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EXPERIMENTAL PROGRAM FOR THE DEVELOPMENT OF PEAT GASIFICATION

Interim Report No. 4

PHYSICAL PROPERTIES EVALUATION

TASK 1

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SUMMARY

This interim report presents the results of tests conducted to determine the physical properties of Minnesota reed sedge peat. The work was conducted by the Institute of Gas Technology (IGT) for the Minnesota Gas Company as a part of ERDA* Contract No. EX-76-C-01-2469, "Experimental Program for the Development of Peat Gasification." The overall program objectives are to obtain engineering data and develop a model for peat gasification, to select the gasification process most suitable for peat, and to determine the economics of such a process. The work presented here was conducted under Task 1 on Physical Properties Evaluation of this program.

The tests were conducted with Wilderness Farm reed sedge peat, selected as a representative Minnesota peat based on numerous chemical analyses of peats from various locations. The tests were conducted to determine the grinding, fluidizing, and slurrying characteristics of peat and to investigate the effects of wet-carbonization and high-pressure compaction on its physical properties. Finally, peat briquettes and pellets were made and their strengths and attrition resistances were evaluated. The results of these tests show that —

- Conventional hammer mills can be used for grinding air-dried (40 weight percent moisture) peat.
- Dried and ground peat can be fluidized.
- Grinding and drying of peat reduces its liquid-retention capacity.
- A peat-toluene slurry containing 30 to 35 weight percent peat is pumpable.
- High-pressure compaction is effective in dewatering raw and wet-carbonized peat to 60-65 and 50-55 weight percent water, respectively.
- Air-dried peat (35 weight percent moisture) can be briquetted or pelletized without binders.
- The angles of internal friction, repose, slide, and rupture for dry peat are similar to those of coal.

The physical properties of peat mentioned above suggest the possibility of peat gasification in fluidized-bed as well as in moving-bed reactors. These

* Presently known as the United States Department of Energy (DOE).

properties also suggest that peat could be fed to a high-pressure gasifier using either a lockhopper or a light-oil slurry system.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
ACHIEVEMENT OF PROJECT OBJECTIVES	8
SIZE-REDUCTION CHARACTERISTICS	9
Laboratory Grinders	9
Industrial Grinders	13
FLUIDIZATION CHARACTERISTICS	18
SLURRYING CHARACTERISTICS	31
Toluene-Retention Capacity Tests	31
Slurry Pumpability	35
Slurry Viscosity Measurements	36
PEAT WET CARBONIZATION	42
HIGH-PRESSURE COMPACTION	49
PELLETIZING AND BRIQUETTING	52
Pelletizing Tests	52
Briquetting	54
FLOW CHARACTERISTICS OF PEAT	57
CONCLUSIONS	63
REFERENCES CITED	64

LIST OF FIGURES

Figure No.		Page
1	Comparison of the Total Estimated U.S. Peat Reserves With the Total Identified Reserves of Other Energy Resources	2
2	Recoverable Fossil Fuel Reserves in the United States	2
3	U.S. Coal, Lignite, and Peat Deposits	3
4	Peat Gasification Program Schedule	6
5	Effect of Gas Velocity on Pressure Drop Characteristics of Peat (–10+100 U.S.S.)	20
6	Effect of Gas Velocity on Bed Density Characteristics of Peat (–10+100 U.S.S.)	21
7	Effect of Gas Velocity on Pressure Drop Characteristics of Peat (–40+60 U.S.S.)	22
8	Effect of Gas Velocity on Bed Density Characteristics of Peat (–40+60 U.S.S.)	23
9	Effect of Gas Velocity on Pressure Drop Characteristics of Peat (–60+80 U.S.S.)	24
10	Effect of Gas Velocity on Bed Density Characteristics of Peat (–60+80 U.S.S.)	25
11	Effect of Gas Velocity on Pressure Drop Characteristics of Peat (–20+30 U.S.S.)	26
12	Effect of Gas Velocity on Bed Density Characteristics of Peat (–20+30 U.S.S.)	27
13	Effect of Gas Velocity on Bed Pressure Drop Characteristics of Husky Lignite Char (–40+60 U.S.S.)	28
14	Effect of Gas Velocity on Bed Density Characteristics of Husky Lignite Char (–40+60 U.S.S.)	28
15	Effect of Particle Size on Minimum and Complete Fluidization Velocities of Minnesota Reed Sedge Peat	29
16	Schematic Diagram of Slurry Viscometer	36

LIST OF FIGURES, Cont.

Figure No.		Page
17	The Effects of Particle Size and Toluene Concentration on the Viscosities of Peat and Lignite Slurries in Toluene	38
18	The Effects of Moisture Content and Pretreatment on the Viscosities of Peat and Lignite Slurries in Toluene	40
19	Sample Holder for High-Pressure Compaction and Dewatering Tests	49
20	The Effect of Pressure on Water Remaining in Raw and Wet-Carbonized Peat After Compaction	51
21	Schematic Presentation of Pelletizing Apparatus	52
22	Schematic of Apparatus Used for Determining Angles of Repose, β, and Internal Friction, α	58
23	Pictoral Representation of Angle of Rupture, ω	58

LIST OF TABLES

Table No.		Page
1	Major Tasks and Objectives of the Peat Gasification Program	5
2	Summary of Size-Reduction Tests in a Mechanical Mortar and Pestle (Torsion Balance Model No. MG-2)	10
3	Summary of Size-Reduction Tests Conducted in a Bleuler Rotary Mill (Willy Bleuler Rotary Mill, Fab. No. 1084)	11
4	Effect of Moisture Content on the Characteristics of Peat Ground in a Mechanical Mortar and Pestle and in a Bleuler Rotary Mill	12
5	Results of the Size-Reduction Tests Conducted With Peat in Laboratory-Scale Industrial Grinders	14
6	Results of Size-Reduction Tests Conducted With Peat and Coals in a Hammer Mill	15
7	Screen Analysis of the Feed for Run PF-1 Conducted With Minnesota Reed Sedge Peat	19
8	Comparison of the Fluidization Characteristics of Husky Lignite Char and Peat	30
9	Effect of Particle Size and Moisture Content on Toluene-Retention Capacity of Reed Sedge Peat	32
10	Toluene-Retention Capacities of Raw and Wet-Carbonized Peat	33
11	The Effect of Compaction Pressure on the Toluene-Retention Capacity of Reed Sedge Peat	34
12	Size Distribution of the Reed Sedge Peat Used in Slurry Viscosity Measurements	39
13	Size Distribution of Lignite Used in Slurry Viscosity Measurements	39
14	Operating Conditions and Analysis of Solids	44
15	Analyses of Off-Gases Collected During Wet-Carbonization of Peat	46
16	Analysis of Hydrocarbon Liquids Collected During Wet-Carbonization of Peat	47

LIST OF TABLES, Cont.

Table No.		Page
17	Results of Pelletization of Peat Samples That Have Different Moisture Contents	53
18	Results of Compression and Splitting Strength Tests on Pelletized Samples of Reed Sedge Peat	54
19	Results of Attrition Tests Conducted With Several Varieties of Peat Pellets	55
20	Effect of Particle Size and Briquetting Pressure on the Splitting Strength (Crossload) of Peat Briquettes and Their Bulk Density	56
21	Particle-Size Distribution of Peat and Coal Samples Used in Tests to Determine Angles of Internal Friction, Repose, Slide, and Rupture	59
22	The Effect of Particle Size and Moisture Content on the Angle of Internal Friction for Peat and Coal Samples	60
23	The Effect of Particle Size and Moisture Content on the Angle of Repose for Peat and Coal Samples	60
24	The Effect of Particle Size and Moisture Content on the Angle of Slide (on Steel Plate) for Peat and Coal Samples	62
25	The Effect of Particle Size and Moisture Content on the Angle of Rupture for Peat and Coal Samples	62

INTRODUCTION

Peat can be considered a geologically young coal. In Europe it has been extensively used for years as a source of fuel and chemicals. The United States has the second largest peat resources in the world, estimated[1] to be about 120 billion tons of air-dried peat (35 weight percent moisture content basis). The energy available from these reserves is estimated to exceed 1440 quads (10^{15} Btu), which is equivalent to 240 billion barrels of oil. These energy reserves surpass those estimated as being available from uranium, oil shale, natural gas, or petroleum (Figure 1) and are exceeded only by the energy available from coal. Peat, therefore, represents a significant amount of the United States energy resources. Even in the contiguous 48 states, the relative energy potential of peat is similar to that for the entire United States (Figure 2). It totals about 690 quads and exceeds the potential energy available from recoverable lignite reserves (calculated by using a 50% recovery factor on the reserve base).[4] Because peat generally occurs at the ground surface (with an average depth of about 7 feet and a maximum depth of only about 20 feet), it is assumed that all of the peat reserves are recoverable.

Although peat is found in all 50 states, about 90% of the reserves are concentrated in seven states: Alaska, Minnesota, Michigan, Florida, Wisconsin, Louisiana, and North Carolina. Most of the states that are rich in peat resources do not have significant reserves of other solid fuels (Figure 3); therefore, peat represents a very important energy resource. The states with large peat deposits also have plentiful water supplies, thus making peat a potential raw material for substitute natural gas (SNG) production. Even though Alaska has significant oil and gas reserves, it might be feasible, in the future, to convert peat to SNG so that the gas would continue to flow to the Lower 48 States through the proposed multibillion dollar natural gas pipeline.

Of the contiguous 48 states, Minnesota has the largest single peat reserves, totaling about 16 billion tons or 198 X 10^{15} Btu. This represents significant energy reserves for this area. The Minnesota Gas Company, concerned about its long-term reserves of natural gas, sponsored a study* at IGT to evaluate the

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* This study, completed in August 1975, was submitted to ERDA by Minnesota Gas Company as Supplementary Report No. FE-2469-8 of this project.

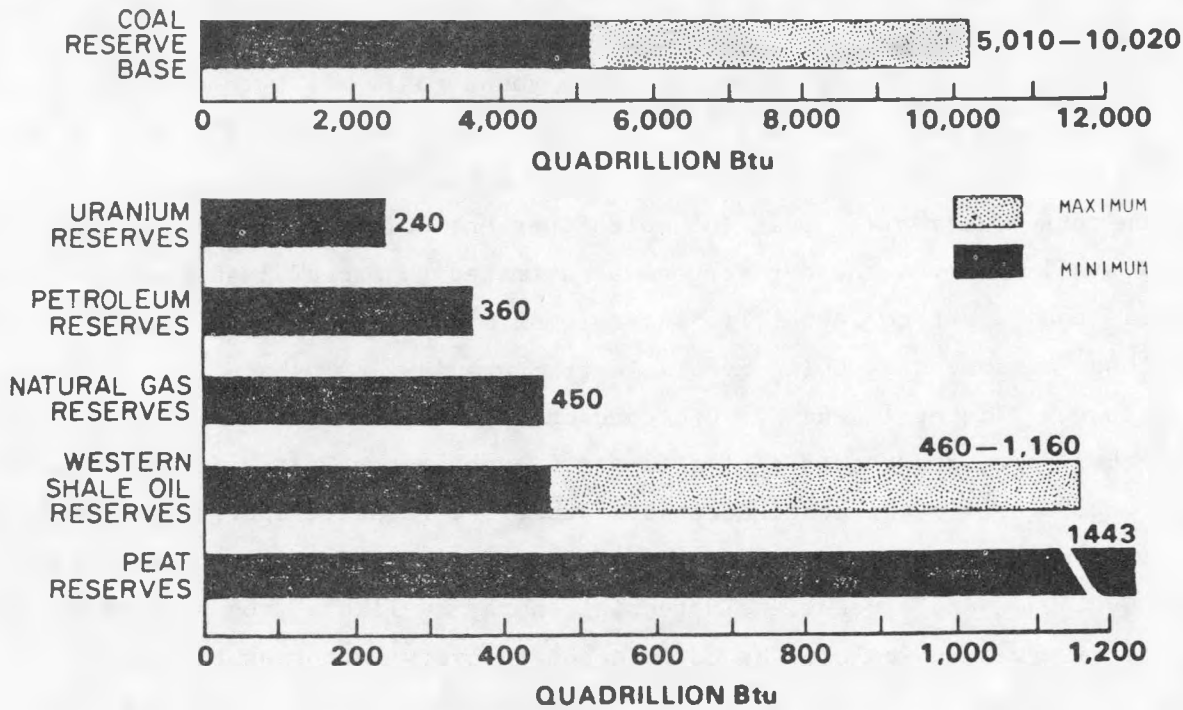

Figure 1. COMPARISON OF THE TOTAL FSTIMATED U.S. PEAT RESERVES WITH THE TOTAL IDENTIFIED RESERVES OF OTHER ENERGY RESOURCES
Source (except for peat): U.S. Energy Perspectives 2, U.S. Dept. of the Int., June 1976

