDF, the binder, and the water. Each mixer took 40-50 pounds, resulting in a total of 150-200 pounds per run. Approximately two runs were conducted each day, and 54 runs were conducted during the time at JAX-NAS. Plant-sprayers were obtained to spray the water on RDF throughout the mixing process. A gun sand blaster was used to spray the binders.

Mixing Process

Mixing was done in runs of 150-200 pounds per run. Each of the two cement mixers took 40-50 pounds at a time, thus a half-run consisted of 80-100 pounds in two mixers. Each half run required one hour of tumbling.

After being tumbled for 20 minutes, the moisture content was measured with a moisture-analyzer to determine the amount of water to be added. Water was sprayed into the RDF with a plant-sprayer while the mixers were tumbling. After 20 minutes of tumbling the mixers were again stopped for another moisture content analysis. Once tumbling began again the binders were sprayed into the RDF, and the tumbling continued for 20 minutes. The tumblers were then stopped, the moisture content measured, and the mixture from the first run was put in a buggy to await pelletizing. The mixture was covered carefully so the moisture would not evaporate before finishing the second half of the run. After the second half of the run was completed, by the same procedure, the two halves were combined and taken to the pelletizer.

During the mixing process the binder and the water were weighed accurately and mixed well with the RDF. The binder and water were added while the mixer was running to ensure a homogeneous mixture. At least 95% of the binder and water were mixed into the RDF. Water was added by spraying into the RDF while the mouth of the mixer was open. The binder was added by inserting the head of the sprayer through a plastic cover which covers the mouth of the mixer to minimize binder loss.

The three moisture checks during the mixing process, and a moisture check after pelletization, were made with a microwave moisture analyzer, which provided results both in typed form and on a screen. Requiring about eight minutes for analysis, this procedure was far more efficient than the twenty-four hours needed for use of an oven. (See summary of the process, Appendix F)

Pelletizing

The homogeneous RDF mixture was transferred to buggies and taken to the other side of the plant. A crane was used to lift each buggy for pouring into the surge bin. The material passed from the surge bin and conveyer belt into another surge bin. From there it was conveyed into the pelletizer.

A Sprout-Waldron pelletizer is a large cylindrical die, about twenty inches in diameter, with holes in the surface. The RDF was fed into the middle of the die. Three iron wheels inside pressed the RDF through the die holes. A metal blade periodically cut the pellets.

When the pellets came out of the pelletizer they were passed through a cooling system. The cooling process took about 10-15 minutes. After cooling the pellets emerged and were dropped into buckets.

Fifty-four complete runs of pellets were made. During the runs a variety of binder and moisture contents were tried. Two sizes of pellets 1/2 and 3/4 inches, were made. (See Appendix B)

After the pelletization process, analysis revealed that (6):

1. The binder increased the bulk density of the pellets.
2. The binder increased the particle size distribution of the pellets.
3. The pellets became harder as a function of time.
4. The optimum moisture content was 15%.
5. Pelletization with binder helped maintain the chemical and biological stability of the pellets.
6. The pellet form is optimum for transporting and provides good storage properties.
7. Using binder should reduce emissions during combustion.

Role of the Binder

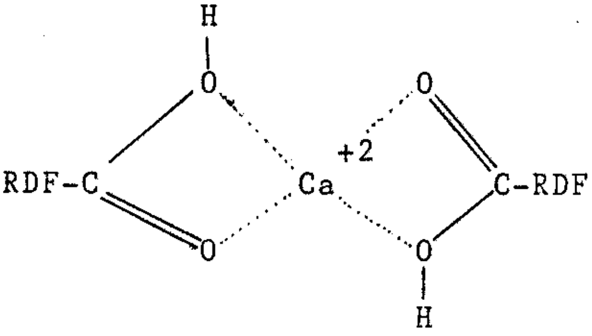
An examination of the role of the binder is important. As the six binders contained calcium, it appears that calcium plays an important role. Calcium oxide reacts with water to produce calcium hydroxide (6):

$$CaO + H_2O \rightleftharpoons Ca(OH)_2$$

The calcium hydroxide is also ionized to calcium ions and hydroxide ions:

$$Ca(OH)_2 \rightleftharpoons Ca^{+2} + 2OH^-$$

RDF contains organic compounds which can be oxidized to carboxylic acids. The carboxylic acids can form a variety of complexes and chelates with calcium, such as:



This might be one of the many ways in which a binder interacts and binds with RDF particles.

Analysis of the RDF composition revealed that it contained cellulose (2). During pelletization an elevated temperature is produced. In the presence of moisture, the hydrogen bonds of cellulose weaken and the cellulose acts as a thermoplastic, binding the RDF particles together (2).

CHAPTER V

RDF-DENSITY

The density of the individual pellets is a measure of the effectiveness of the densification process, and may be used in quality control (7). Density may also be useful in predicting the durability of the pellets, their resistance to moisture absorption, and their general handling and storage characteristics (6).

This research project included testing the density of the pellets. Three procedures were used: two from the American Society of Testing and Materials (ASTM) and a method developed at North Texas State University by Attili (NTSU/A).

ASTM Method

The first ASTM method is called "Test Method for Determining Particle Density and Water Repellency for RDF-5." (ASTM Designation E38.08-3.3/3.7; see Appendix D). It is easy and available in every lab.

Summary of the Method

This method first determines, gravimetrically the mass of a representative sample of RDF-5. The volume measured by water displacement to calculate particle density (the mass per unit volume). By reweighing the wet sample after the water displacement volume determination, the water weight gain of the sample is determined. The percent of water weight gain is inversely proportional to ability to resist absorbing water (water repellency).

Comments

Several points concerning this method should be made:

1. Section 1.2 of the ASTM states that the density should be greater than that of the water (>1.0 gm/cc).

Density depends on the method of pelletization. If the instrument used results in pellets with a density of less than 1 g/cc, this method is not applicable. (See section 4.1, Appendix D).

2. Section 5.2 states that drying the sample is required. This causes a moisture content loss, thus affecting density.

3. There is difficulty in arriving at accurate measurements when one works with large volumes of water. Even a small mistake will make a difference of (± 20 to 50) milliliters.

4. Air bubbles resulting from the dry pellets affect the volume.

5. The equation used for calculating the density is:

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

D_p = particle density

M_i = net mass of the sample, g

V_i = initial volume of the water, cc

V_f = final volume of water.

This is not accurate because the result does not indicate the actual density of the pellets. This equation neglects to include the water absorbed by the pellets, which should be added to the new volume of the water. Perhaps a more accurate formula for calculating actual density would be:

$$D_p = M_i / [(V_f - V_i) + V_a]$$

V_a = volume of water absorbed by the pellets

6. The ASTM procedure is perhaps better for measuring water repellency rather than density. Table I contains some results of the ASTM particle density and water repellency

procedure (ASTM.E38.03-3.3/3.7). These runs include: 2, 44 (no binder); 20,21,30,31,41,45,46 (varying percentages of binder); and the two size pellets 2,20,21,30 (1/2 inch diameter) and 31,41,44,45,46 (3/4 inch diameter).

NTSU/A Method

This method was developed to be used to determine the density or the mass per unit volume of d-RDF. It can be used for any form of pellets (RDF-5), with a density higher or lower than 1g/cc.

Summary of the Method

The weight of the pellets can be determined by a gravimetric method. The volume is calculated by measuring the length and the radius of a pellet after it has been cut into a cylindrical shape (the volume $=\pi r^2 l$). By calculating the actual density (m/v) various densification processes can be compared. The pellets can be evaluated according to the density. A higher density probably improves the handling, storage, and combustion characteristics of RDF.

Procedure

1. A sample of 3-4 pellets was selected.
2. The pellets were cut sharply, with a wet-cut cut-off saw (with a silicon blade) to form cylinders.

3. The pellets (cylinders)were air-dried for 24 hours.

4. The cylindrical pellets were weighed to the nearest 0.0001 gm.

5. The length and the diameter of the cylindrical pellets was measured, using calipers to the nearest 0.001 cm.

6. The average radius of each pellet alone was calculated.

7. The volume and the density of each cylindrical pellet alone was calculated.

8. The average density of all the pellets of the same run was calculated (See Table II).

Calculations

1. $D_i = M/V = M/(\pi r^2 l)$

D_i = density of the i-th pellet

M = mass (weight) of the pellet (g)

V = volume of the pellet

$V = \pi r^2 l$

V = volume of the pellet

$\pi = 3.1415927$

r = average radius of the pellet

l = length of the pellet

2. Average Density

$$D = (D_1 + D_2 + D_3 + D_4) / 4$$

3. $$D = \frac{\text{the sum of the densities}}{\text{the number of densities}}$$

Comments

1. Cutting the pellets by the wet-cut cut-off saw was found to be the best. Other methods failed to result in a perfect cylinder.