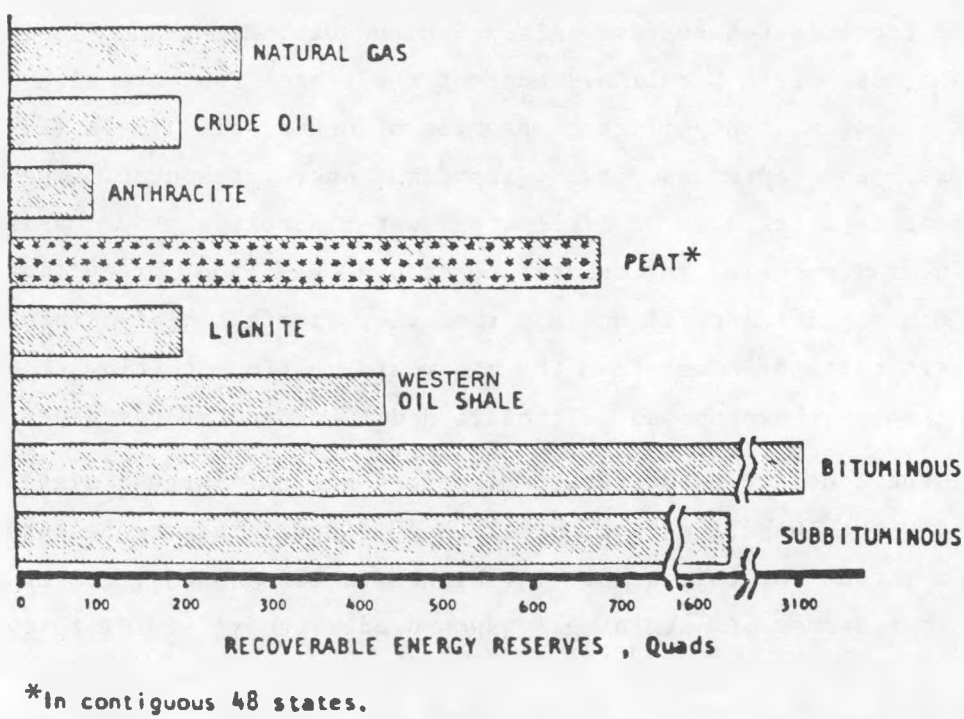

Figure 2. RECOVERABLE FOSSIL FUEL RESERVES IN THE UNITED STATES

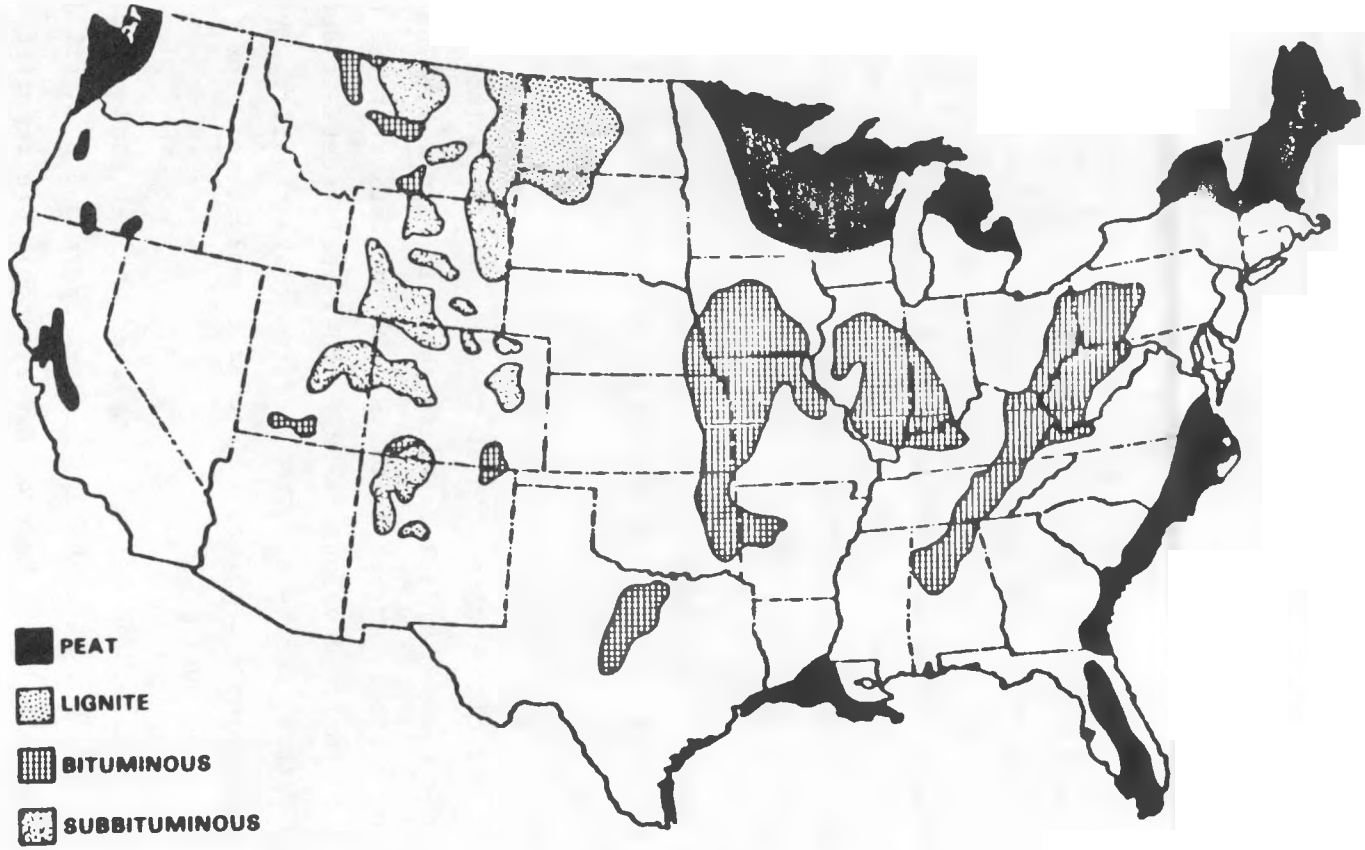

Figure 3. U.S. COAL, LIGNITE, AND PEAT DEPOSITS

conversion of Minnesota peat to SNG. Because of limited design information and funds, only the use of the HYGAS® Process to make SNG was studied. The results of that study, obtained by extrapolating coal-conversion technology to peat processing, indicate that converting peat to SNG is technically feasible and economically attractive.

To develop and achieve commercialization of any peat conversion process, the process concepts should be verified by obtaining design data from direct experimentation. Based on these data, the technology and economics of the process should be reassessed. To this end, the Minnesota Gas Company proposed a 24-month, cost-sharing program to the United States Energy Research and Development Administration (ERDA)* for experimental work to develop the necessary engineering data for peat gasification. On July 1, 1976, ERDA Contract No. E(49-18)-2469† was awarded for this purpose. IGT, a subcontractor to the Minnesota Gas Company, is conducting the experimental study. Based on the engineering data obtained from this program, a peat gasification model will be developed and the coal gasification process that is most suitable for converting peat to SNG will be selected. A technical and economic evaluation of the process selected will then be made. Existing coal gasification technology will be used as much as possible.

Table 1 shows the eight major program tasks and their objectives. The program schedule for the individual tasks is shown in Figure 4. The first three tasks relate to laboratory-scale tests. The objective of the next three tasks is to conduct process-development-unit (PDU)-scale tests to determine the effect of the initial scale-up. The last two tasks relate to evaluating the laboratory and PDU-scale data and to economic analyses of a preferred process to produce SNG from peat.

Task 2 (Thermobalance Studies) was completed earlier, and the results were reported in ERDA Report No. FE-2469-10, Interim Report No. 2, April 1977. The results from Task 3 (Coiled-Tube Reactor Experiments) were reported in ERDA Report No. FE-2469-17, Interim Report No. 3, January 1978. Based on the data obtained in Task 3, a preferred process for converting peat to SNG has been recommended, and PDU-scale tests are now in progress.

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* Now the Department of Energy (DOE).

† Currently DOE Contract No. EX-76-C-01-2469.

Table 1. MAJOR TASKS AND OBJECTIVES OF THE PEAT GASIFICATION PROGRAM

TASK NO.	TITLE	OBJECTIVE
1	Physical Properties Evaluation	Determine the grinding, flow, pelletization, slurring, and fluidization characteristics of peat.
2	Thermobalance Studies	Determine the gasification kinetics of peat char.
3	Coiled-Tube Reactor Experiments	Determine the hydrogasification kinetics of peat.
4	Lift-Line Reactor Studies	Conduct peat hydrogasification tests in PDU.
5	Steam-Oxygen Reactor Studies	Conduct peat char gasification tests in PDU.
6	Fluidized-Bed Hydrogasification Experiments	Conduct PDU tests for hydrogasification of peat char.
7	Kinetic Studies and Modeling	Analyze the data obtained from various experimental tasks in the program and develop a kinetic model for peat gasification.
8	Technical and Economic Evaluation	Evaluate the overall technical and economic viability of the peat gasification process.

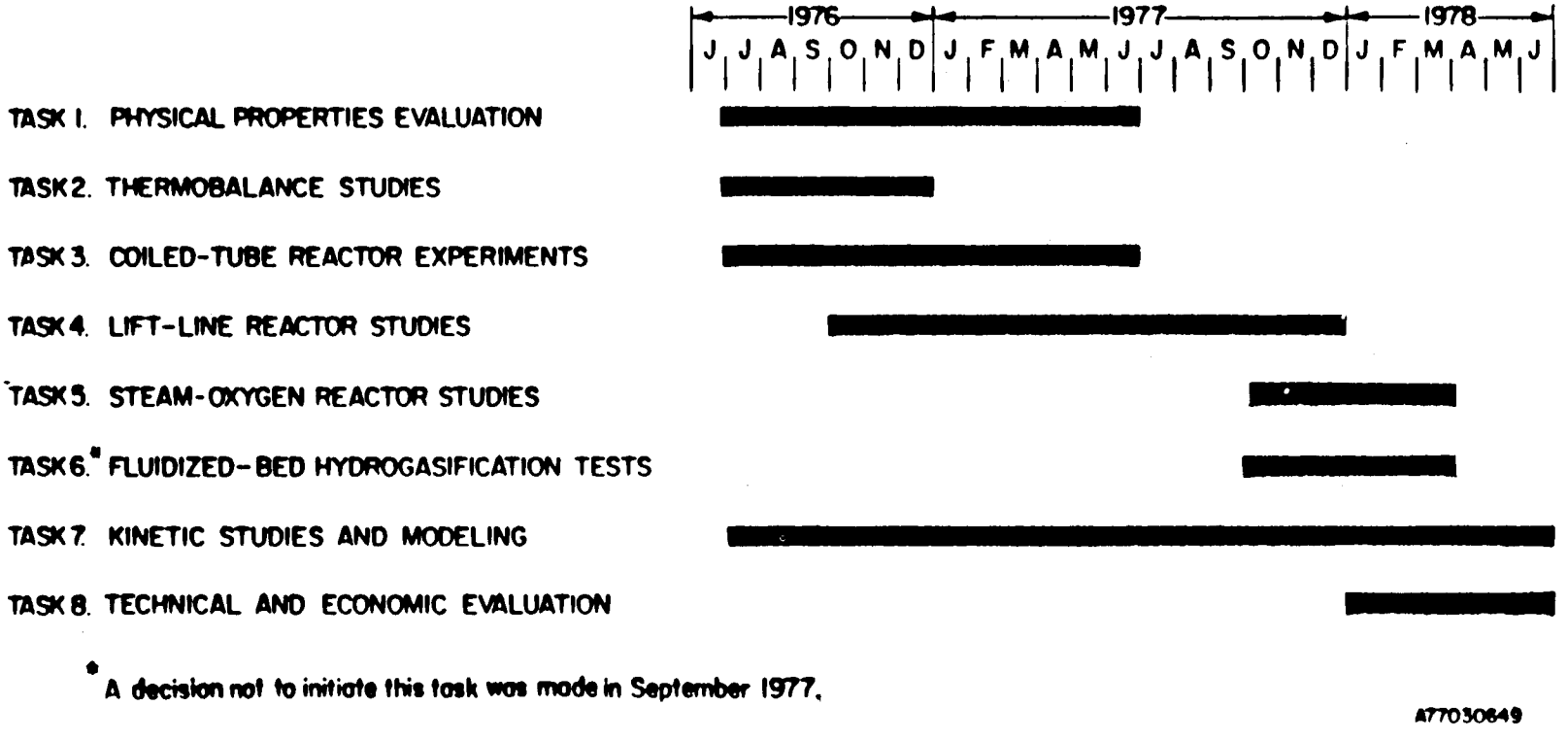

Figure 4. PEAT GASIFICATION PROGRAM SCHEDULE

Some work relating to the physical properties of peat was carried out between February 10 and June 30, 1976, in anticipation of the present contract. The results of that work show that drying and size reduction decrease peat's liquid-reabsorption capacity. (Several liquid-retention tests were also conducted.) Results of these tests, conducted to determine the reabsorption capacity of dried and ground peat for five potential slurry media, show that toluene was the least absorbed (35.9 weight percent) slurry media followed by acetone (37.8 weight percent), propanol (45.2 weight percent), ethanol (50.5 weight percent), and water (60.7 weight percent). The details of this work have been reported in ERDA Report No. FE-2469-3, Interim Report No. 1, October 1976.

This interim report presents the results of the work completed under Task 1 on the various physical properties (grinding, fluidization, slurrying, high-pressure compaction, briquetting, and pelletizing) of Minnesota reed sedge peat.

ACHIEVEMENT OF PROJECT OBJECTIVES

The overall program objective is to develop a process for the conversion of peat to SNG and to evaluate its process economics. All of the objectives of the laboratory-scale tests (Task 1, Task 2, and Task 3) have been achieved. On the basis of the engineering data obtained from the laboratory tests, a gasifier configuration has been selected to optimize methane production.

Peat hydrogasification PDU tests (Task 4) and peat char gasification PDU tests (Task 5) are currently in progress. The objective of these tests is to corroborate the peat gasification process yields and thus facilitate an evaluation of its process economics.

The laboratory work indicated that a fluidized-bed hydrogasification step would not be necessary in the preferred gasification configuration. Therefore, Task 6 (Fluidized-Bed Hydrogasification Tests) will not be included in the schedule of work.

SIZE-REDUCTION CHARACTERISTICS

The objective of this series of tests was to compare the size-reduction characteristics of peat with those of lignite and bituminous coals. Twenty-four tests were conducted in two laboratory grinders and in two industrial-type grinders to evaluate the effects of peat moisture content, feed particle size, pretreatment, and grinding conditions on the generation of fines. The tests generally show that the fines generation tendencies of dry and air-dried peat during size reduction are similar to those of coals.

Laboratory Grinders

Twelve tests, Runs SR-1 through SR-12, were conducted in two laboratory sample-preparation grinders: a mechanical mortar and pestle and a rotary-disc grinder. The mechanical mortar and pestle (Torsion Balance Model MG-2) consists of a stationary porcelain pestle and a mortar that revolves at 90 rpm. The grinding time usually is from 5 to 10 minutes for typical laboratory samples. The rotary disc-grinder (Willy Bleuler mill) consists of two grinding elements, a ring and a puck, that are free to rotate within the sample container, which revolves in an orbit at 830 rpm. The standard grinding time in this mill is 1 minute. For both grinders, a typical sample load ranges from about 20 to 40 grams. The results of the grinding tests are shown in Tables 2 through 4.

Table 2 summarizes the results obtained with the mortar and pestle grinder. Runs SR-1 and SR-2 were conducted with dry peat, primarily to determine the effect of grinding time. The results show that reducing the grinding time from 10 to 1 minute increases the average particle size from 25% of the original feed size to 33% of the feed size. Based on these results, it was decided to conduct future tests in this equipment for a grinding time of 1 minute only. A comparison of the tests conducted with bituminous and lignite coals with those conducted with peat, under similar conditions, shows that the average particle size of ground peat is similar to that of ground lignite, or about 25% to 30% of the feed size. The results also show that the average particle size of ground bituminous coal is only about 70% of the feed size.

The results obtained with the rotary-disc grinder are summarized in Table 3. They show that the size-reduction characteristics of peat are similar to those

Table 2. SUMMARY OF SIZE-REDUCTION TESTS IN A MECHANICAL MORTAR AND PESTLE (Torsion Balance Model No. MG-2)

	Feed[a]				Product			
Sample	Peat[d]		Bituminous[e]	Lignite[f]	Peat	Peat	Bituminous	Lignite
Run No.					SR-1	SR-2	SR-4	SR-6
Feed Moisture Content, wt %	0	0	2	15				
Grinding Time, min					10	1	1	1
Screen Size, U.S.S., wt %								
+20	34.5	37.7	11.8	49.0	--	--	--	--
−20+40	17.9	22.0	27.3	23.7	--	--	--	--
−40+60	17.5	11.6	17.8	11.6	--	33.1	40.5	51.7
−60+80	7.5	6.1	3.0	3.9	15.8	8.3	7.8	10.0
−80+100	3.6	3.0	12.2	3.3	5.7	3.8	8.9	5.0
−100+140	7.9	6.4	8.6	2.7	13.1	10.3	9.6	7.3
−140+170	1.6	1.4	2.4	0.6	3.5	3.0	3.4	2.0
−170+230	3.2	4.0	4.2	1.2	19.4	9.1	6.4	4.6
−230+325	--	4.3	6.4	1.8	9.2	15.6	13.8	8.1
−325[b]	6.3	3.5	6.3	2.2	33.3	16.8	9.6	11.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mean[c] Particle Size, in.	0.152	0.180	0.119	0.279	0.038	0.060	0.081	0.084

[a] Nominal feed size, −10 mesh.

[b] Average particle size of 17.2μ obtained by Coulter Counter analysis.

[c] $1/\Sigma(x_i/d_i)$.

[d] Minnesota Wilderness Farm reed sedge peat.

[e] Illinois No. 6 seam bituminous coal.

[f] North Dakota lignite.

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Table 3. SUMMARY OF SIZE-REDUCTION TESTS CONDUCTED IN A BLEULER ROTARY MILL
(Willy Bleuler Rotary Mill, Fab. No. 1084)

	Feed[a]			Product[b]		
Sample	Peat[e]	Bituminous[f]	Lignite[g]	Peat	Bituminous	Lignite
Run No.				SR-3	SR-5	SR-7
Feed Moisture Content, wt %	0	2	15			
Screen Size, U.S.S., wt %						
+20	37.7	11.8	49.0	--	--	--
−20+40	22.0	27.3	23.7	--	--	--
−40+60	11.6	17.8	11.6	--	--	--
−60+80	6.1	3.0	3.9	3.7	0.2	--
−80+100	3.0	12.2	3.3	3.9	3.1	2.1
−100+140	6.4	8.6	2.7	9.2	10.6	11.8
−140+170	1.4	2.4	0.6	3.9	9.7	9.6
−170+230	4.0	4.2	1.2	79.0	16.5	19.1
−230+325	4.3	6.4	1.8	0.3	56.6	49.3
−325[c]	3.5	6.3	2.2	0.0	3.3	8.1
Total	100.0	100.0	100.0	100.0	100.0	100.0
Mean[d] Particle Size, mm	0.180	0.119	0.279	0.082	0.059	0.053

[a] Nominal feed size, −10 mesh.

[b] Obtained after 1 minute of grinding.

[c] Average particle size of 17.2μ obtained by Coulter Counter analysis.