2. Air-drying for 24 hours gave the best result. With less than 24 hours the pellets retained moisture from the cutting machine, affecting the weight of the pellets. With more than 24 hours drying time, the pellets seemed to lose some of their original moisture.

Table II contains the results of NTSU/A procedure. It shows the fifty three runs, with variable moisture and binder content, done at the Jacksonville, Florida Naval Air Station.

Figures 1 to 9 show the plot of the moisture versus the density for Calcium Hydroxide binder at varient percentages. These figures show the effect of binder and moisture on 1/2 and 3/4 inch diameter pellets.

General Results

An examination of the graphs and the results of the density measurements (Table II) shows the following general results:

1. Using a binder increased the density of the pellets (Figures 8 and 9). All densities with binder were higher than the zero binder curve.

2. Increasing the percent of binder used increased the density of the pellets (Compare Figures 3 and 5 with 4 and 6).

3. Increasing the percent of moisture increased the density until it reached a maximum at 15 per cent. At that point the density decreased. The optimum moisture depended on the kind of binder used, but 15 per cent generally gave the best results. (See Figures 1, 2, and 7).

4. Calcium Hydroxide was the best binder. It gave the highest density (Table II), and produced the best results in physical and chemical tests.

5. The 1/2 inch diameter pellets had a higher density than the 3/4 inch pellets. (See figures 1, 2, 3, 4).

6. The slight increase in density below 3 percent binder might have been because the binder filled the spaces between the RDF particles. Less than 3 percent binder was too low to bind the RDF particles (unsaturated region).

7. At a binder percent of higher than 3 percent the

chemical reaction of the binder with the RDF particles lead to an increase in density.

8. At 10 percent binder or more the density began to decrease (over saturated region). At this percent the binder became a factor in making the pellets loose (super saturation).

9. The best moisture for 5 percent binder is 15 percent; the best moisture for 2 percent binder (calcium hydroxide) is 10 percent. Thus, the optimum moisture percent depends on the binder. In other words, the moisture determines the percent of the binder to be used, but not in excess of the optimum percentage.

10. In general, the density is affected by both binder and moisture.

The Wax Method

A third method for measuring the pellet density uses wax. It is "The Proposal Standard Method for Measuring Density of RDF-5" (ASTME38.08-3.3).

In this procedure, ten representative pellets are weighed, then double coated in hot wax to waterproof them. The volume of each pellet is determined individually by water displacement and the average density is calculated.

This procedure is time-consuming. It has also been reported, in the ASTM draft procedure, that this method gives results which are only accurate to one decimal fraction.

Choosing representative sample pellets, and the complication of working with hot wax are factors which affect the results of this method. This procedure has a very low probability of producing acceptable results. Therefore, this procedure was not tested and evaluated.

CHAPTER VI

CONCLUSION

Measuring the density is important to the effectiveness of the densification process. The pellets can be evaluated by examining the density values. The pellet density values indicate durability, storage and transportation characteristics, and resistance to moisture absorption.

There are three procedures for measuring density:

a. Water displacement procedure (ASTM);
b. Cylindrical cut-off procedure (NTSU/A);
c. Wax double coating procedure (ASTM).

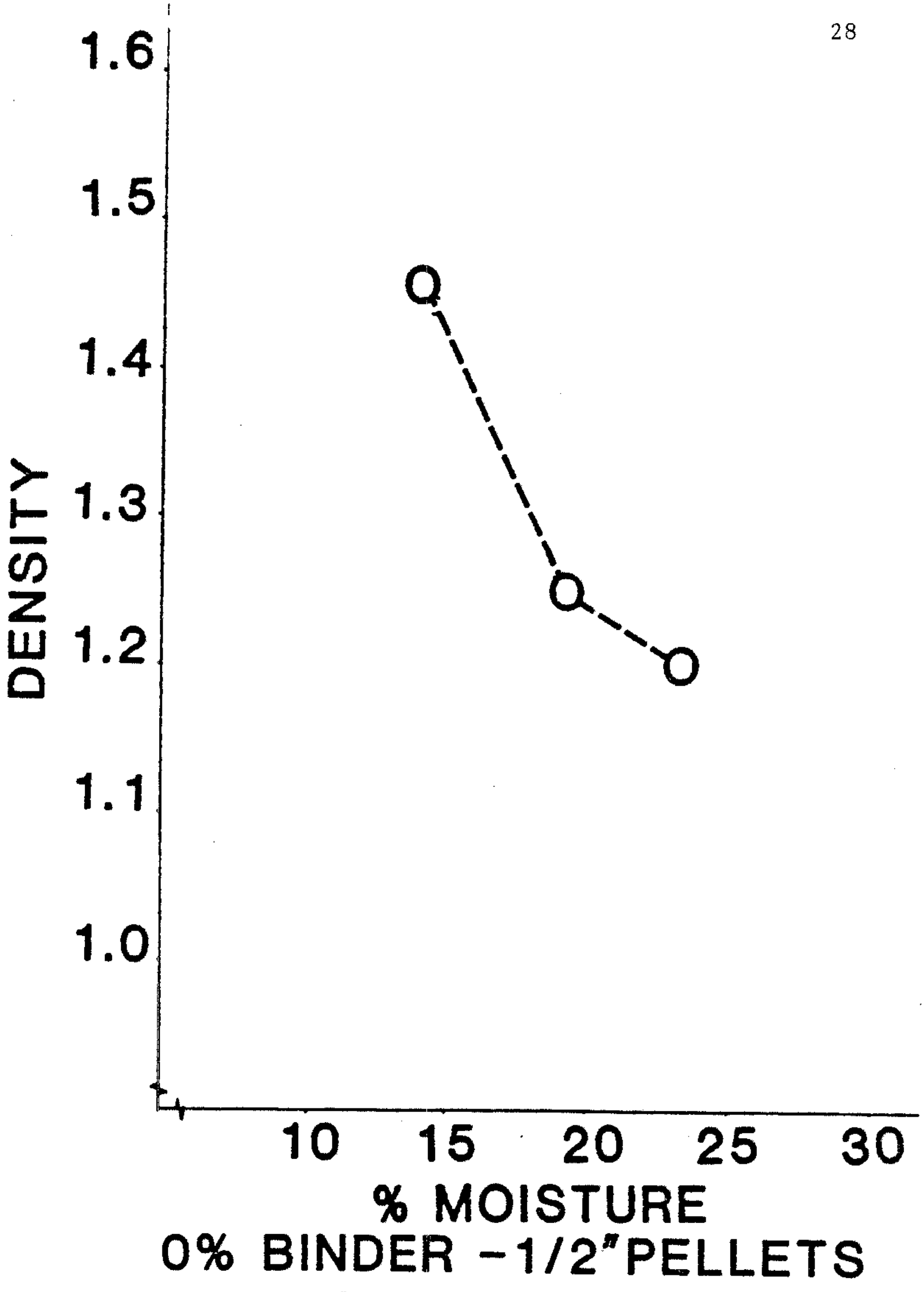
A comparison of these three procedures for measuring the actual density indicates that the NTSU/A procedure is the most accurate. Because this procedure measures the length and radius of the pellets, it provides an accurate measure of volume, resulting in more accurate density values. The two ASTM procedures only give an approximate volume, thus the density values are not accurate. The water displacement procedure gives results accurate to two decimal fractions (± 0.02 gm/cc). The wax double coating procedure gives results accurate to the first decimal fraction (±0.1 gm/cc). The NTSU procedure gives densities good to the third decimal fraction (+0.002 gm/cc).

The three methods vary in terms of ease and time required. The water displacement method is the generally available and easiest to do. The wax coating procedure is difficult and time-consuming. The NTSU procedure is easy, but requires 24 hours for air-drying.

A comparison between the water displacement procedure and the NTSU cut-off procedure appears in table 1 and 2. The NTSU procedure appears to result in more accurate density figures. (See RDF-density comments on the procedure). The ASTM method can be used to differentiate between different types of pellets or to measure water-repellency.