[d] $1/\Sigma(x_i/d_i)$.

[e] Minnesota Wilderness Farm reed sedge peat

[f] Illinois No. 6 seam bituminous coal.

[g] North Dakota lignite.

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Table 4. EFFECT OF MOISTURE CONTENT ON THE CHARACTERISTICS OF PEAT[a] GROUND IN A MECHANICAL MORTAR AND PESTLE AND IN A BLEULER ROTARY MILL

Sample	Product[b]				
Grinder Type	Mechanical Mortar and Pestle			Bleuler Rotary Mill	
Run No.	SR-8	SR-9	SR-10	SR-11	SR-12
Feed Moisture Content, wt %	0	40	64.6	40	64.6
Residue Moisture Content, wt %	0	38.5	61.8	38.5	61.8
Screen Size, U.S.S., wt %					
+20	--	8.8	6.6	2.3	17.9
−20+40	7.6	26.3	37.6	33.3	23.4
−40+60	11.7	14.4	23.4	21.6	28.9
−60+80	9.3	6.4	10.9	11.2	16.6
−80+100	6.6	12.7	11.4	10.2	6.8
−100+140	7.8	7.4	2.0	3.2	0.9
−140+170	5.1	4.3	2.4	2.7	0.9
−170+230	16.5	15.2	4.1	9.3	2.5
−230+325	12.6	1.8	0.8	3.4	1.2
−325[c]	22.8	2.7	0.8	2.8	0.9
Total	100.0	100.0	100.0	100.0	100.0
Mean[d] Particle Size, mm	0.049	0.142	0.238	0.155	0.257

[a] Nominal feed size of −10+20 U.S.S, average particle size of 1.297 mm.

[b] Obtained after grinding for 1 minute.

[c] Average particle size of 17.2μ obtained by Coulter Counter analysis.

[d] $1/\Sigma(x_i/d_i)$.

of bituminous coal. In both cases, the average particle size of the ground sample is about 50% of the feed size. The average particle size of the ground lignite is about 20% of the feed size. For the bituminous coal and the peat, the fines (—325 mesh) content decreases during grinding from 6.3 to 3.3 and from 3.5 to 0 weight percent, respectively, indicating some agglomeration of very fine particles. This effect is not observed with lignite.

The size-reduction characteristics of peat appear to be similar to those of lignite in the mechanical mortar and pestle and to those of bituminous coal in the rotary-disc grinder. The pulling and tearing action of the mortar and pestle was more effective in grinding the fibrous structure of the peat than the compressive action of the rotary-disc grinder. Both coal samples showed more size reduction during grinding in the rotary disc than in the mortar and pestle grinder.

A comparison of the results obtained in the mechanical mortar and pestle with those obtained in the rotary-disc grinder shows that the former gives a wider size distribution than the latter for all types of feed tested.

Table 4 shows the effect of moisture content on the size-reduction characteristics of peat. The tests in the mechanical mortar and pestle show that increasing the moisture content of peat from 0 to 64.6 weight percent decreases the amount of fines (—325 mesh) generated from 22.8 to 0.8 weight percent. The results from tests conducted in the rotary-disc mill show a similar trend. Increasing the moisture content of peat from 40 to 64.6 weight percent decreases the amount of fines (—325 mesh) generated from 2.8 to 0.9 weight percent. These tests, conducted with a nominal —10+20 U.S.S. feed size, show that grinding moist peat is not only feasible but is also preferred to grinding dry peat because the former has a lesser tendency to generate fines during grinding.

Industrial Grinders

Twelve size-reduction tests were conducted with peat, lignite, and bituminous coals in laboratory-scale, hammer-and-rod mills, which are more representative of the industrial grinders than of the mortar-and-pestle and the Bleuler rotary mills used in the earlier tests. Results of these tests, conducted at the Illinois Institute of Technology Research Institute (IITRI), are given in Tables 5 and 6.

Table 5. RESULTS OF THE SIZE-REDUCTION TESTS CONDUCTED WITH PEAT IN LABORATORY-SCALE INDUSTRIAL GRINDERS

Sample	Feed[c]	Product	Feed[c]	Product				Feed[h]	Product
Run No.		SR-13		SR-14	SR-15	SR-16	SR-17		SR-24
Feed Moisture Content, wt %	0		35						
Grinder Type		Hammer mill[d]		Hammer mill	Rod mill[e]	Rod mill[f]	Rod mill[g]		Hammer mill[i]
Toluene Content, total, wt %		--		--	--	--	72.7		--
Screen Size, U.S.S., wt %									
+6	19.7	2.1	33.1	1.8	0.0	0.0	0.0		
−6+10	21.1	3.6	18.3	5.1	0.0	1.8	2.6	83.2	2.4
−10+20	23.9	3.4	12.8	17.9	10.9	9.2	1.7	7.7	9.1
−20+40	14.6	6.7	9.7	21.8	11.0	16.3	5.8	4.7	19.3
−40+60	8.9	18.9	6.8	16.4	18.3	15.9	10.1	1.8	22.2
−60+80	3.7	9.1	6.2	8.6	10.2	9.7	1.3	1.0	17.1
−80+100	2.3	5.2	4.0	3.9	3.7	3.1	13.1	0.3	9.3
−100+140	2.4	11.4	3.6	6.9	8.8	10.6	12.5	0.5	9.5
−140+170	1.7	6.5	1.1	1.5	0.0	2.2	5.1	0.2	3.6
−170+230	1.7	16.8	2.0	4.5	5.8	5.7	14.2	0.3	4.1
−230+325	0.0	5.4	2.4	5.4	13.1	10.1	11.2	0.2	2.3
−325[a]	0.0	10.9	0.0	6.2	18.2	15.4	22.4	0.1	1.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mean Particle[b] Size, mm	0.573	0.081	0.438	0.135	0.065	0.073	0.052	1.291	0.201

a Average particle size of 18.3μ obtained by coulter counter analysis.

b $1/\Sigma(x_i/d_i)$.

c Dried, but not crushed, "as-received" peat. Sample weight ~50 grams for each run.

d With auger-type feed system, hammers revolving at 8050 rpm.

e Containing fifty 1/2-inch-diameter, 8-inch-long rods. Revolving at 70 rpm. Grinding time, 10 minutes.

f Revolving at 70 rpm. Grinding time, 5 minutes.

g Grinding time, 5 minutes.

h High-pressure compacted at 1450 psi, crushed to −1 inch mesh, and dried to a moisture content of about 35 weight percent.

i Hammer revolving at 4600 rpm.

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Table 6. RESULTS OF SIZE-REDUCTION TESTS CONDUCTED WITH PEAT AND COALS IN A HAMMER MILL

Sample	Peat					Lignite[b]		Bituminous[b]	
	Feed[c]	Product				Feed[d]	Product	Feed[d]	Product
Run No.		SR-18	SR-19	SR-20	SR-21		SR-22		SR-23
Mill Speed, rpm (ft/min)		1970 (2580)	4600 (6020)	5520 (7225)	6038 (7905)		4600 (6020)		4600 (6020)
Sieve Size, U.S.S., wt %									
−6+10	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
−10+20	93.6	39.1	46.8	40.4	37.5	72.7	12.5	85.2	10.7
−20+40	4.3	34.1	30.1	30.4	29.6	24.9	43.1	14.3	40.0
−40+60	0.4[g]	7.0	9.3	11.0	11.9	2.4[g]	19.1	0.5[g]	18.0
−60+80	--	4.1	4.3	5.1	6.2	--	8.8	--	10.1
−80+100	--	1.6	1.6	1.9	2.5	--	3.5	--	4.5
−100+140	--	3.1	2.7	3.8	4.2	--	4.7	--	6.2
−140+170	--	1.2	0.9	1.3	1.3	--	1.4	--	2.3
−170+230	--	3.2	1.7	2.0	3.2	--	2.9	--	5.1
−230+325	--	4.6	1.2	1.7	2.5	--	2.0	--	1.1
−325[e]	--	2.0	1.4	2.4	1.1	--	2.0	--	2.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mean Particle[f] Size, mm	1.225	0.241	0.335	0.259	0.279	0.930	0.226	1.090	0.209

[a] Mikro-pulverizer Type-CF hammer mill operated with no screens or discharge plate.

[b] Montana lignite; Illinois No. 6 seam bituminous coal.

[c] Contains 35 weight percent moisture; nominal size (−10+20 U.S.S.). Approximately 150-gram sample used in each test.

[d] Average particle size of 18.3μ obtained by Coulter Counter analysis.

[e] Dry (~0 weight percent moisture) coal of nominal size (−10+20 U.S.S.). Sample weights of about 130 grams for lignite and 40 grams for bituminous coal.

[f] $1/\Sigma(x_i/d_i)$.

[g] These quantities correspond to −40 U.S.S. size fractions. Average particle size taken as 0.250 mm.

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Nine tests were conducted in a hammer mill (Mikro-Pulverizer Type-CR) consisting of six movable "hammers" attached to the shaft of a variable-speed motor. This hammer assembly rotates inside a small cylindrical chamber with a discharge port that can be fitted with various sizes and types of screens. No screens were employed for these grinding tests.

Three tests were conducted in a rod mill (made by IITRI) consisting of a 5-1/2 inch diameter, 8-inch-long metal cylinder containing 50 metal rods that

are 1/2 inch in diameter and 8 inches long. The cylinder can be completely sealed and rotated at various speeds for any desired grinding period. All of the tests in the rod mill were conducted at a constant speed of 70 rpm.

Results of the tests conducted in the hammer mill show (Table 5) that peat containing 35 weight percent moisture generates fewer fines than dry peat. (Compare Runs SR-13 and SR-14.) This is consistent with previous experiences in similar tests in the mortar and pestle and Bleuler rotary mills. These tests also confirm that there is no problem in grinding peat that contains about 35 weight percent moisture.

The objectives of Runs SR-18 through SR-23, conducted in the hammer mill with narrow-size fractions (nominal size −10+20 mesh) of peat that contained 35 weight percent moisture and dry bituminous and lignite coal, were to compare the size-reduction characteristics of those materials and to determine the effect of hammer-mill speed on the size distribution of the ground peat. The results of these tests are shown in Table 6.

The data show that the effect of increasing the hammer-mill speed from about 2000 to 6000 rpm was insignificant. A comparison of the results of tests conducted with peat with those conducted with coals, at a constant hammer-mill speed of 4600 rpm, show that similar amounts (about 2 weight percent) of the −325 U.S.S. size fractions of peat and the coals were generated in these tests.

Results of the peat size-reduction tests, conducted in a rod mill, are also given in Table 5. Runs SR-15 and SR-16 were conducted with peat containing 35 weight percent moisture and had grinding times of 10 and 5 minutes, respectively. Results of these two tests show that decreasing grinding time from 10 to 5 minutes has no significant effect on the average particle size of ground peat.

The objective of Run SR-17 was to determine the effectiveness of wet-grinding in toluene for reducing the fines generated during grinding. In this test, 250 ml of toluene was added to 94 grams of peat and the mixture was ground for 5 minutes. After the wet-grinding test was completed, the mixture of peat and toluene was dried in a glass fluidization column equipped with a porous-plate distributor. The mixture was fluidized with air. Drying the peat and toluene mixture in a furnace would have resulted in a dry cake, which could not be analyzed for particle-size distribution. The results show

that the peat from the wet-grinding in toluene has a lower mean particle size and a higher fines content than that from the corresponding dry-grinding test. Therefore, wet-grinding of peat in toluene in a rod mill is not effective in reducing the quantity of fines generated.

Additionally, air-dried (35 weight percent moisture) peat ground in a rod mill has considerably more fines in all cases than that ground in a hammer mill.

FLUIDIZATION CHARACTERISTICS

The objective of this phase of the work was to investigate the fluidization characteristics of peat and to compare the results with those of earlier tests with coal and coal char. Five fluidization tests were conducted: four with various size fractions of peat and one with a narrow-size fraction of Husky lignite char.

The tests were conducted with dry air in a 2-1/2 inch diameter Plexiglas column with a porous-plate gas distributor. The minimum fluidization velocity, U_{mf}, was determined by the conventional method, i.e., intersection of the lines through the fixed- and fluidized-bed regions of the pressure drop vs. decreasing gas velocity curve. The complete fluidization velocity, U_{cf}, which refers to the gas velocity when the whole bed is fliudized and when there is good top-to-bottom mixing of the solids, was also determined.

The first test, Run PF-1, was conducted with a −10+100 U.S.S. size fraction of peat. (See Table 7 for the detailed size distribution.) Visual observation of the bed showed that at U_{mf}, only the top half of the bed had good solids mixing and gas bubbling, while the bottom half appeared to be packed. This characteristic is also typical of coal that has a similarly wide particle size distribution. As the gas velocity was increased above U_{mf}, a larger fraction of the bed appeared to be fluidized. The bed pressure drop and bed density characteristics of −10+100 U.S.S. size fraction peat are shown in Figures 5 and 6, respectively. Note that the differences in the bed pressure drops for the increasing and decreasing velocities are quite large. This hysteresis effect is caused by the realignment of the nonspherical, nonuniform sized particles in the sample. A sample consisting of uniformly sized, spherical particles would show identical pressure-drop characteristics for increasing as well as decreasing velocities.

In Runs PF-2 through PF-4, narrow-size fractions of peat (−40+60, −60+80, and −20+30 U.S.S., respectively) were fluidized. The bed-pressure drop and bed density characteristics of these size fractions of peat are shown in Figures 7 through 12, respectively.

The results of the tests conducted with the narrow-size fractions show that the hysteresis effect is much less than that observed in Run PF-1 with a

Table 7. SCREEN ANALYSIS OF THE FEED FOR RUN PF-1 CONDUCTED WITH MINNESOTA REED SEDGE PEAT

Nominal Feed Size, U.S.S.	−10+100
Screen Size, U.S.S., wt %	
−10+12	4.1
−12+14	15.5
−14+16	16.1
−16+18	9.7
−18+20	10.7
−20+25	9.4
−25+30	6.8
−30+35	10.1
−35+40	0.3
−40+50	6.5
−50+60	2.1
−60+80	4.1
−80+100	2.0
−100+120	0.9
−120*	1.7
Total	100.0
Mean Particle Diameter, Dp, μ	604

* Assumed to be 114μ.

wide-size fraction of peat. A similar effect is observed in Run PF-5, conducted with a narrow (−40+60 U.S.S.) size fraction of Husky lignite char. The objective of Run PF-5 was to compare the fluidization characteristics of char with those of peat. The bed pressure drop and bed density characteristics of char are shown in Figures 13 and 14.

Figure 15 correlates the effects of average particle size on the minimum and complete fluidization velocities of peat and Husky lignite char. The correlations show that the minimum fluidization velocities of peat and char are directly proportional to the 1.0 and 1.1 powers of the particle size, respectively. The correlations for the complete fluidization velocities for peat and char are directly proportional to the 1.3 and 1.4 powers of the particle size, respectively.

A comparison of the results (Table 8) from Run PF-5, conducted with a −40+60 U.S.S. size fraction of a North Dakota lignite char, with those for Run PF-2, conducted with a similar-sized peat, shows that the fluidization

characteristics of peat are similar to those of coal. However, there is one difference: Peat, with a lower particle density and a slightly smaller average particle size, has higher minimum and complete fluidization velocities than the char. Examination of Figure 15 shows that both the U_{mf} and U_{cf} of peat are higher than those of lignite char. Such results indicate that peat probably does not fluidize as a discrete particle but as a conglomerate of particles; therefore, elutriation of fines from a fluidized bed of peat will be less than that expected on the basis of feed-particle size distribution.