The water displacement procedure requires that the sample be sieved, and four samples of 250 gm from + 1/2 inch length pellets be used each time. This gives results of only ± 0.02 gm/cc. For results, of ± 0.01 gm/cc, sixteen samples, of 250 gm each, should be used (See Appendix D.) This increases the time necessary to complete the procedure. The double coating with hot wax procedure was not evaluated by ASTM, which indicates that it is not recommended.

The NTSU cylindrical cut-off pellets procedure is recommended, for density measurement. It is easy, accurate, and does not require a long work-time. The 24 hours drying can be standardized and reduced to a few minutes by using the microwave oven.


DENSITY
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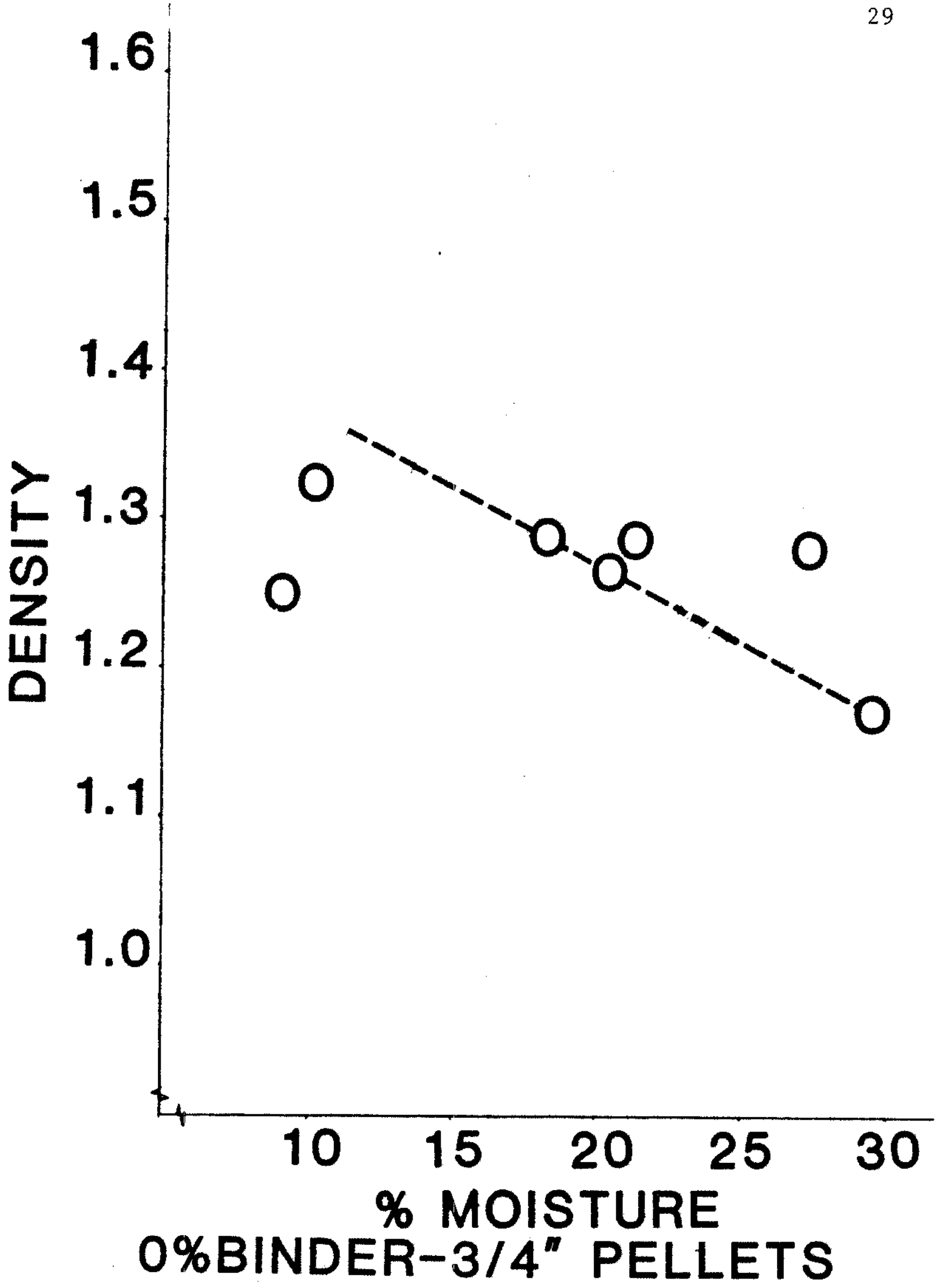
30
% MOISTURE
0% BINDER -1/2"PELLETS

Figure 1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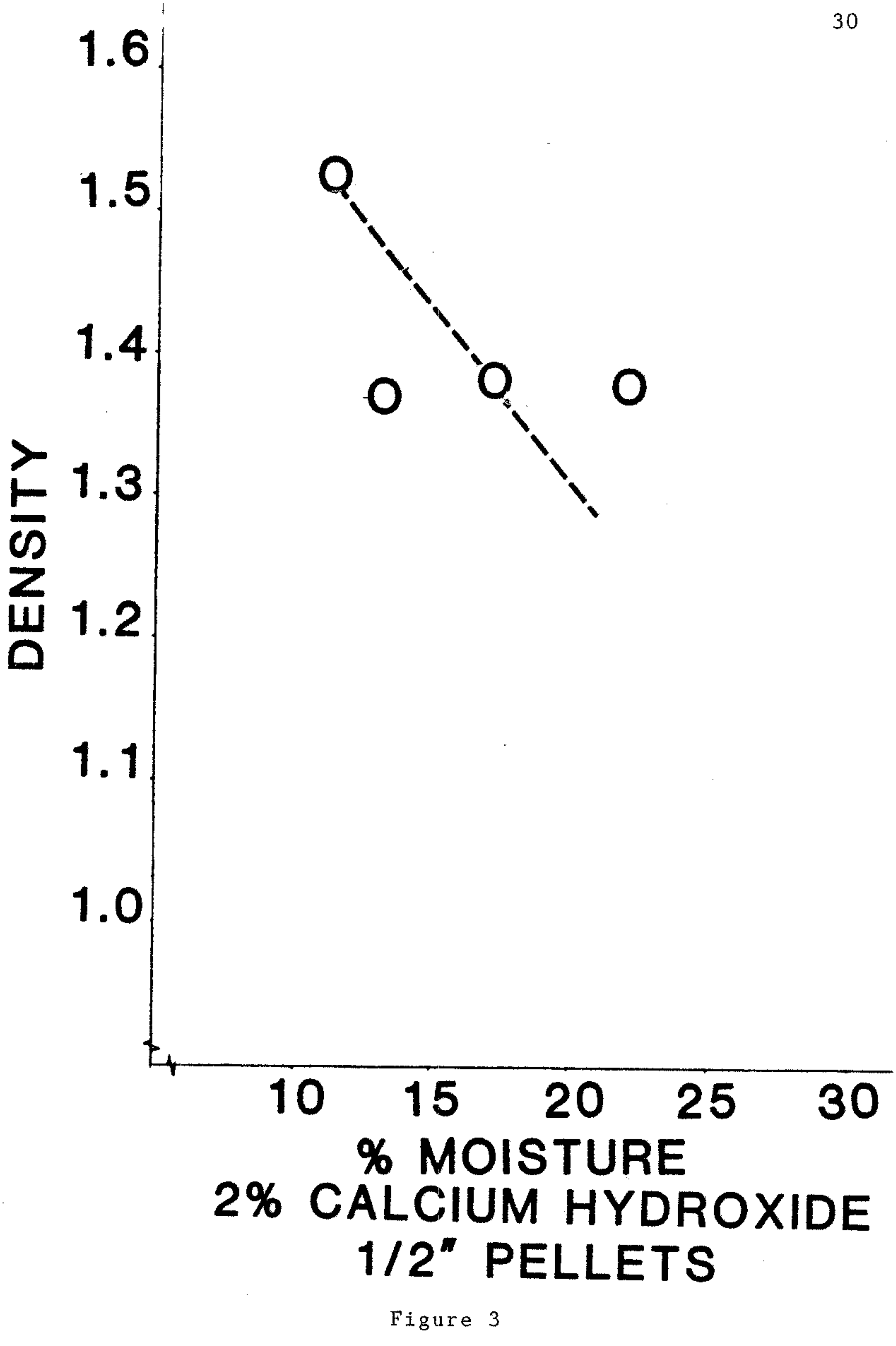
% MOISTURE
0%BINDER-3/4" PELLETS

Figure 2


DENSITY
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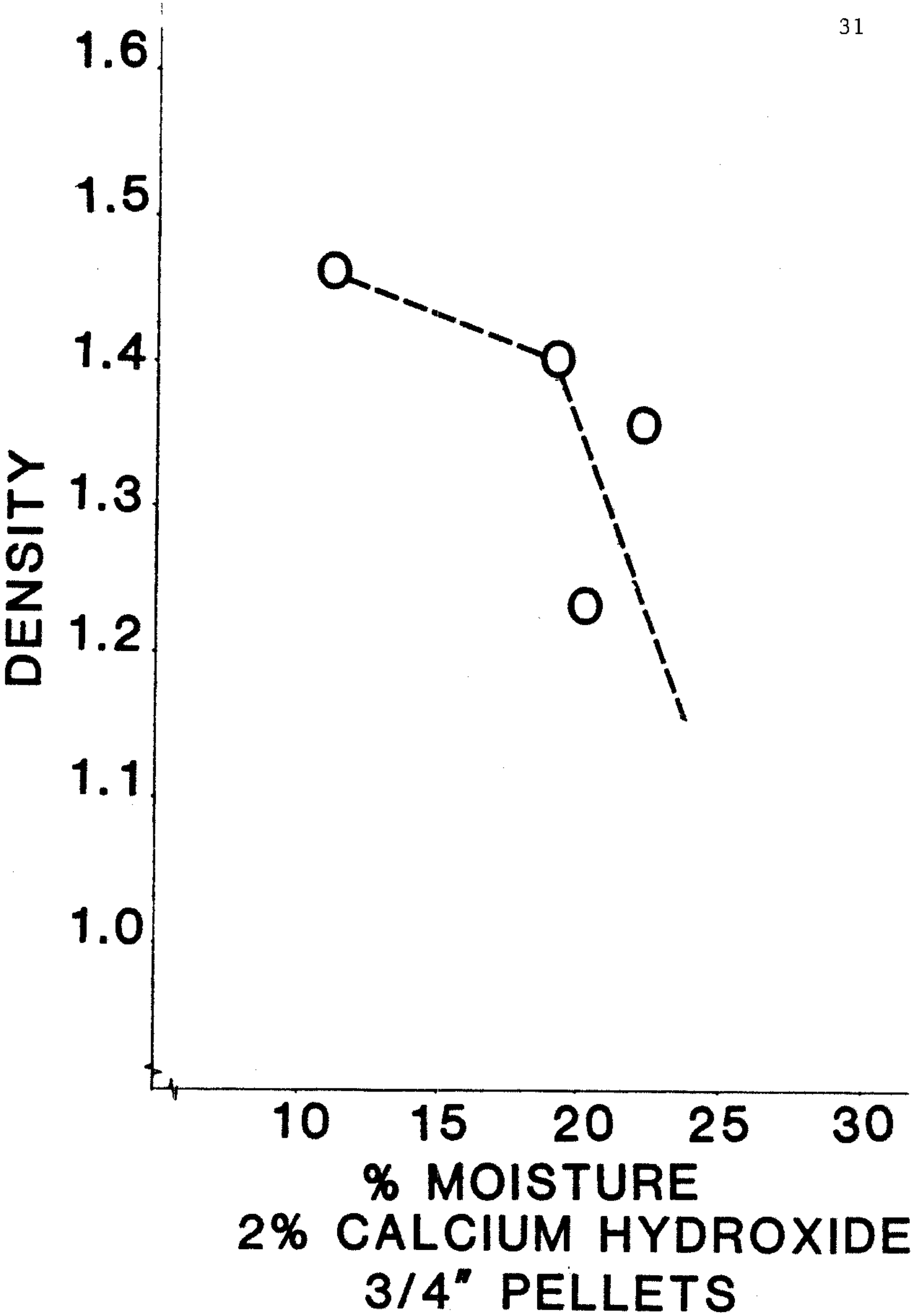
% MOISTURE
2% CALCIUM HYDROXIDE
1/2" PELLETS

Figure 3


DENSITY
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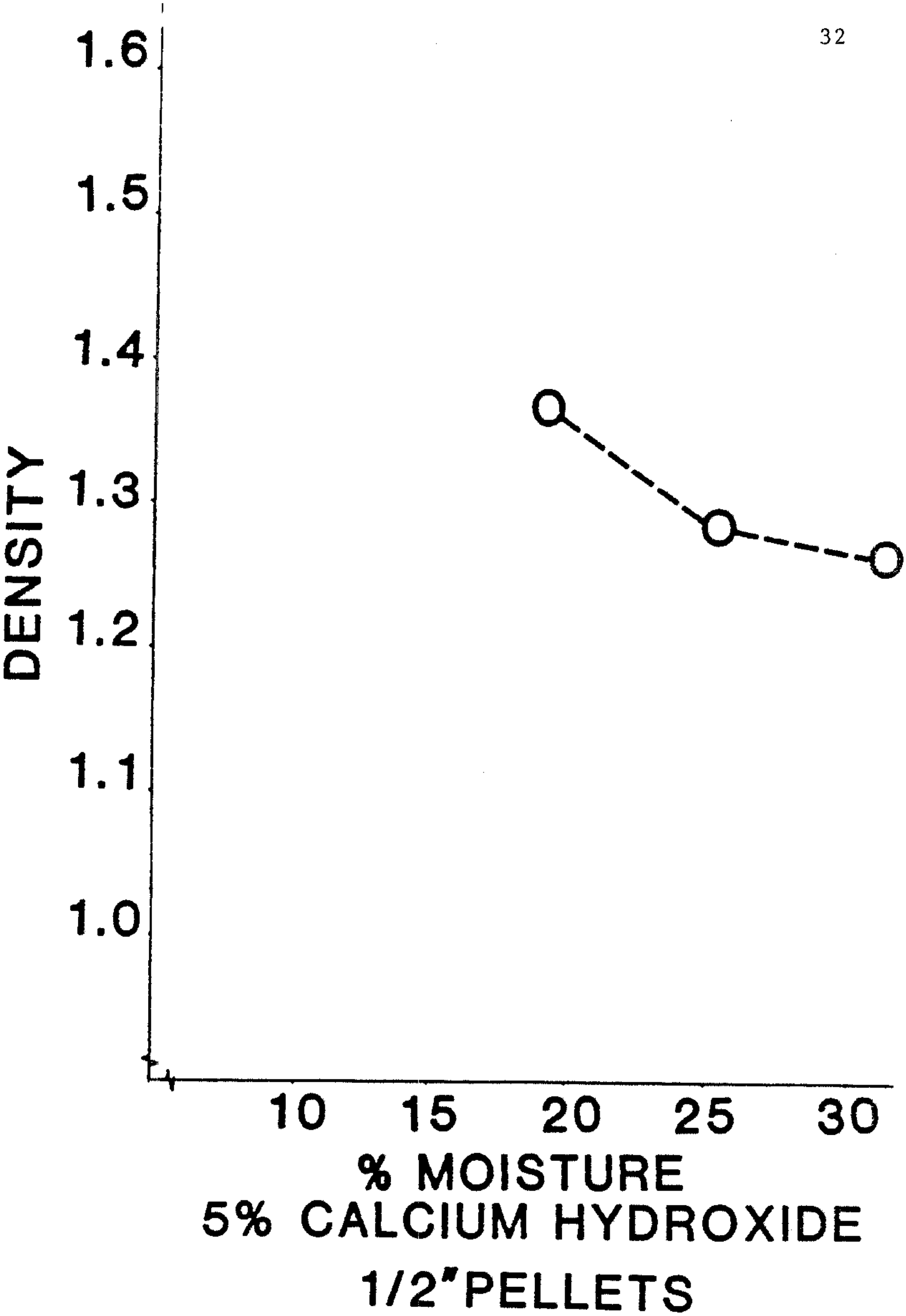
2% CALCIUM HYDROXIDE
3/4" PELLETS