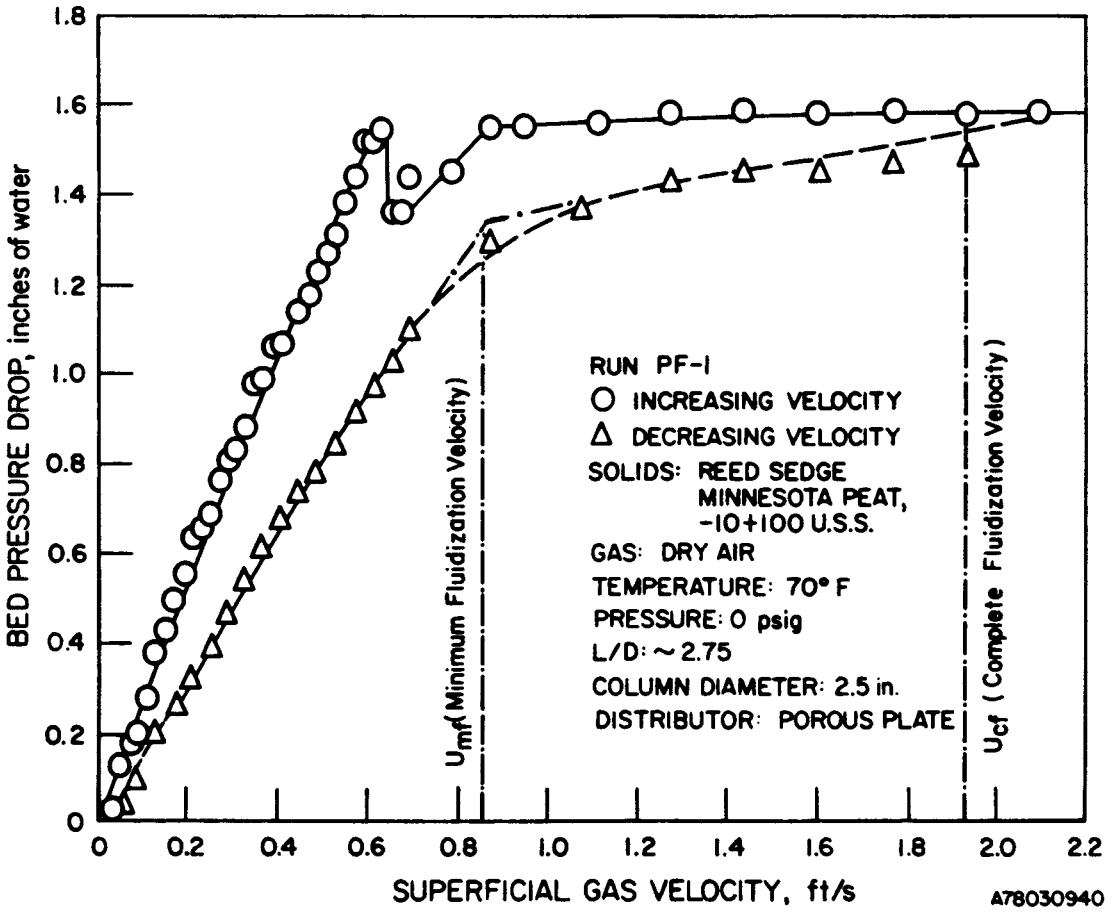

Figure 5. EFFECT OF GAS VELOCITY ON PRESSURE DROP CHARACTERISTICS OF PEAT (–10+100 U.S.S.)

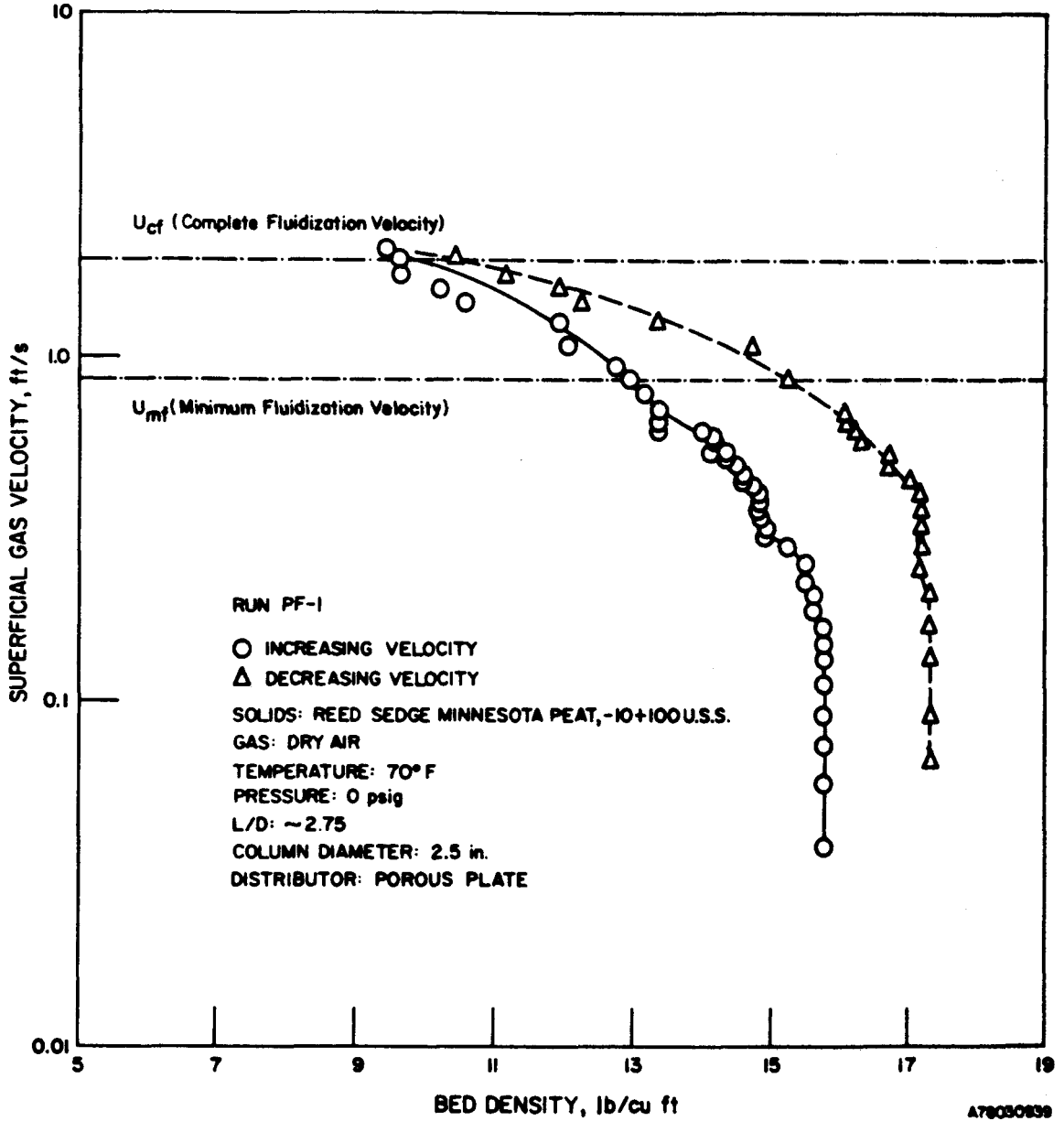

Figure 6. EFFECT OF GAS VELOCITY ON BED DENSITY CHARACTERISTICS OF PEAT (−10+100 U.S.S.)

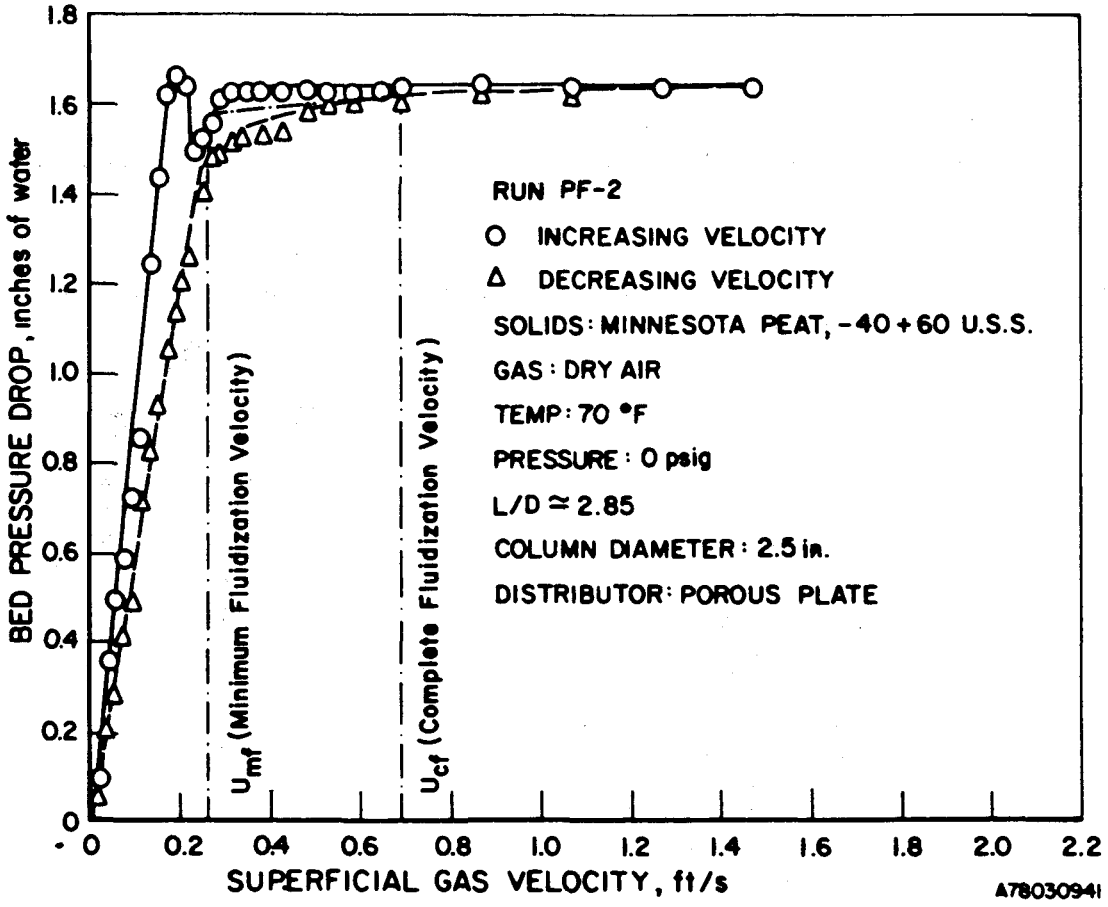

Figure 7. EFFECT OF GAS VELOCITY ON PRESSURE DROP CHARACTERISTICS OF PEAT (−40+60 U.S.S.)

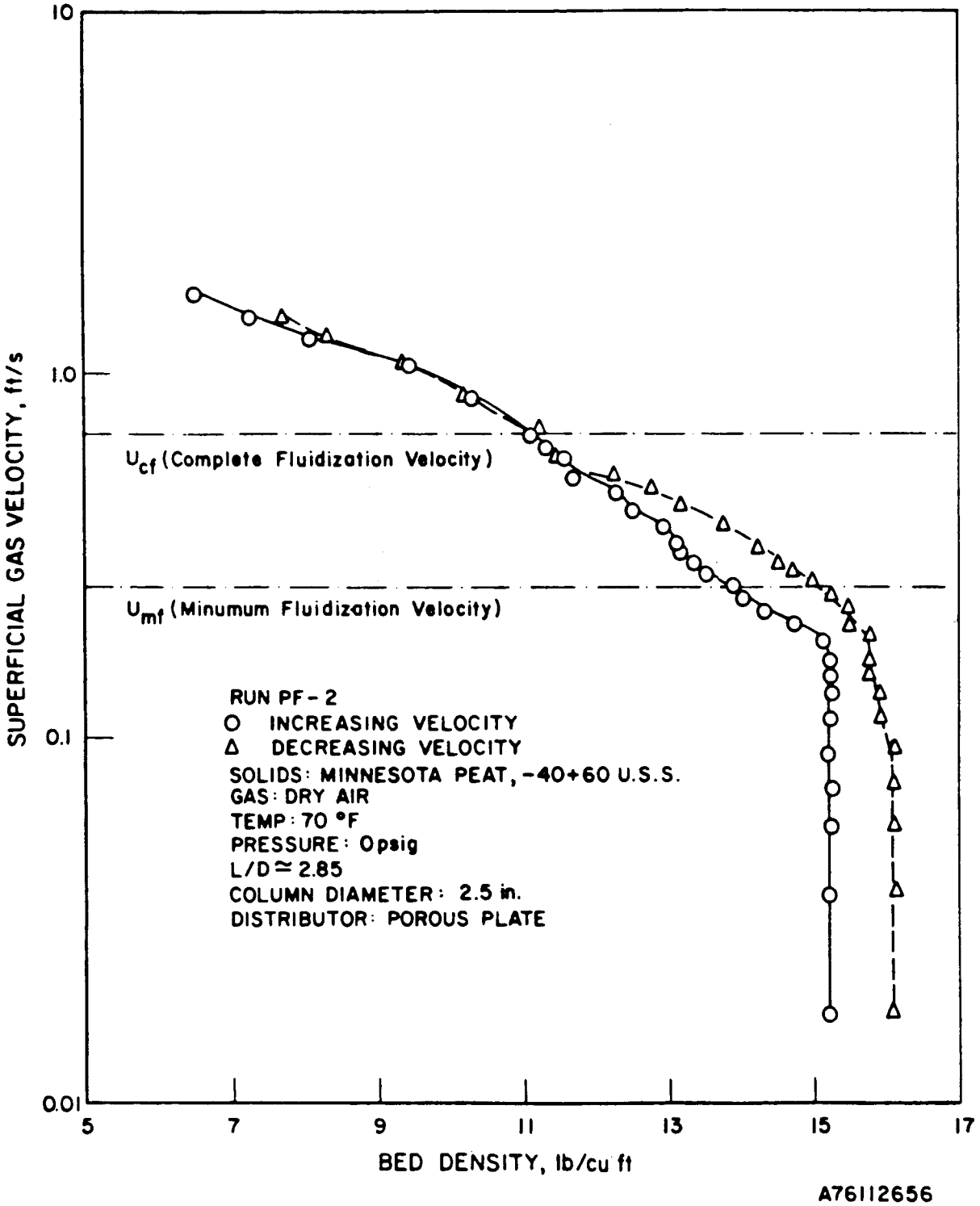

Figure 8. EFFECT OF GAS VELOCITY ON BED DENSITY CHARACTERISTICS OF PEAT (−40+60 U.S.S.)

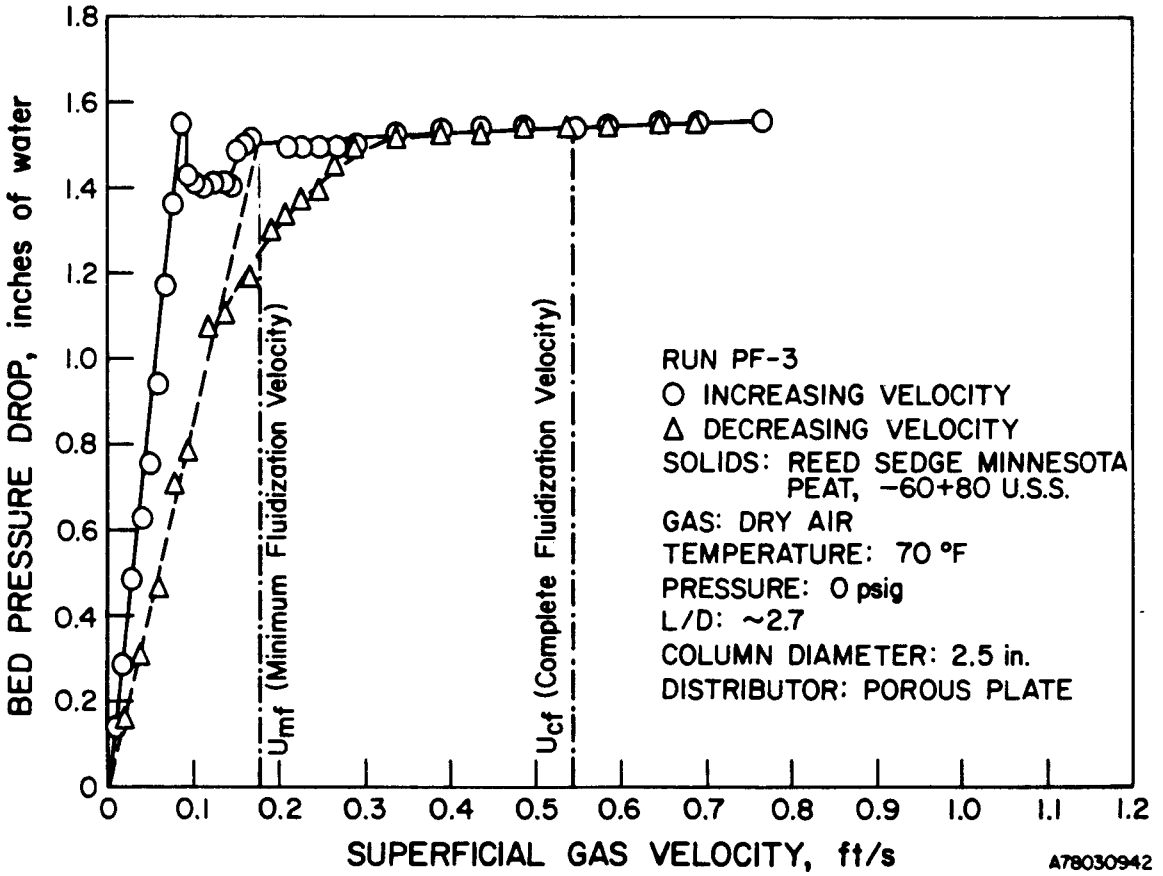

Figure 9. EFFECT OF GAS VELOCITY ON PRESSURE DROP CHARACTERISTICS OF PEAT (−60+80 U.S.S.)