Figure 4


DENSITY
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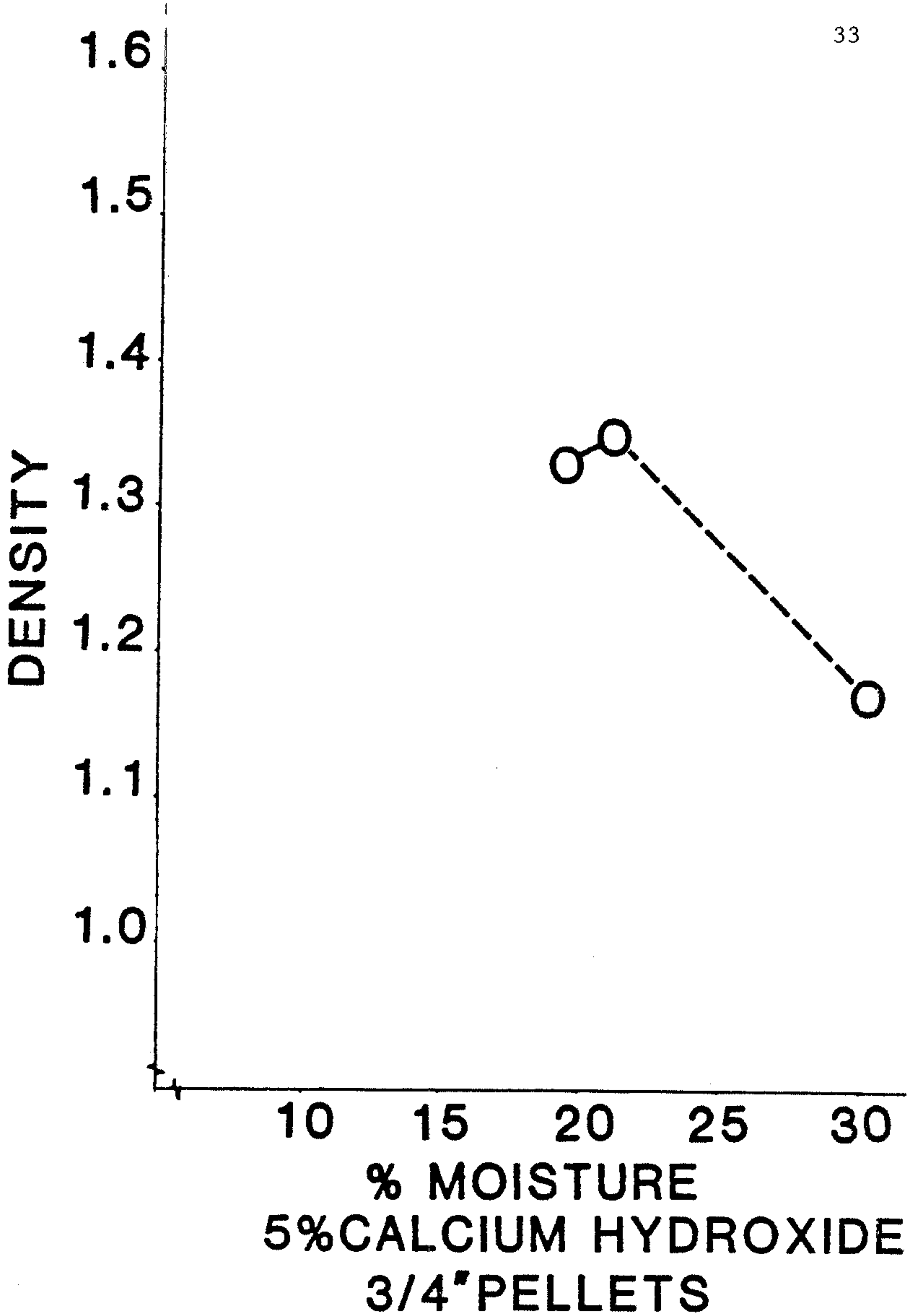
5% CALCIUM HYDROXIDE
1/2"PELLETS

Figure 5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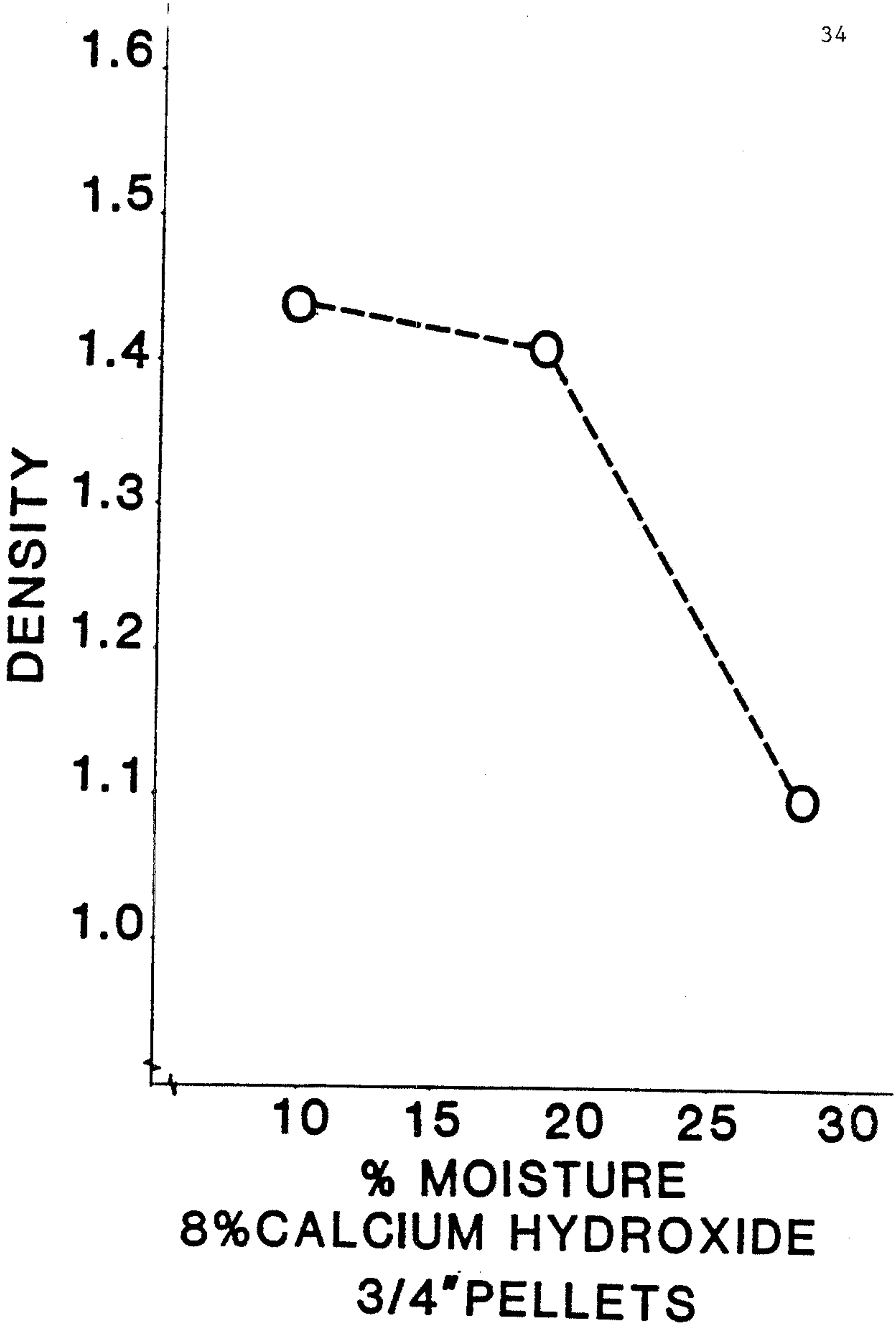
5%CALCIUM HYDROXIDE
3/4"PELLETS

Figure 6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% MOISTURE
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3/4"PELLETS

Figure 7

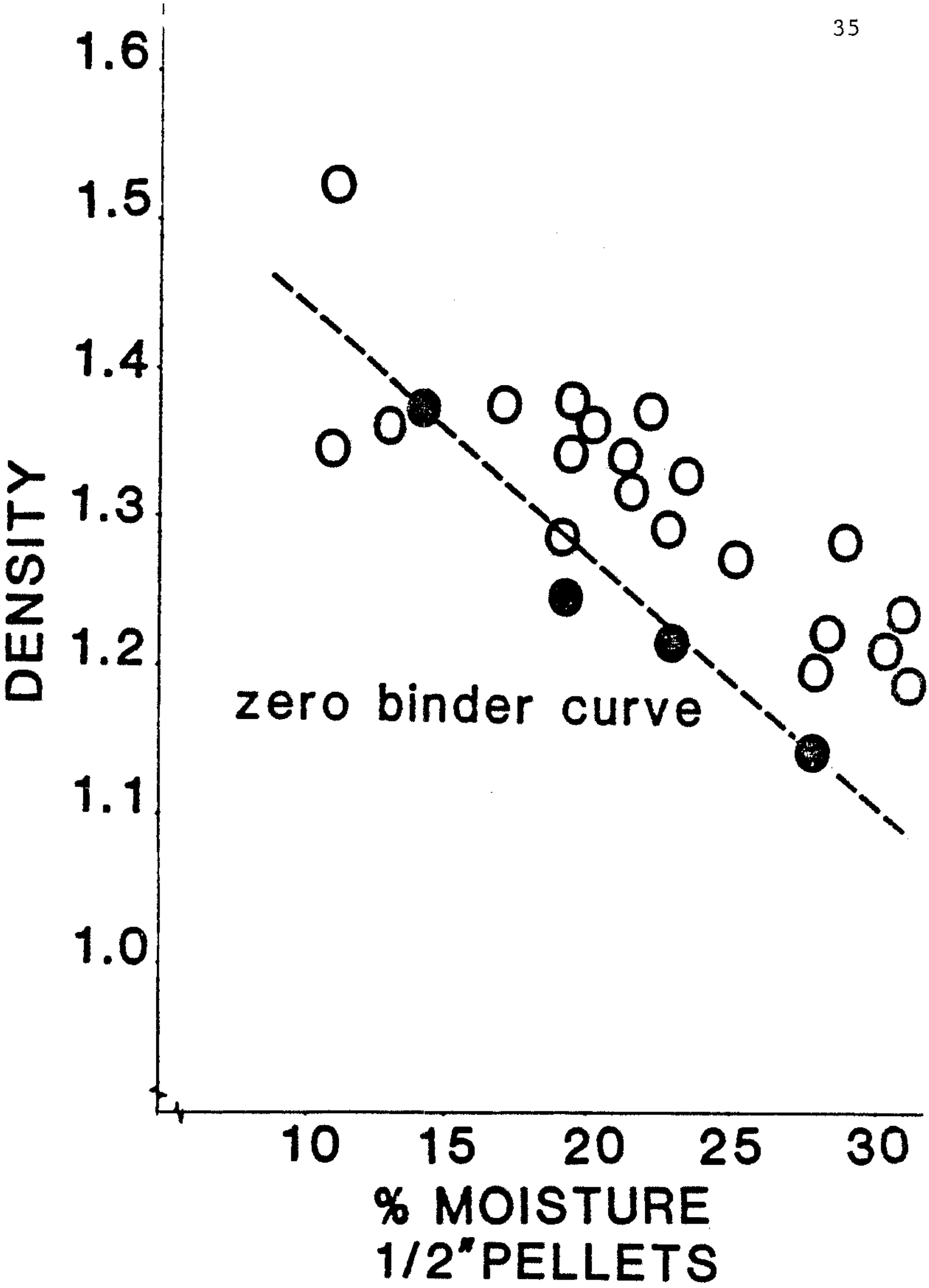
1.6
1.5
1.4
1.3
1.2
1.1
1.0
DENSITY
zero binder curve
10
15
20
25
30
% MOISTURE
1/2"PELLETS

Figure 8

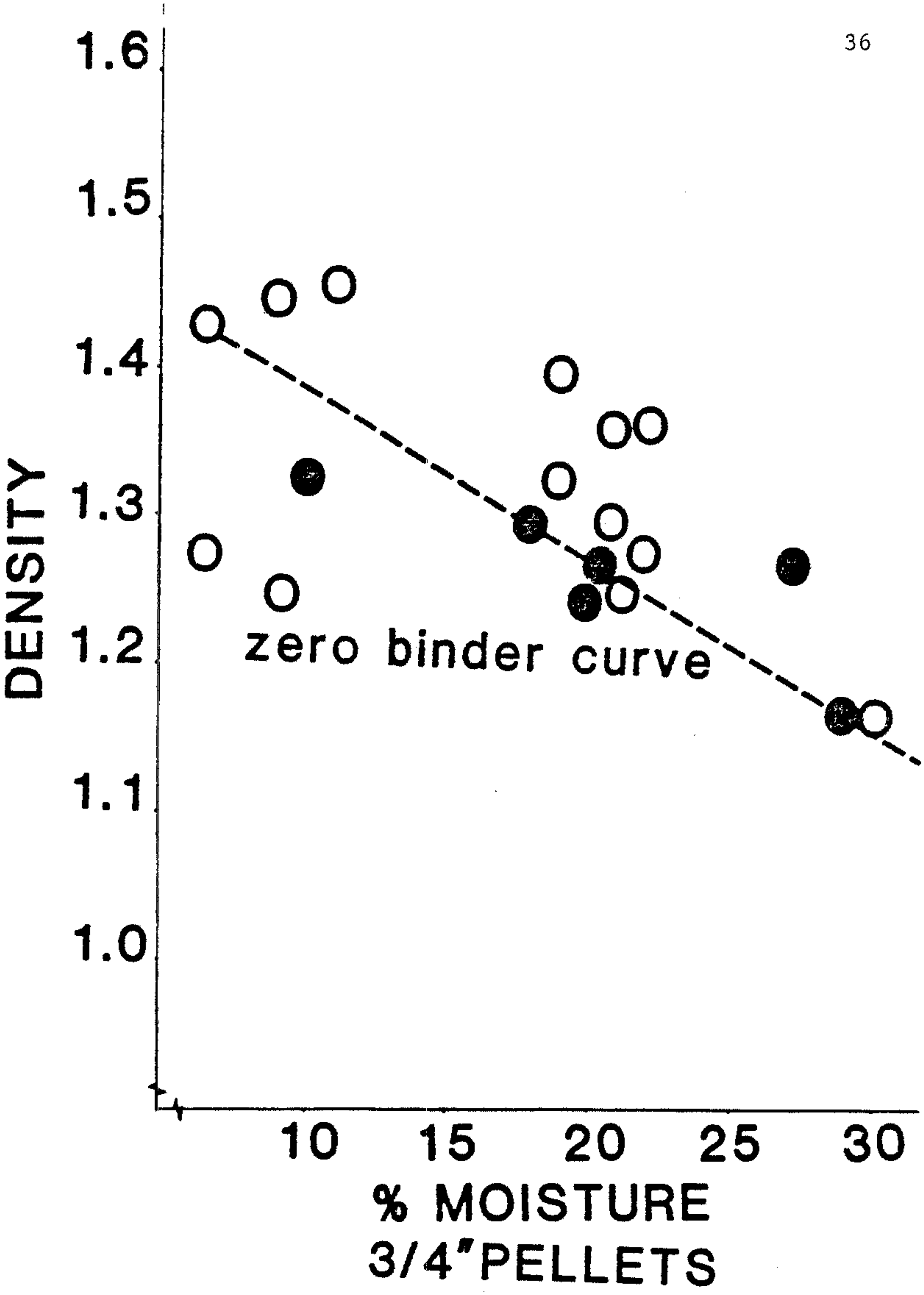
1.6
1.5
1.4
1.3
1.2
1.1
1.0
DENSITY
zero binder curve
10
15
20
25
30
% MOISTURE
3/4"PELLETS

Figure 9

TABLE I

The Results of ASTM Procedure

Run	Density g/cc	% Water Repellency
2	1.130	83.02
20	1.368	93.92
21	1.276	93.87
30	1.509	93.81
31	1.294	96.25
41	1.138	95.95
44	1.011	84.04
45	1.062	90.76
46	1.042	87.74

TABLE II

THE RESULTS OF NTSU PROCEDURE

Run #	% Moisture	% Binder	Average Density
1	14	0	1.387 g/cc
2	19	0	1.249
3	23	0	1.223
4	28	0	1.151
5	31	5 calcium hydroxide	1.280
6	30	5 kiln dust	1.187
7	25	5 calcium hydroxide	1.266
8	29	5 portland cement	1.290
9	20	2 portland cement	1.362
10	28	5 fly ash	1.221
11	23	5 fly ash	1.289
12	33	5 iowa coal	1.048
13	23	5 western coal	1.325
14	30	4 1% calcium hydroxide 4% fly ash	1.233
15	21	5 1% calcium hydroxide 4% fly ash	1.351