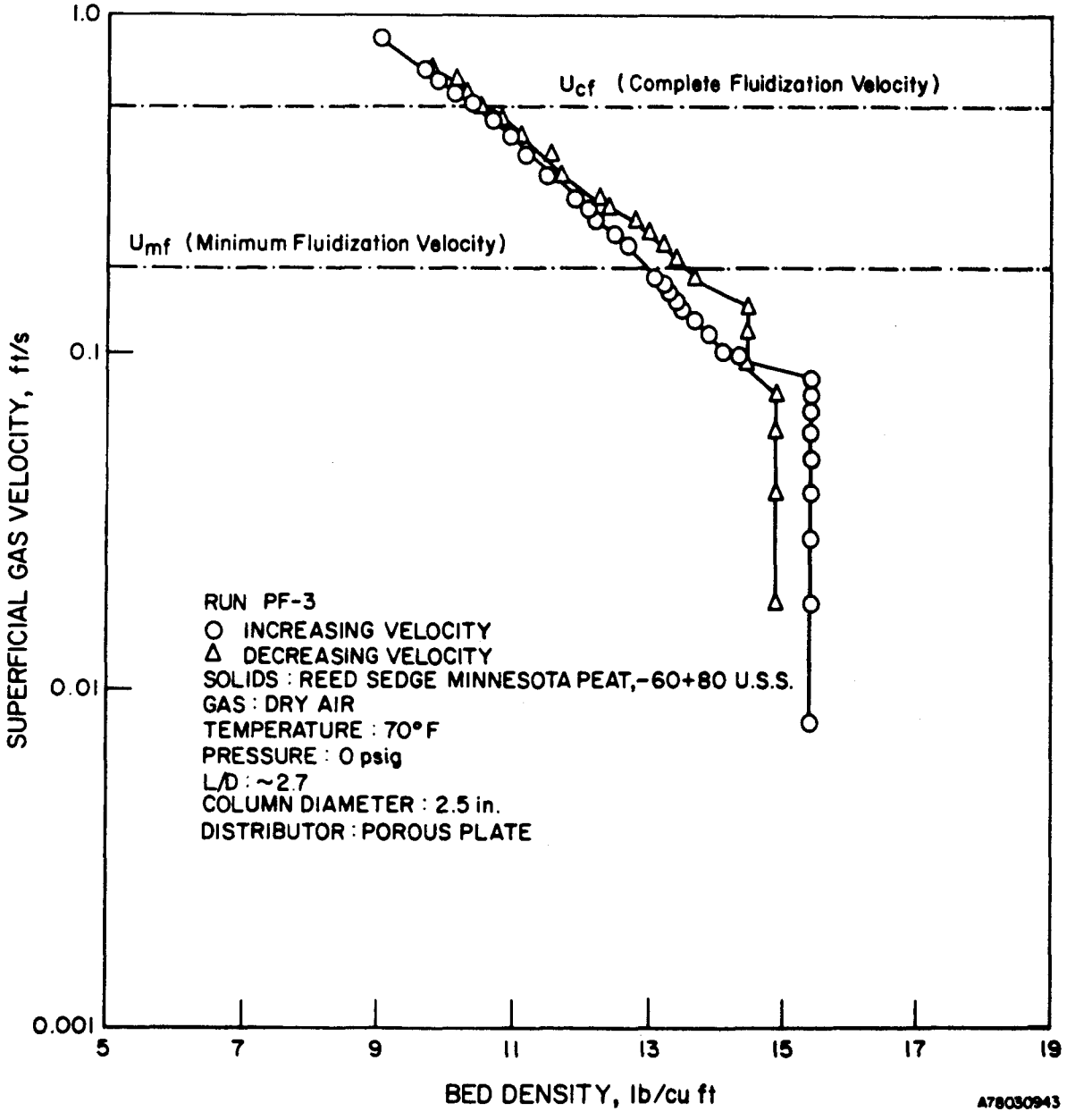

Figure 10. EFFECT OF GAS VELOCITY ON BED DENSITY CHARACTERISTICS OF PEAT (−60+80 U.S.S.)

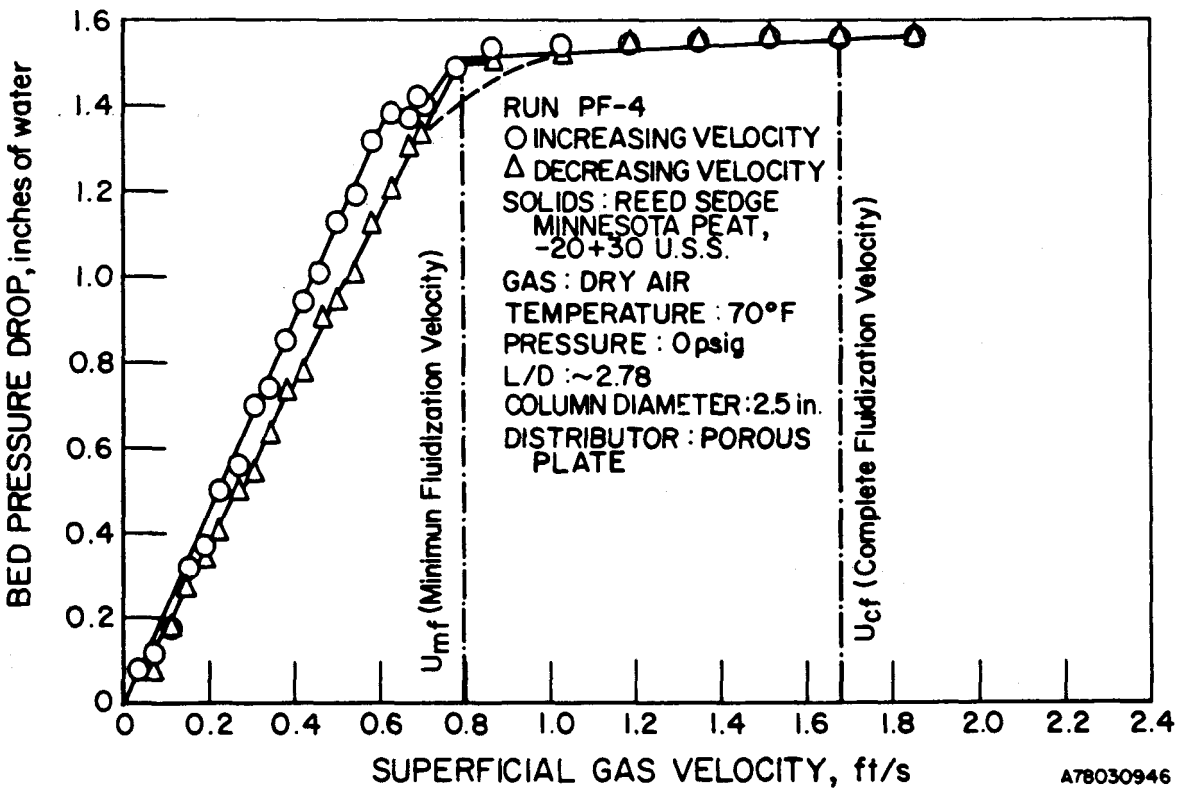

Figure 11. EFFECT OF GAS VELOCITY ON PRESSURE DROP CHARACTERISTICS OF PEAT (−20+30 U.S.S.)

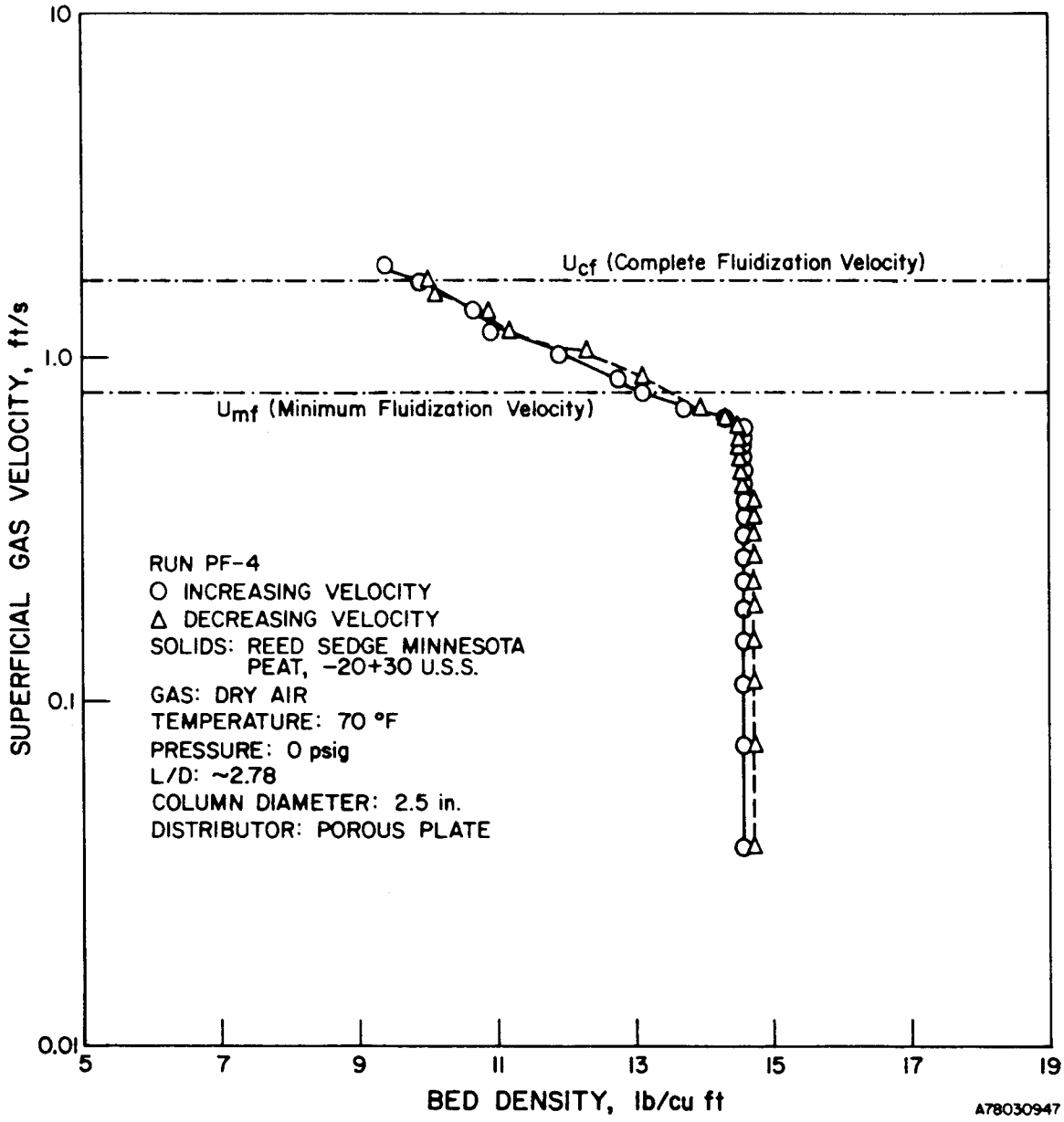

Figure 12. EFFECT OF GAS VELOCITY ON BED DENSITY CHARACTERISTICS OF PEAT (−20+30 U.S.S.)

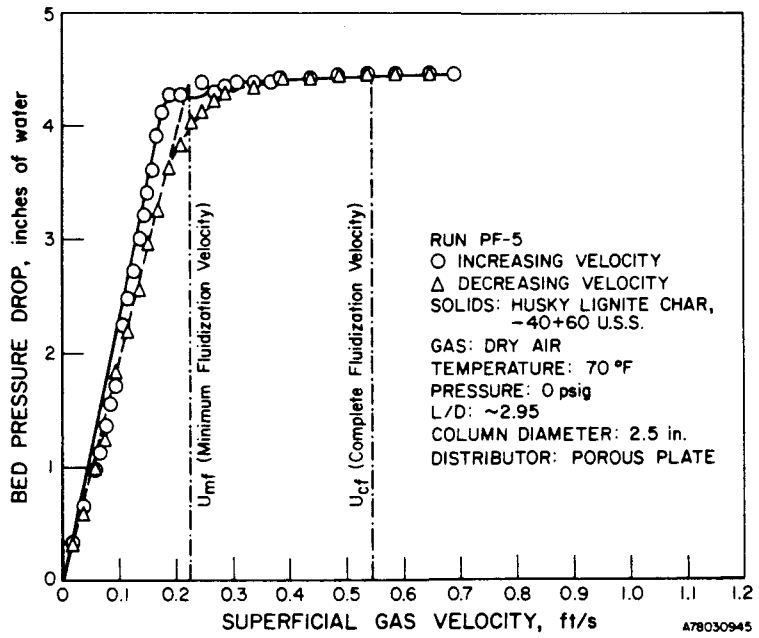

Figure 13. EFFECT OF GAS VELOCITY ON BED PRESSURE DROP CHARACTERISTICS OF HUSKY LIGNITE CHAR (−40+60 U.S.S.)

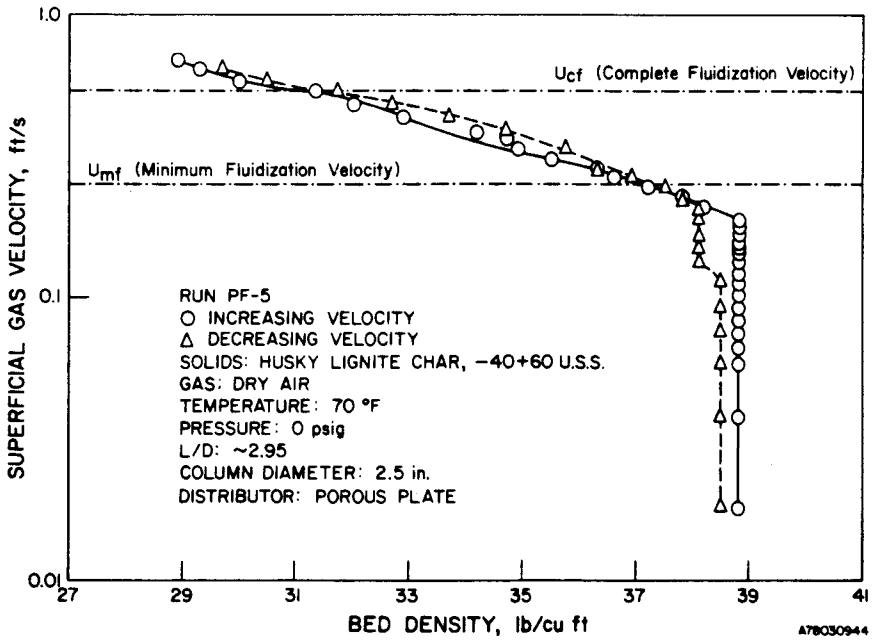

Figure 14. EFFECT OF GAS VELOCITY ON BED DENSITY CHARACTERISTICS OF HUSKY LIGNITE CHAR (−40+60 U.S.S.)