TABLE II--CONTINUED

Run #	% Moisture	% Binder	Average Density
16	30	5 1% calcium hydroxide 4% fly ash	1.212
17	22	5 1% calcium hydroxide 4% kiln dust	1.323
18	31	1 calcium hydroxide	1.193
19	21	1 calcium hydroxide	1.254
20	19	5 calcium hydroxide	1.378
21	17	2 calcium hydroxide	1.379
22	36	10 calcium hydroxide	1.091
23	35	10 5% calcium hydroxide 5% portland cement	1.372
24	22	2 calcium hydroxide	1.375
25	13	2 calcium hydroxide (repellitized)	1.365
26	11	2 calcium hydroxide (repellitized)	1.346
27	19	5 dolmite	1.288
28	19	5 2.5% calcium hydroxide 2.5% dolmite	1.345

TABLE II--CONTINUED

Run #	% Moisture	% Binder	Average Density
29	28	5 2.5% calcium hydroxide 2.5% dolmite	1.235
30	11	2 calcium hydroxide	1.524
31	11	2 calcium hydroxide	1.458
32	19	2 calcium hydroxide	1.398
33	22	5 calcium hydroxide	1.363
34	30	5 calcium hydroxide	1.164
35	21	5 calcium hydroxide (repelletized)	1.358
36	20	0	1.273
37	9	0	1.241
38	29	0	1.171
39	22	2 calcium hydroxide	1.164
40	21	3.5 1.75% calcium hydroxide 1.75% dolmite	1.260
41	19	5 calcium hydroxide	1.333
42	21	0	1.294
43	10	0	1.331
44	18	0	1.297

TABLE II--CONTINUED

Run #	% Moisture	% Binder	Average Density
45	20	1 calcium hydroxide	1.253
46	20	2 calcium hydroxide	1.222
47	19	4 calcium hydroxide	1.269
48	19	8 calcium hydroxide	1.406
49	27	0	1.275
50	28	8 calcium hydroxide	1.098
51	9	8 calcium hydroxide	1.444
52	6.53	4.5 calcium hydroxide portland cement dolmite	1.437
53	6.53	4.5 calcium hydroxide portland cement dolmite	1.281

WORKSHEET

BINDER/PELLET/RDF EVALUATION

Binder Number __________ Description:

Binder Cost (cents/pounds) _________ Points ________

Toxicity: Points ________

Odor: Points ________

Emissions: SO_x ______ NO_x ______ Points ________

Cl ______ Other______

Binder dispersability: Points ________

Binder ability to wet: Points ________

Binder Btu content: Points ________

Binder ash content: Points ________

Pellet weatherability: Points ________

Pellet water sorbability: Points ________

Pellet caking: Points ________

Pellet ignition temperature and burning time: Points ________

Moisture content: Points ________

Durability: Points ________

Aerobic stability: Points ________

Remarks on above evaluation:

Appendix B

Run	Total lbs.	% Binder	Binder	Initial Moisture	Final Moisture	Pellet Diameter	PSD	Bulk Density	% + 3/8"
1	200	0	None	12	14	1/2"	As Recv'd	0.72	95.0
2	200	0	None	--	19	1/2"	As Recv'd	0.60	97.1
3	100	0	None	14	23	1/2"	As Recv'd	0.59	98.2
4	100	0	None	12	28	1/2"	As Recv'd	0.47	94.7
5	100	5	Calcium Hydroxide	10	31	1/2"	As Recv'd	0.64	96.9
6	150	5	Kiln Dust	11	30	1/2"	As Recv'd	0.56	96.7
7	150	5	Calcium Hydroxide	11	25	1/2"	As Recv'd	0.65	98.0
8	150	5	Portland Cement	12	29	1/2"	As Recv'd	0.61	97.2 96.2
9	150	2	Portland Cement	10	20	1/2"	As Recv'd	0.71	97.9
10	150	5	Bituminous Fly Ash	14	28	1/2"	As Recv'd	0.56	96.3
11	150	5	Bituminous Fly Ash	9	23	1/2"	As Recv'd	0.59	97.6
12	150	5	Iowa Coal	10	33	1/2"	As Recv'd	0.53	95.6
13	150	5	Western Coal	9	23	1/2"	As Recv'd	0.65	96.8
14	150	5	1 Calcium Hydroxide 4 Fly Ash	13	30	1/2"	As Recv'd	0.61	96.6
15	150	5	1 Calcium Hydroxide 4 Fly Ash	9	21	1/2"	As Recv'd	0.67	97.9

Run	Total lbs.	% Binder	Binder	Initial Moisture	Final Moisture	Pellet Diameter	PSD	Bulk Density	% +3/8"
16	150	5	1 Calcium Hydroxide	9	30	1/2"	As Recv'd	0.52	96.7
17	150	5	1 Calcium Hydroxide 4 Kiln Dust	11	22	1/2"	As Recv'd	0.70	99.0
18	150	1	Calcium Hydroxide	9	31	1/2"	As Recv'd	0.54	96.9
19	150	1	Calcium Hydroxide	10	21	1/2"	As Recv'd	0.68	98.1
20	150	5	Calcium Hydroxide	9	19	1/2"	As Recv'd	0.74	97.8
21	150	2	Calcium Hydroxide	9	17	1/2"	As Recv'd	0.76	99.0
22	150	10	Calcium Hydroxide	36	36	1/2"	As Recv'd	0.62	97.0
23	150	10	5 Calcium Hydroxide 5 Portland Cement	35	35	1/2"	As Recv'd	0.64	96.4
24	150	2	Calcium Hydroxide	12	22	1/2"	As Recv'd	0.71	98.2
25	150	2	Calcium Hydroxide	Re-pelletized	13	1/2"	As Recv'd	0.72	95.3
26	150	2	Calcium Hydroxide	Re-pelletized	11	1/2"	As Recv'd	0.79	97.1
27	150	5	Dolmite	13	19	1/2"	As Recv'd	0.71	98.2
28	150	5	2.5 Calcium Hydroxide 2.5 Dolomite	12	19	1/2"	As Recv'd	0.78	99.2
29	150	5	2.5 Calcium Hydroxide 2.5 Dolomite	28	28	1/2"	As Recv'd	0.66	94.8

Run	Total lbs.	% Binder	Binder	Initial Moisture	Final Moisture	Pellet Diameter	PSD	Bulk Density	% + 3/8"
30	150	2	Calcium Hydroxide	11	11	1/2"	As Recv'd	0.85	99.0
31	150	2	Calcium Hydroxide	11	11	3/4"	As Recv'd	0.81	98.5
32	150	2	Calcium Hydroxide	10	19	3/4"	As Recv'd	0.71	98.6
33	150	5	Calcium Hydroxide	9	22	3/4"	As Recv'd	0.75	99.3
34	225	5	Calcium Hydroxide	9	30	3/4"	As Recv'd	0.67	97.8
35	150	5	Calcium Hydroxide	Re-pelletized	21	3/4"	As Recv'd	0.80	96.9
36	150	0	None	11	20	3/4"	As Recv'd	0.67	98.4
37	150	0	None	9	9	3/4"	As Recv'd	0.73	97.9
38	150	0	None	10	29	3/4"	As Recv'd	0.51	96.7
39	150	2	Calcium Lignosulfonate	10	22	3/4"	As Recv'd	0.68	98.5
40	150	3.5	1.75 Calcium Hydroxide 1.75 Dolomite	10	21	3/4"	As Recv'd	0.72	99.0
41	150	5	Calcium Hydroxide	19	19	3/4"	As Recv'd	0.84	98.5
42	150	0	None	21	21	3/4"	As Recv'd	0.76	98.2
43	150	0	None	10	10	3/4"	Fines	0.71	98.0
44	150	0	None	8	18	3/4"	Fines	0.61	98.9