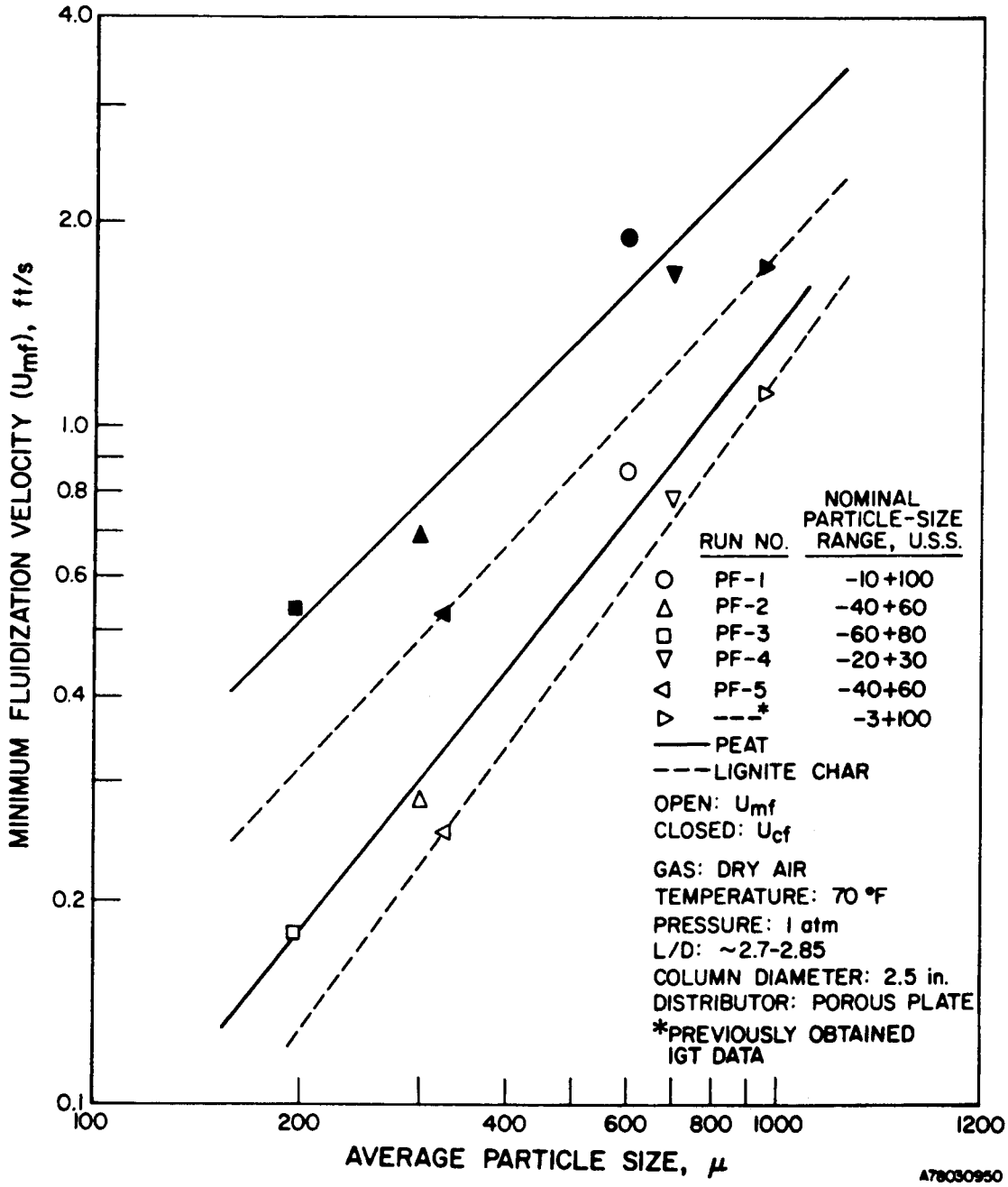

Figure 15. EFFECT OF PARTICLE SIZE ON MINIMUM AND COMPLETE FLUIDIZATION VELOCITIES OF MINNESOTS REED SEDGE PEAT

Table 8. COMPARISON OF THE FLUIDIZATION CHARACTERISTICS OF HUSKY LIGNITE CHAR AND PEAT

Sample	Peat		Husky Lignite Char	
Run No.	PF-2	PF-1	PF-5	--*
Nominal Particle Size, U.S.S. mesh	−40+60	−10+100	−40+60	−3+100
Mean Particle Size, μ	300	604	322	950
Particle Density, lb/cu ft	47	47	78	78
Minimum Fluidization Velocity, U_{mf}, ft/s	0.28	0.86	0.25	1.13
Complete Fluidization Velocity, U_{cf}, ft/s	0.69	1.9	0.54	1.8
Fluidized-Bed Density, lb/cu ft				
At U_{mf}	14.8	15	37.3	35
At U_{cf}	11.1	10	31	34

* Previously obtained IGT data.

SLURRYING CHARACTERISTICS

In certain peat-harvesting techniques (hydraulic mining), peat is slurried with water (96 to 98 weight percent water) and is pumped through a pipeline to processing facilities. Because it has a great affinity for water in its natural state, peat may contain 90 weight percent, or more, absorbed moisture. Therefore, a very high concentration of water is required to make a pumpable slurry with raw peat. The use of slurry systems may be considered for feeding peat to a high-pressure reactor for gasification.

The objective of this program subtask was to investigate the liquid (water or other liquid)-holding properties of peat and to evaluate the effect of various pretreatments on maximizing solids concentration in a pumpable peat slurry. By minimizing the liquid concentration in the pumpable slurry, the energy required for vaporization in slurry dryers is reduced, and the overall thermal efficiency of the process for peat gasification is improved.

One indicator that may be used to determine the relative quantities of liquids required to make a pumpable slurry is the liquid-retention capacity of the material. Various methods of pretreatment to reduce the quantity of liquid required for a pumpable slurry were evaluated on the basis of the toluene-retention capacity (TRC) of peat. TRC tests were performed on dried, air-dried, ground, wet-carbonized, and high-pressure-compacted peat samples. Because slurry viscosity is another parameter that can be used for comparing the pumpability of slurries, viscosities of various concentrations of peat-toluene and lignite-toluene slurries were determined using a viscometer.

Toluene-Retention Capacity Tests

The TRC tests were conducted in graduated cylinders or in tared bottles containing a known weight of peat. Toluene was added, and the mixture was stirred and allowed to settle until a layer of toluene just appeared above the peat surface. The excess toluene was carefully removed with a syringe. The TRC is calculated as the pounds of toluene per pound of dry peat in the remaining mixture. Results of the TRC tests are presented in Tables 9 through 11.

Table 9. EFFECT OF PARTICLE SIZE AND MOISTURE CONTENT ON TOLUENE-RETENTION CAPACITY OF REED SEDGE PEAT

Sample	Peat		Lignite*
Moisture Content, wt%	0	40	25
Screen Size, U.S.S.	lb Toluene/lb Dry Peat		
−10+20	3.08	4.33	0.47
−30+40	--	3.99	0.45
−60+80	2.77	2.74	0.57
−100+120	--	1.77	0.53
−200+230	--	1.07	0.65
−100+170	1.87	--	--
−230+325	1.29	--	--
−325	1.00	--	--

* Montana lignite.

Table 9 shows the TRC of various size fractions of dry and air-dried (40 weight percent moisture content) peat and lignite (25 weight percent moisture). The −10+20 and −60+80 U.S.S. samples of bone-dry peat retain 6.5 and 4.8 times the toluene of the same sized lignite particles. The TRC of air-dried peat is about 9 times higher than that of the large particle sizes of lignite and about 1.7 times higher than that of the smallest particle size lignite sample. The results show that decreasing the peat particle size from −10+20 to −325 U.S.S. decreases the TRC from 3.08 to 1.0 pounds of toluene per pound of dry peat, thus indicating that grinding peat breaks up some of its cellular structure and reduces its liquid-retention capacity.

The results of the tests conducted with lignite show that the effect of particle size is less significant on lignite than on peat and a decrease in particle size tends to slightly increase the liquid-absorption capacity of lignite, thus indicating that reducing the size of lignite might open up access to more pores. Both moisture content and particle size significantly affect the TRC of peat. The tests conducted to determine the effect of peat moisture content on its liquid-retention capacity show that decreasing its moisture content from 40 to 0 weight percent decreases its TRC. The effect of moisture content is more pronounced for larger particle sizes than for smaller ones.

Table 10 shows the results of TRC tests conducted with wet-carbonized peat. Each sample had been completely dried prior to screening and testing.

Table 10. TOLUENE-RETENTION CAPACITIES OF RAW AND WET-CARBONIZED PEAT

Sample	Raw Peat*	Wet-Carbonized Peat*							
Run No.		PWC-1†	PWC-2,3,4‡	PWC-5	PWC-6	PWC-7	PWC-8	PWC-9	PWC-10
Feed Material Sample Description		"As-Received" Peat (78 wt % Moisture)					−10+20 U.S.S. Air-Dried Peat (38.6 wt % Moisture)		
Operating Conditions									
Temperature, °F		155	390	375	410	390	390	445	525
Pressure, psig		200	200	200	200	200	200	200	375
Time, min		20	20	2	2	2	2	2	2
Heat-Up Time, min		58	61	31	219	107	32	30	33
Toluene-Retention Capacity Size Fraction, U.S.S. sieve size	lb Toluene/lb Dry Peat								
−10+20	3.08	2.31	1.80	2.50	2.78	2.76	2.39	2.01	2.00
−60+80	2.77	2.37	2.06	2.77	2.70	2.63	2.52	2.60	2.36
−100+170	1.87	2.42	2.05	2.69	1.96	2.01	2.29	2.22	2.13
−230+325	1.29	2.22	1.69	2.23	1.53	1.50	1.15	1.61	1.50
−325	1.00	1.99	1.30	1.44	1.47	1.25	1.25	1.05	1.33
−60+200	--	2.51	2.08	3.26	3.22	3.17	--	--	--

* Oven dried (~0 wt % moisture) prior to toluene-retention tests.

† Run PWC-1 was conducted in a closed autoclave that was pressure-regulated by a water condenser above.

‡ Residues from Runs PWC-2 through PWC-4 have been combined for this test sample.

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Table 11. THE EFFECT OF COMPACTION PRESSURE ON THE TOLUENE-RETENTION CAPACITY OF REED SEDGE PEAT*

Compaction Pressure, psig	0	362	1087	1449	2173	2897
Toluene-Retention Capacity Size Fraction, U.S.S.	lb Toluene/lb Dry Peat					
−10+20	3.08	2.29	1.81	1.60	1.47	1.31
−60+80	2.77	1.54	1.76	1.41	1.62	1.19
−100+170	1.87	1.40	1.54	1.28	1.18	1.30
−230+325	1.29	1.25	1.16	0.94	1.07	1.02
−325	1.0	1.04	1.08	0.86	1.22	0.84
−60+200	--	--	--	0.99	--	--

* For the high-pressure compaction tests, the sample originally contained 78.9 weight percent moisture. For toluene-retention tests, the sample consisted of 5 grams of bone-dry peat (after compaction tests).

The results of the tests, conducted with six different size fractions of peat that had been carbonized in Run PWC-1, show that the effect of decreasing the particle size from −10+20 mesh to −325 mesh was not as significant as it had been for the same decrease in particle size of raw, uncarbonized peat samples.

The data for Runs PWC-2 through PWC-10, conducted under a different set of wet-carbonization conditions, show that the average TRC of carbonized peat decreases from 2.3 to 1.3 with a decrease in particle size from −10+20 to −325 mesh. For the same decrease in particle size, the TRC of raw, uncarbonized peat decreases from 3.08 to 1.0. The average TRC for all particle sizes (i.e., −10+20, −60+80, −100+170, −230+325, and −325 mesh) of raw and wet-carbonized peat samples is 2.0. The effect of temperatures, pressures, or reaction times on the TRC of carbonized peat appears to be minimal.
to be minimal.

The results of TRC tests conducted with high-pressure-compacted peat are presented in Table 11. Even though experimental errors tend to produce local abnormalities, the overall trends indicate that higher compaction pressure and smaller particle sizes significantly reduce the TRC of peat. At a compaction pressure of 2897 psig, the TRC of raw peat decreases from 1.3 to 0.8 for a decrease in particle size from −10+20 to −325 mesh. The average TRC of all particle sizes decreases from 2.0 for raw, uncompacted peat to 1.1 at a compaction pressure of 2897 psig. High-pressure compaction is more effective than wet carbonization in reducing the TRC of peat. High-pressure compaction increases the particle density of peat relative to the raw-peat density and may account for the lower TRC values.

Slurry Pumpability

IGT has previously* conducted pumping tests with lignite-water slurries in a test loop consisting of a 1-1/2 inch diameter pipe, several right-angle bends, and a straight horizontal section over 100 feet long. The low-pressure slurry system was capable of pumping lignite slurries at concentrations down to 47 weight percent water (0.9 pounds of water per pound of dry lignite). However, below this concentration, the flow rates were observed to drop drastically. The results of these tests show that the minimum liquid concentration required to make a pumpable slurry is one that will result (when allowed to gravity

* Development of Project 8907 (HYGAS Process) Interim Report No. 1, U.S. Office of Coal Research Contract No. 14320001-1221, R&D Report No. 110, July 1975.

settle) in a free-liquid layer equal to at least 5% of the volume of the settled layer of solids. Using the same criteria for a peat-toluene slurry, the results show that a −10+100 U.S.S. size fraction of peat, containing about 8 weight percent moisture, will require 68.4 weight percent toluene (2.35 pounds of toluene per pound of dry peat) to make a pumpable slurry.

Slurry Viscosity Measurements

The objective of this work was to measure the viscosities of lignite-toluene and peat-toluene slurries and to quantitatively relate them to lignite slurries that are known to be pumpable. In order for a peat slurry to be as pumpable as a lignite slurry, the viscosity of the peat slurry must be equal to or less than that of the lignite slurry. The minimum toluene concentration in a pumpable lignite slurry is taken to be about 1.0 pounds of toluene per pound of dry lignite. The moisture content of the lignite in the slurry may be as high as 35 weight percent as mined; if dried prior to slurrying, lignite may contain 11 to 13 weight percent moisture.

A Brookfield Synchro-Lectric viscometer (Model LTV) was modified and calibrated for use in these tests. Figure 16 is a schematic diagram of the viscometer. The viscometer consists of a variable-speed motor connected to

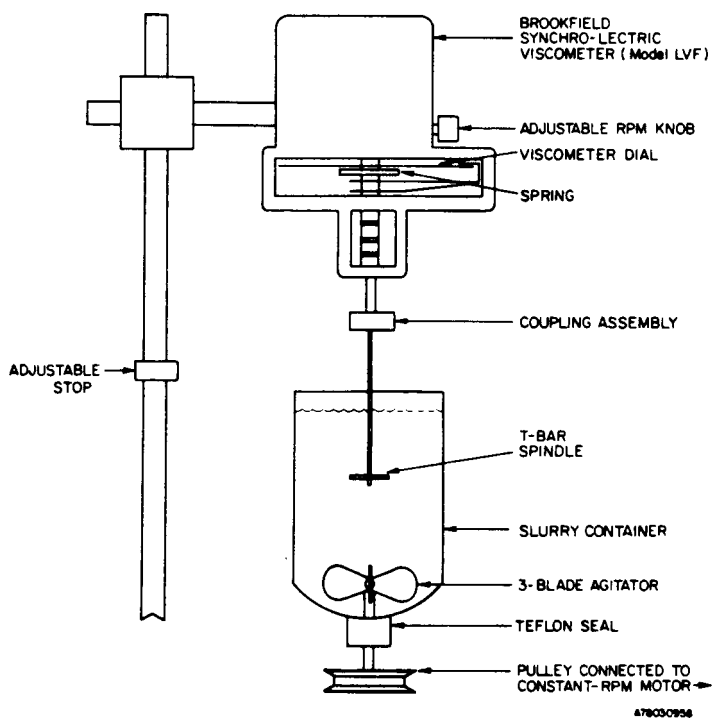

Figure 16. SCHEMATIC DIAGRAM OF SLURRY VISCOMETER

a short shaft, to which one of several sizes and types of spindles can be connected. The motor is operated at an appropriate speed, and the revolving spindle is dipped in the test slurry. The torque exerted on the spindle is calibrated in terms of viscosity. This viscometer is designed primarily for measuring the viscosities of liquids, although it can also be used for measuring viscosities of homogeneous slurries containing very low concentrations of fine (—325 mesh) particles. The sample holder for these liquids and slurries is generally an ordinary beaker. Slurries containing high concentrations of large particles tend to settle without vigorous stirring; therefore, for these tests, the sample holder was modified to incorporate an agitator. A three-blade agitator was sealed and connected to a constant-rpm motor. The agitator rotated counterclockwise and the spindle rotated clockwise so that differences in viscosity were magnified. The spindle was positioned 1/2 inch from the center of the agitator, and the quiescent liquid level was maintained at 1-1/2 inches above the agitator. The agitator and spindle revolved at 390 and 60 rpm, respectively. A Brookfield T-bar spindle (F) was used in all tests. Calibration tests were conducted with glycerol, glycerol-water mixtures, and special viscosity solutions obtained from Brookfield Engineering Co.

Slurry viscosity determinations were conducted on both narrow- and wide-size fractions of dry peat and lignite. The effects of pretreatment and moisture content on peat slurries were also investigated. Figure 17 shows the effects of toluene concentrations and particle size on the viscosities of peat and lignite slurries in toluene. The results show that decreasing the peat particle size from —60+80 mesh to —325 mesh in slurries with toluene concentrations of 70 weight percent (2.33 pounds of toluene per pound of dry solids) decreases the viscosities from 1150 to 15 centipoises. The results also show that the viscosities of peat slurries are significantly higher than those of the corresponding lignite slurries. The viscosity differences between peat and lignite slurries are more pronounced for larger particle sizes.

In both peat and lignite slurries, the wide-size distribution particles result in lower slurry viscosities than the narrow-size distribution particles. Screen analyses of the wide-size distribution peat and lignite are shown in Tables 12 and 13, respectively. At the same toluene concentration,(about 2.33 pounds of toluene per pound of dry solids), the viscosities of wide-size distribution peat and lignite slurries are about 9 and 3 centipoises, respectively.

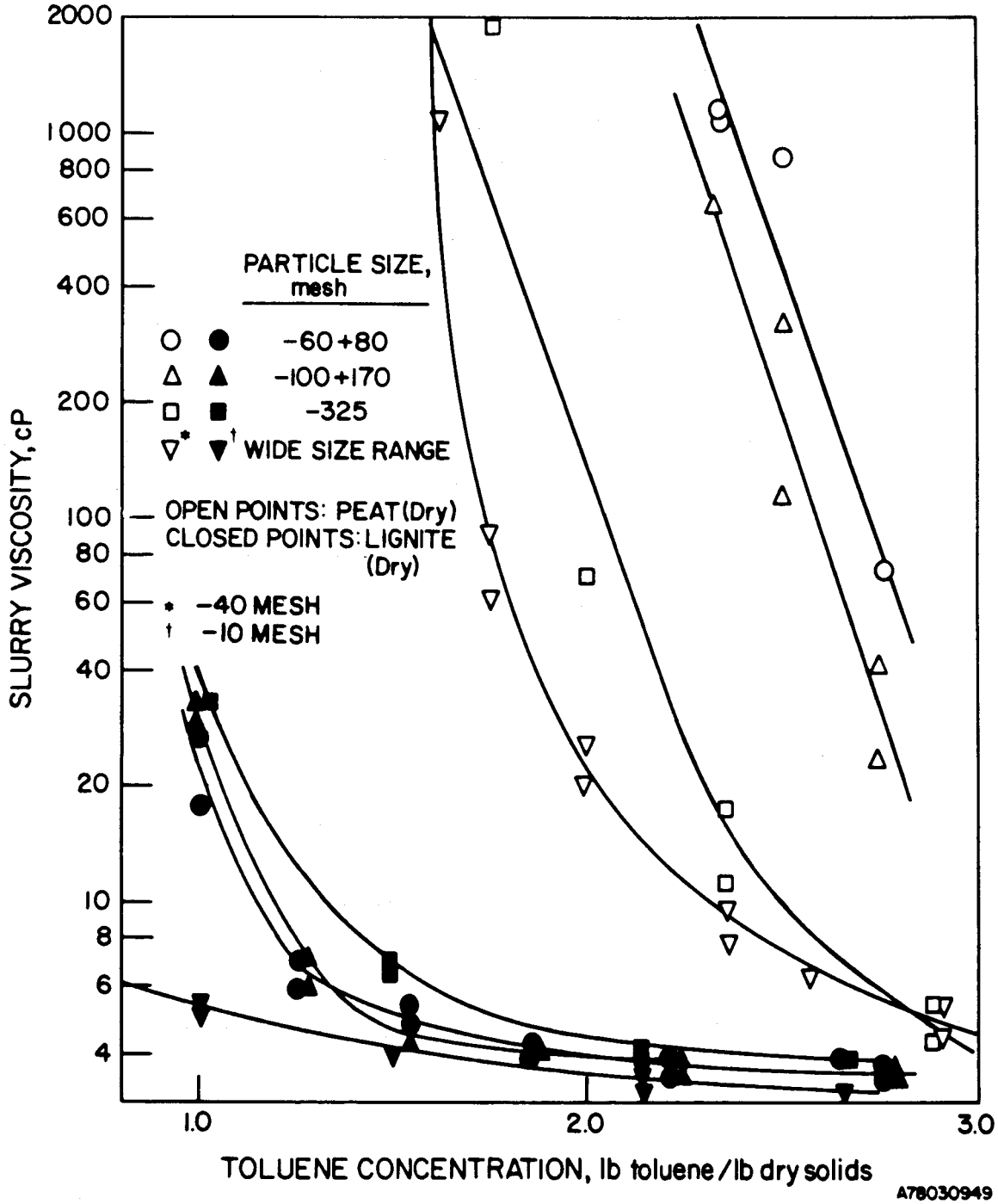

Figure 17. THE EFFECTS OF PARTICLE SIZE AND TOLUENE CONCENTRATION ON THE VISCOSITIES OF PEAT AND LIGNITE SLURRIES IN TOLUENE

The particle-size distribution of the peat used in these tests (Table 12) was selected to simulate the size distribution obtained by grinding air-dried (about 35 weight percent moisture) peat in a hammer mill.

Table 12. SIZE DISTRIBUTION OF THE REED SEDGE PEAT USED IN SLURRY VISCOSITY MEASUREMENTS

Screen Size, U.S.S., wt %	
−40+60	40.3
−60+80	18.6
−80+100	6.9
−100+140	11.7
−140+170	3.9
−170+230	7.4
−230+325	5.2
−325	6.0
Total	100.0
Mean Particle Size, mm	0.125

The particle-size distribution of the lignite used in these tests, Table 13, was the same as that obtained by grinding lignite in the roller mill at the HYGAS pilot plant.

Table 13. SIZE DISTRIBUTION OF LIGNITE USED IN SLURRY VISCOSITY MEASUREMENTS

Screen Size, U.S.S., wt %	
−10+20	25.5
−20+30	11.9
−30+40	12.0
−40+60	16.4
−60+80	6.7
−80+100	4.9
−100+200	9.8
−200+325	4.8
−325+Pan	8.0
Total	100.0
Mean Particle Size, mm	0.174

Another series of tests was conducted on wide-size distribution peat and lignite to determine the effect of moisture content on the toluene slurry viscosity. The results, presented in Figure 18, show that increasing the peat moisture content from 0 to 10.9 to 32.7 weight percent at a toluene concentration of 3 pounds of toluene per pound of dry peat, increases the slurry viscosity from about 3 to 15 to 1700 centipoises.

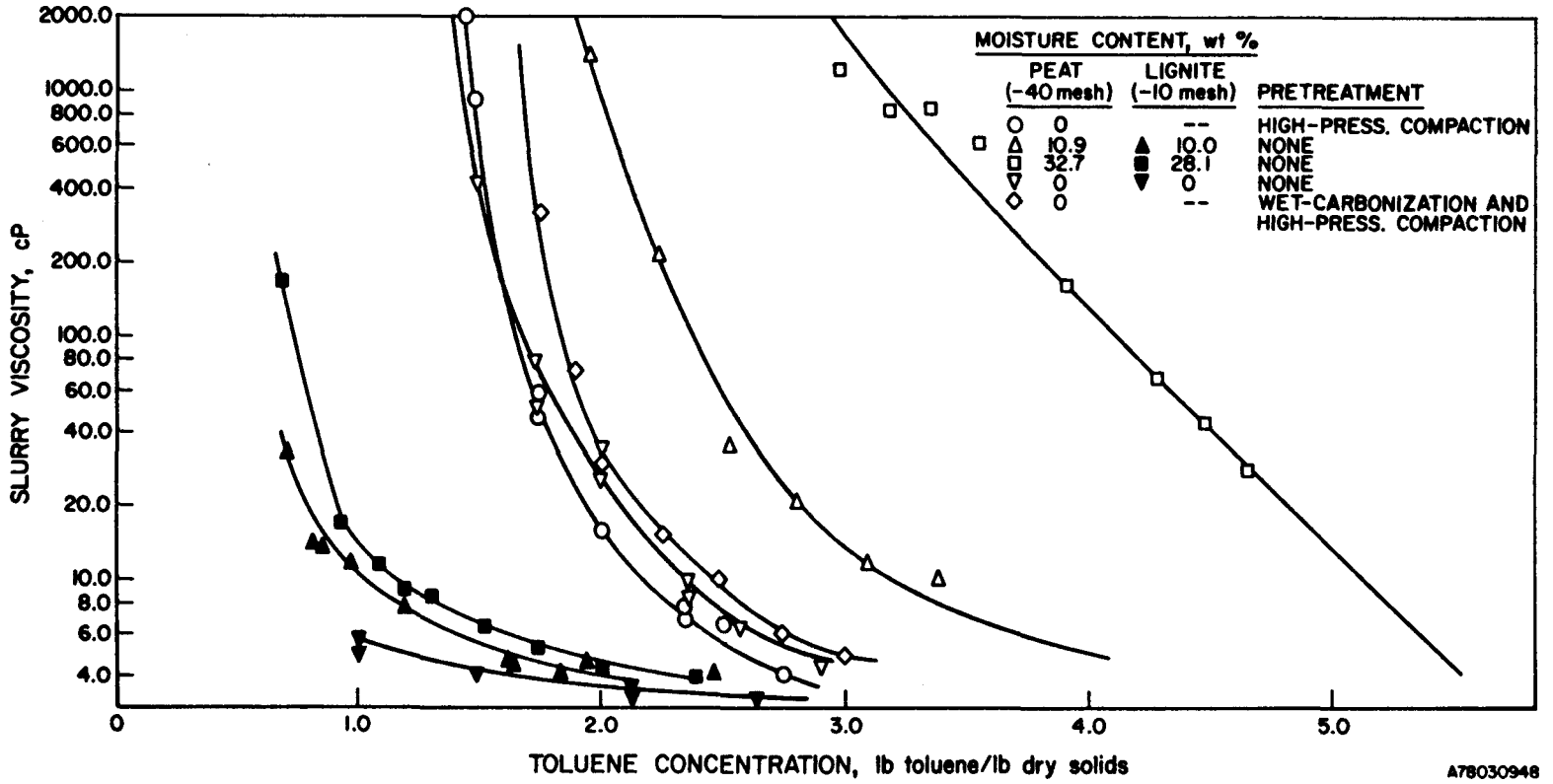

Figure 18. THE EFFECTS OF MOISTURE CONTENT AND PRETREATMENT ON THE VISCOSITIES OF PEAT AND LIGNITE SLURRIES IN TOLUENE

The results show that the effect of moisture content on the lignite-toluene slurry viscosity is significantly less than that on peat-toluene slurries. The viscosities of slurries known to be pumpable (with 1 pound of toluene per pound of dry lignite) containing lignite with moisture contents of 0, 10, and 28 weight percent are 5, 10, and 15 centipoises, respectively. Peat-toluene slurries with the same relative pumpability (viscosity of 15 centipoises) containing peat with 0 and 10.9 weight percent moisture have toluene concentrations of 2.2 and 2.9 pounds per pound of dry peat, respectively. At a peat moisture content of 8 weight percent (as interpolated from Figure 18) and a viscosity of 15 centipoises, the toluene concentration is 2.7 pounds per pound of dry peat. This agrees quite well (15% more) with the toluene concentration of 2.35 pounds per pound of dry peat as determined from the 5 volume percent excess slurry media pumpability criterion mentioned earlier.

Figure 18 also includes the results of slurry viscosity measurements of pretreated peat samples. The slurries containing high-pressure-compacted peat have slightly lower viscosities than those containing raw peat. At a slurry concentration of 3.0 pounds of toluene per pound of dry peat, the viscosities of slurries containing raw and high-pressure-compacted peat are about 4.5 and 3.3 centipoises.

The slurries made with wet-carbonized, high-pressure-compacted peat show slightly higher viscosities than those of slurries prepared with only high-pressure-compacted and raw peats. The wet-carbonized peat was prepared by autoclaving it at 390°F and 200 psig for 10 minutes. All samples were compacted at a pressure of 1450 psig.

PEAT WET CARBONIZATION

Wet carbonization has been used for many years in the U.S.S.R. to facilitate the mechanical dewatering of peat, which reduces its moisture content to about 37 weight percent. In this batch operation, 13 to 17 tons of raw peat (containing 70-74 weight percent moisture) are loaded into large autoclaves (about 9 feet in diameter and 32 feet long) and are treated with 365°F and 190 psia* steam for 20 to 30 minutes. During the wet-carbonization period, intercellular moisture expands and vaporizes, partially disrupting the colloidal bonding between peat and water.

After autoclaving the peat is dewatered from about 67 to 37 weight percent moisture in large plate filter presses at pressures as high as 1400 psia. The dewatered peat is suitable for use as a fuel, and the filtrate is a source of several by-product chemicals such as ethyl alcohol, oxalic acid, furfural, and acetic acid. One wet-carbonization facility at Boksitogorsk, U.S.S.R., processes 500 tons/day of 72% moisture peat and consumes 50,000 tons annually. It produces 160 tons/day of peat fuel.[3]

The objective of this subtask was to evaluate the effectiveness of wet carbonization for reducing the liquid-retention capacity and improving the mechanical dewatering characteristics of peat. A reduction in the liquid-retention capacity of peat is desirable to lower the slurry liquid concentration required in a pumpable peat slurry. An improvement in the mechanical dewatering characteristics of peat is desirable to maximize water removal by mechanical methods and thus minimize the peat thermal drying requirements.

In all, 21 wet-carbonization tests were conducted at various pressures, temperatures, and carbonization times. The objective of the first 12 tests (Runs PWC-1 through PWC-12) was to determine the effect of temperature, pressure, and residence time on the TRC of wet-carbonized peat. Runs PWC-13 through PWC-16 were conducted to produce sufficient quantities of carbonized residue for high-pressure compaction tests. (See the following report sections: Slurrying Characteristics and High-Pressure Compaction.) A slight decrease in TRC had been observed with an increase in carbon conversion. Therefore, the objective of Runs PWC-17 through PWC-21, in conjunction with results of all earlier tests, was to further investigate the effects of different operating conditions on peat carbon conversion.

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* Even though the autoclaves are evacuated prior to steaming, some noncondensable gases are generated during wet carbonization.

This section of the report discusses the equipment, operating conditions, and results of the wet-carbonization tests conducted by IGT. The wet-carbonization apparatus consisted of a small high-pressure autoclave (about 200 milliliter capacity) installed in a vertical-tube furnace. The furnace could provide rapid heating up to 1800°F if required. Samples could be withdrawn from a top-mounted line that fed into an ice-water-bath condenser to collect water and other condensable liquids. The noncondensable gases produced during wet-carbonization tests PWC-2, 3, 4, and 21 were collected downstream from the condenser in a large (19-liter capacity) evacuated gas cylinder.