Run	Total lbs.	% Binder	Binder	Initial Moisture	Final Moisture	Pellet Diameter	PSD	Bulk Density	% +3/8"
45	150	1	Calcium Hydroxide	8	20	3/4"	Fines	0.66	98.9
46	150	2	Calcium Hydroxide	9	20	3/4"	Fines	0.69	99.0
47	150	4	Calcium Hydroxide	8	19	3/4"	Fines	0.71	99.3
48	150	8	Calcium Hydroxide	8	19	3/4"	Fines	0.80	99.2
49	150	0	None	8	27	3/4"	Fines	0.54	98.0
50	150	8	Calcium Hydroxide	8	28	3/4"	Fines	0.63	98.0
51	150	8	Calcium Hydroxide	9	9	3/4"	Fines	0.83	98.8
52	150	4.5	Calcium Hydroxide Portland Cement Dolomite	6.53	6.53	3/4"	Fines	0.77	98.3
53	4000	4.5	Calcium Hydroxide Portland Cement Dolomite	6.53	6.53	3/4"	Fines	0.77	98.3
54	100	4.5	Calcium Hydroxide Portland Cement Dolomite	--	--	3/4"	Fines	Hammermilled #53	

Appendix C

BINDER RESULTS

BINDER

1) Blank RDF
2) 1% COAL FINES
3) 5% COAL FINES
4) 1% BENTONITE
5) 5% BENTONITE
6) 1% SODIUM CHLORIDE
7) 5% SODIUM CHLORIDE
8) 1% UREA-FORMALDEHIDE
9) 5% UREA-FORMALDEHIDE
10) 1% GRANULATED SLAGE
11) 5% GRANULATED SLAGE
12) 1% LIME
13) 3% LIME
14) 5% LIME
15) 1% WAX
16) 5% WAX
17) 5% PORTLAND CEMENT
18) 5% LIMESTONE
19) 5% ASCARITE
20) 1% CALCIUM HYDROXIDE
21) 5% CALCIUM HYDROXIDE
22) 1% CALCIUM HYDROXIDE

23) 5% CALCIUM CARBONATE

24) 1% LIGNOSULPHONATE

25) 5% LIGNOSULFONATE

26) 1% ANTI-GELLING AGENT

27) 5% ANTI-GELLING AGENT

28) 1% DISPESANT

29) 5% DISPESANT

30) 10% WATER

31) 1% KILN DUST

32) 5% KILN DUST

33) 5% CARBON BLACK

34) 1% PARAFFINE

35) 5% PARAFFINE

36) 5% STARCH

37) 10% AMBERLIG

38) 1% SAW DUST

39) 5% SAW DUST

40) 5% PLIOLITE

41) 5% AMMONIUM CHLORIDE

42) 5% WALNUT OIL

43) 10% ELMERS GLUE SOLUTION

44) 5% CONTACT CEMENT

45) 5% ARTIFICIAL FETILIZER

46) 5% SODIUM SILICATE

47) 5% SODIUM CHLORIDE

48) 5% 50/50 LIME/COAL FINES

49) 5% 75/25 LIME/COAL FINES

50) 5% GLOSS VARNISH

51) 5% PAINT SLUDGE MIXTURE

52) 5% ROOFING CEMENT

53) 5% MULTI PURPOSE FLOOR ADHESIVE

54) 5% 0.3 gm LIME, 2 gm AMMONIUM SULFATE, 2 CALCIUM PHOSPHATE, 2 gm KNO3.

55) 5% PERMOUNT

56) 5% RECTOR SEAL GLUE

57) 5% LIME/BORIC ACID

58) 5% 1/4 BENZOIC ACID

59) 5% BITUMINOUS FLY ASH

60) 5% LIGNITE FLY ASH

61) 5% ANHYDRITE

62) 5% 50/50 LIME/LIGNOSUFONATE

63) 5% 50/50 Na2CO3/CALCIUM CARBONATE

64) 5% 50/50 Na2CO3/LIME

65) 5% GYPSUM

66) 5% HEMIHYDRATE

67) 5% PHOSPHOGYPSOM

68) 5% FLOUROGYPSOM

ASTM Designation E38.08-3.3/3.7 (Alternative Standard)

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

Task Group No. E38.08-3
Draft No. A
Date: October 1985
T. G. Cahirman: Ray Lotito
Author: Gary Smith

1.0 SCOPE

1.1 This method determines two characteristics of densified RDF (d-RDF) particles; the particle density, or mass per unit volume of typical fuel particles; and the ability of the fuel particles to resist absorbing water, their 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 loggetts) or to the characterization of less dense forms of RDF-5 (>1.0 gram/cc).

2.0 APPLICABLE DOCUMENTS--ASTM STANDARDS

2.1 E--Air Drying RDF-5 Samples.

2.2 E--Determination of the Size Distribution of RDF-5.

3.0 SUMMARY METHOD

3.1 This method first determines the mass of a representative sample of RDF-5 gravimetrically and then the volume by water displacement to calculate particle density, the mass per unit volume. By reweighing the wetted sample after the water displacement volume determination, the water weight gain of the sample is determined. The percent of water weight gain is inversely proportional to the ability to resist absorbing water, the water repellency.

4.0 SIGNIFICANCE AND USE

4.1 The particle 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 an indication of the handling, storage and combustion characteristics of the RDF and may be used as a purchasing specification.

4.2 The water repellency of the RDF particles indicates their short-term tolerance to less than ideal storage and handling conditions as regards weather. A favorable result for this characteristic would not indicate a tolerance to long-term exposure to weather results in significant particle deterioration. Water repellency may be used as a purchasing specification.

5.0 PROCEDURE

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

5.2 Air dry the laboratory sample as per ASTM E 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 all fines according to ASTM E___ "Determination of the Size of Distribution of RDF-5." 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 briquetts.

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 ml 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 particles or expect to be able to remove all of the air bubbles.

5.8 At the end of the first minute, observe the combined volume of the water and fuel particles in the cylinder to the nearest 5 ml. Record the final volume, V_f.

5.9 Allow the fuel particles 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 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, remove from the fuel particles as much of the remainnig water as possible by alternately shaking and then sharply rapping the sieve on a solid surface five to ten times.

5.10 Transfer the fuel particles 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 Report the above steps E through J for the remaining three analytical samples.

6.0 REPORT

6.1 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.

6.2 Particle Density Calculation - calculate the mass (grams) per unit volume (cubic centimeters) of the fuel particles as follows: Dp= Mi/ (vp-vi)

D_p = Particle density, gramm/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.

6.3 Water Repellency Calculation - calculate the water repellency of the samples as follows:

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

H = Hydorphylic tendency of the fuel particles, percent.

W_f = Final (wetted) net mass of the sample, gram.

W_i = Initial net mass of the sample, gram.

6.4 Calculation of the mean - calculate the average values of density and water repellency from the results of the four analytical samples as follows:

$$x = (n_1 + n_2 + n_3 + n_4) / 4$$

where:

x = The average of the four determinations.

$n_1..4$ = The individual results of the four analytical samples.

7.0 PRECISION

To be determined.

8.0 BIAS

NOTE: RDF-5 particles which have considerable surface texture, such as those which 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. The ability to correctly determine the "true" volume of such particles by any technique is subject to debate. The exaggeration of volume results in a decrease in the apparent density. This lowered density value accurately reflects the deterioration of particle density as a fuel characteristic, even though it does not accurately (linearly) measure the "true" density of the particle. In a similar fashion, particles with a highly textured surface will tend to retain small water droplets at the end of the water repellency procedures, therefore, resulting in an exaggerated water weight gain value giving a resultant decrease in the water repellency. Once, again, the tendency is to yield values which accurately reflect the relative worth of the RDF-5 characteristic as regards its desirability as a fuel. Any resultant bias relates to the linearity of the response, not to the relative meaning of the results.

Appendix E

```
:===================:
:concrete mixer     :
:  RDF-3            :         :=================:
:tumble for 20 minu.:  ---------+measure moisture :
:=======+===========:         :=================:
        !
        !
        !
:===================:
:spray water        :
:===================:
        !
        !
        !
:===================:         :=================:
:mix for 20 minutes :  ---------+check moisture   :
:===================:         :=================:
        !
        !
        !
:===================:
:spray binder       :
:===================:
        !
        !
        !
:===================:         :=================:
:mix for 20 minutes :  ---------+check moisture   :
:===================:         :=================:
        !
        !
        !
:=======+===========:         :=================:
:pellitize          :  ---------+check moisture   :
:===================:         :=================:
```

SUMMARY OF THE PELLETIZATION PROCESS

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