At the beginning of each test the autoclave was evacuated, sealed, and then heated to the desired operating temperature. The temperature was high enough to ensure that the saturated steam pressure generated from the water in the peat was equal to or greater than the desired operating pressure. In most of the tests, the pressure in the autoclave was closely controlled by allowing steam and evolved gases to bleed through the valve that fed to the ice-water-bath condenser, while adjustments were made on the temperature contoller. Although the venting procedure resulted in a loss of material from the autoclave, the amount removed during any test was not significant compared with the amount of steam and gases remaining in the autoclave to produce the desired pressure. A water condenser had been used in the first test as a means of controlling the autoclave pressure; however, it proved to be clumsy and inadequate for use during any other test. At the end of the carbonization period, the autoclave was quench-cooled to ambient temperature, weighed, opened, and the peat residue removed.

A summary of the operating conditions and ultimate analyses of the solid residues produced by wet carbonization are presented in Table 14. The results show a considerable amount of scatter, and the reasons for this will be discussed later. However, certain trends can be observed. Increasing the wet-carbonization pressure and temperature from 200 psig and about 400°F to 375 psig and about 530°F at a holding time of 2 minutes and a heat-up time of 30 to 60 minutes (compare Runs PWC-5, 8, 14, 15, and 17 with Runs PWC-10 and 11) results in an increase in average carbon conversion from 10% to 21% of the feed carbon. Increasing the holding time from 2 to 20 minutes and the heating time from about 30 to 60 minutes (compare Runs PWC-5, 8, 14, 15, and 17 with Runs PWC-2, 3, 4, and 19) at the same pressure and temperature (about 200 psig and 400°F) results in an increase in average carbon conversion from 10% to 28% of the

Table 14. OPERATING CONDITIONS AND ANALYSIS OF SOLIDS

Run No.	Feed	PWC-1	PWC-2	PWC-3	PWC-4	PWC-5	PWC-6	PWC-7	PWC-8	PWC-9	PWC-10
Operating Conditions											
Temperature, °F		450	410	390	390	375	410	390	390	445	525
Pressure, psig		200	200	200	200	200	200	200	200	300	375
Time, min		20	20	20	20	2	2	2	2	2	2
Heat-Up Time, min		60	70	60	53	31	219	107	30	30	32
Ultimate Analysis, wt %											
Carbon	50.5	63.3	60.6	59.5	60.7	57.9	51.8	52.5	55.8	55.6	56.5
Hydrogen	5.1	5.0	4.0	4.1	3.9	5.2	5.0	5.1	4.9	4.7	4.7
Others	32.9	18.6	13.0	14.1	16.2	21.4	27.2	29.1	25.4	23.7	22.9
Ash	11.5	13.1	22.4	22.3	19.2	15.5	16.0	13.3	13.9	16.0	15.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Carbon Conversion, %	0		38.4	39.2	28.0	14.9	26.3	10.1	8.6	20.9	19.1

Run No.	PWC-11	PWC-12	PWC-13	PWC-14	PWC-15	PWC-16	PWC-17	PWC-18	PWC-19	PWC-20	PWC-21
Operating Conditions											
Temperature, °F	535	535	390	390	410	390	400	390	400	410	410
Pressure, psig	375	375	200	200	200	200	200	200	200	200	230‡
Time, min	2	2	2	2	2	2	2	10	20	2	60
Heat-Up Time, min	42	52	23	27	27	22	35	51	49	58	60
Ultimate Analysis, wt %											
Carbon	56.7	54.7	48.3	53.0	52.3	53.1	51.9	51.1	52.9	51.1	55.0
Hydrogen	4.7	4.7	4.7	5.2	5.1	5.2	5.0	4.9	4.9	4.9	5.2
Others	21.6	23.3	28.6	29.2	29.8	30.4	29.3	28.2	27.5	29.3	26.1
Ash	16.8	17.3	18.4	12.6	12.8	11.3	13.8	15.8	14.7	14.7	13.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Carbon Conversion, %	22.9	28.0	40.2*	4.2	7.0	--†	14.4	26.4	18.1	20.8	8.6

* When compared, the results from Runs PWC-14 and PWC-15 seem to be erroneous. The error is probably due to the method of sampling the feed material used in this test.

† Please ignore the results of this test because the analyses of the carbonized peat seem to be in error when compared with the feed analyses. The error is probably due to the method of sampling the feed material used in the test.

‡ Maximum pressure in the autoclave for 20 minutes.

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feed carbon. An increase in heat-up time from 32 to 52 minutes at 375 psig, about 530°F, and 2 minutes holding time (compare Runs PWC 10 through 12) increases the carbon conversion from 19% to 28% of the feed carbon. Increasing the heat-up and holding times appears to significantly increase the carbon conversion during peat wet carbonization. However, the carbon conversion obtained in Run PWC-21 during which nothing was removed from the autoclave during the 60-minute heat-up or the 60-minute holding time at 410°F and about 230 psig was only 8.6% of the feed carbon. The regulation of pressure by venting or bleeding gas from the autoclave results in the evolution of more gases than from completely closed tests.

Gas samples were taken during Runs PWC-2 through PWC-4 in order to determine the typical composition range for open autoclave tests at moderate operating conditions (200 psig, 390°F, 20 minutes). For comparison, a gas sample was taken after Run PWC-21, which was a closed autoclave test. Gas analyses were not performed on any other PWC off-gases because no significant variations in composition were expected. Analyses of the gas samples taken during Runs PWC-2 through PWC-4 and after PWC-21 (Table 15) show that carbon dioxide is the major constituent of the gases produced in these tests. The gases collected after PWC-21 contained more than 98 mole percent carbon dioxide, indicating that the closed operating procedure for PWC-21 (described above) suppressed the formation of hydrocarbon gases. The total concentrations of hydrogen, methane, ethane, plus carbon monoxide produced during tests PWC-2, 3, 4, and 21 were about 25.8%, 28.9%, 26.4%, and 0.88%, respectively. Most of the carbon dioxide is derived from the decomposition of carboxyl groups in the peat organic material that is more easily evolved than other hydrocarbon gases such as methane or ethane.

Table 16 compares the analyses of the liquids collected in an ice-water-bath condenser during Runs PWC-1 through PWC-4 with those of the liquids from Rum PWC-21, which were collected during high-pressure compaction of the wet-carbonized material. Runs PWC-2 through PWC-4 were open autoclave tests, during which material (steam and other gases) was allowed to bleed out of the autoclave in order to regulate the pressure. Runs PWC-1 and PWC-21 were closed autoclave tests, during which no material was removed from the autoclave until the test was completed. No other liquid analyses were performed, because no significant variations in composition were expected. The liquids

Table 15. ANALYSES OF OFF-GASES COLLECTED DURING WET-CARBONIZATION OF PEAT

Run No.	PWC-2†	PWC-3	PWC-4	PWC-21
Operating Conditions				
Temperature, °F	410	390	390	410
Pressure, psig	200	200	200	230
Time, min	20	20	20	60
Heat-up Time, min	70	60	53	60
Composition,* mol %				
CO	3.04	2.19	2.68	0.00
CO_2	71.37	68.24	60.32	98.57
H_2	15.38	19.67	16.96	0.44
CH_4	5.90	5.91	5.87	0.22
C_2H_6	1.43	1.16	0.89	0.22
C_3H_8	0.36	0.51	0.51	0.11
n-C_4H_{10}	0.36	0.26	0.00	0.00
i-C_4H_{10}	0.18	0.13	0.26	0.00
H_2S	0.18	0.00	0.00	0.00
Furans	0.54	0.51	0.64	0.11
Pyrroles	0.18	0.13	0.13	0.00
Acetone	0.36	0.39	11.10	0.33
Ethylene	0.54	0.64	0.64	0.00
Propylene	0.18	0.26	0.00	0.00
Total	100.00	100.00	100.00	100.00

* On an air-free basis.

† Gases were not collected during Run PWC-1.

Table 16. ANALYSIS OF HYDROCARBON LIQUIDS COLLECTED DURING WET-CARBONIZATION OF PEAT

Run No.	PWC-1[b]	PWC-2	PWC-3	PWC-4	PWC-21
Operating Conditions					
Temperature, °F	450	410	390	390	410
Pressure, psig	200	200	200	200	230
Time, min	20	20	20	20	60
Heat-Up Time, min	60	70	60	53	60
Quantity, g HC/g peat	0.00544	0.0130	0.0161	0.0279	0.0029
Composition, ppm[a]					
Methanol (CH_3OH)	750	1310	1610	1290	90
Ethanol (CH_3CH_2OH)	--[c]	--	--	--	330
Acetone (CH_3COCH_3)	30	800	720	9030	30
2-Butanone ($CH_3CHCOCH_3$)	--	90	160	110	--
Acetic Acid (CH_3COOH)	570	770	800	1400	560
Propionic Acid	--	--	--	--	<10
Pyridine (C_5H_5N)	--	20	40	10	--
2-Methylpyridine (C_6H_7N)	26	42	40	23	--
3+4-Methylpyridine (C_7H_9N)	--	8	10	7	--
Ethylpyridine (C_6H_6N)	--	31	8	3	--
Methylpyrazine ($C_5H_6N_2$)	--	19	91	59	4
2-Furaldehyde (C_4H_3OCHO)	--	4	8	1	--
5-Methylfuraldehyde ($CH_3C_4H_2OCHO$)	--	11	97	24	--
o-Hydroxybenzaldehyde (HOC_6H_4CHO)	--	30	--	45	--
Naphthalene	--	--	--	--	7
Methyl Naphthalene	--	--	--	--	2
Phenol (C_6H_5OH)	5	96	218	117	21
o-Cresol ($CH_3C_6H_4OH$)	14	39	51	32	1
m + p-Cresol ($CH_3C_6H_4OH$)	20	56	60	47	
o-Methoxyphenol ($CH_3OC_6H_4OH$)	11	1	3	--	--
o-Ethoxyphenol ($C_2H_5OC_6H_4OH$)	--	4	63	34	--
m + p-Ethoxyphenol ($C_2H_5OC_6H_4OH$)	--	11		19	--
2, 4-Xylenol [$(CH_3)_2C_6H_3OH$]	1	6	4	<1	--
o-Ethylphenol ($C_2H_5C_6H_4OH$)	4[d]	5	2	1	--
m + p-Ethylphenol ($C_2H_5C_6H_4OH$)		17	12	11	--
C_3-Phenol	<1	9	3	7	--
C_4-Phenol	<1	3	<1	3	--
UNID Boiling Below Phenol	7	47	64	36	--
UNID Boiling Above Phenol	6	30	217	94	--

[a] On a weight basis.

[b] Some light ends (benzene, etc.) may have been lost during collection and distillation.

[c] Blanks indicate compounds not detected during the analysis.

[d] Braces indicate that the figure given is an average value.

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formed during closed autoclave runs (Runs PWC-1 through PWC-21) contained fewer and smaller quantities of components than those formed during vented tests (Runs PWC-2 through PWC-4). All the components detected in the liquids produced from wet carbonization of peat (except for minute quantities of naphthalenes from Run PWC-21) contained nitrogen in aromatic compounds or oxygen in acids, alcohols, or aldehydes and ketones. In addition, the results show that the amounts of methanol and acetone formed during Run PWC-21 were considerably lower than those formed during Runs PWC-2 through PWC-4. About 330 ppm of ethanol is present in the liquid sample from Run PWC-21, although no ethanol was detectable in the liquid samples from Runs PWC-1 through PWC-4. The concentration of acetic acid was similar in all of the samples.

Some tests were made in order to duplicate results of earlier tests or to prepare additional samples for TRC or high-pressure compaction tests. The carbon conversions of peat wet carbonized under similar operating conditions sometimes varies by a significant amount. The difference in carbon conversion for these tests can be partially attributed to experimental and sampling errors and to the variable nature of the peat composition. It has been shown[2] that the peat composition may vary significantly from one sample to the next even if both are taken from the same peat bog. Obtaining a representative sample of peat is quite difficult. Also, only one feed analysis was made early in this subtask with which all residues have been compared for carbon conversion. The result of this is that a few tests appear to have anomalous carbon conversions.

HIGH-PRESSURE COMPACTION

The objectives of this subtask were to determine the effects of pressure on the amount of water removed from raw and wet-carbonized peat during compaction and also to determine the effect of such compaction on the TRC of peat. It is possible that high-pressure compaction partially destroys the cellular structure of peat and reduces its liquid-retention capacity, thereby making it easier to pump with lower liquid concentrations in the slurry. (The results of TRC tests conducted on high-pressure-compacted peat are presented in the slurrying characteristics section.)

A sample holder for conducting high-pressure compaction studies was designed and constructed, Figure 19. It consists of a 5-inch long, 2-inch, Schedule 80

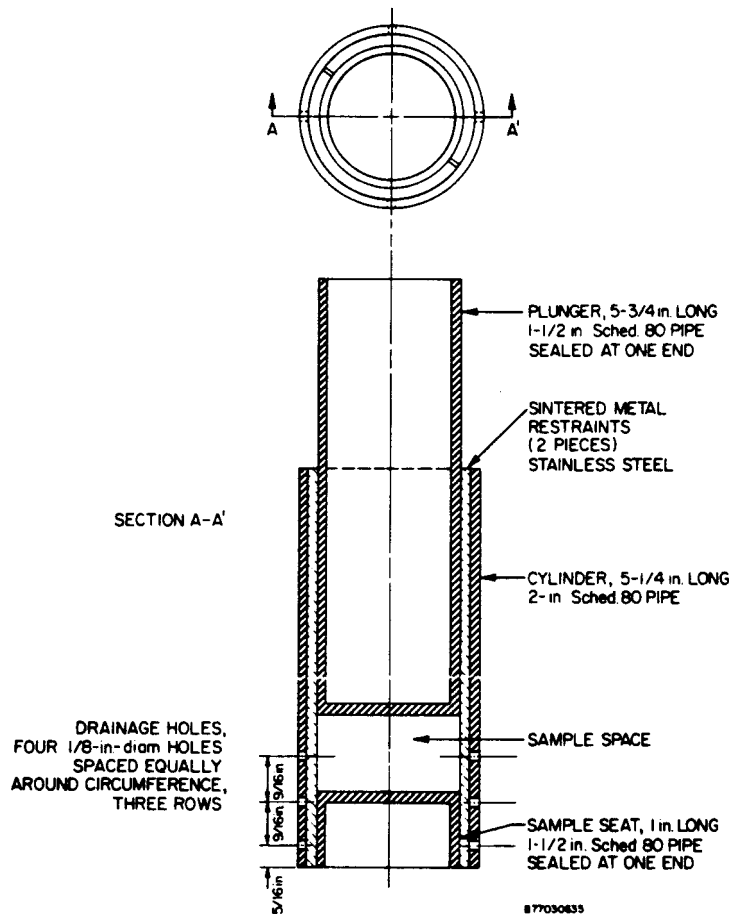

Figure 19. SAMPLE HOLDER FOR HIGH-PRESSURE COMPACTION AND DEWATERING TESTS

pipe that has three rows of 1/8-inch diameter holes. Each row has 4 holes drilled 90 degrees apart. To facilitate removal of the compacted sample, two sintered-metal, semicylindrical inserts are placed inside the 2-inch pipe. The holes and the sintered-metal inserts allow water to flow out during compaction. The sample (about 100 grams) is pressed between a baseplate and a plunger. A standard laboratory Carver press (Model B) was used for applying the desired pressure. A total of 28 high-pressure compaction tests were conducted with raw and wet-carbonized peat samples.

Figure 20 shows the effect of pressure on the amount of water remaining in the peat after compaction. For raw peat, increasing the pressure up to about 1100 psig decreases the water remaining in it (after compaction) from about 3.75 to 1.8 pounds per pound of dry peat, thus removing about 50% of the water present in the raw peat. The effect of increasing the pressure from 1100 to 1800 psig does not appear to be significant. The results also show that, after compaction at about 1450 psig, the carbonized peat retains only about 1.1 pounds of water per pound of dry peat. Therefore, the carbonized peat contains about 40% less water than the raw peat after compaction at the same pressure. The results also show that there is no significant difference in the dewatering characteristics of the peat carbonized by the two methods described earlier for Runs PWC-13 through PWC-16 and PWC-21.

Results of the high-pressure-compaction tests show that it is very effective for removing a considerable fraction of the original water from either raw or wet-carbonized peat. The economics of this method of dewatering should be evaluated.

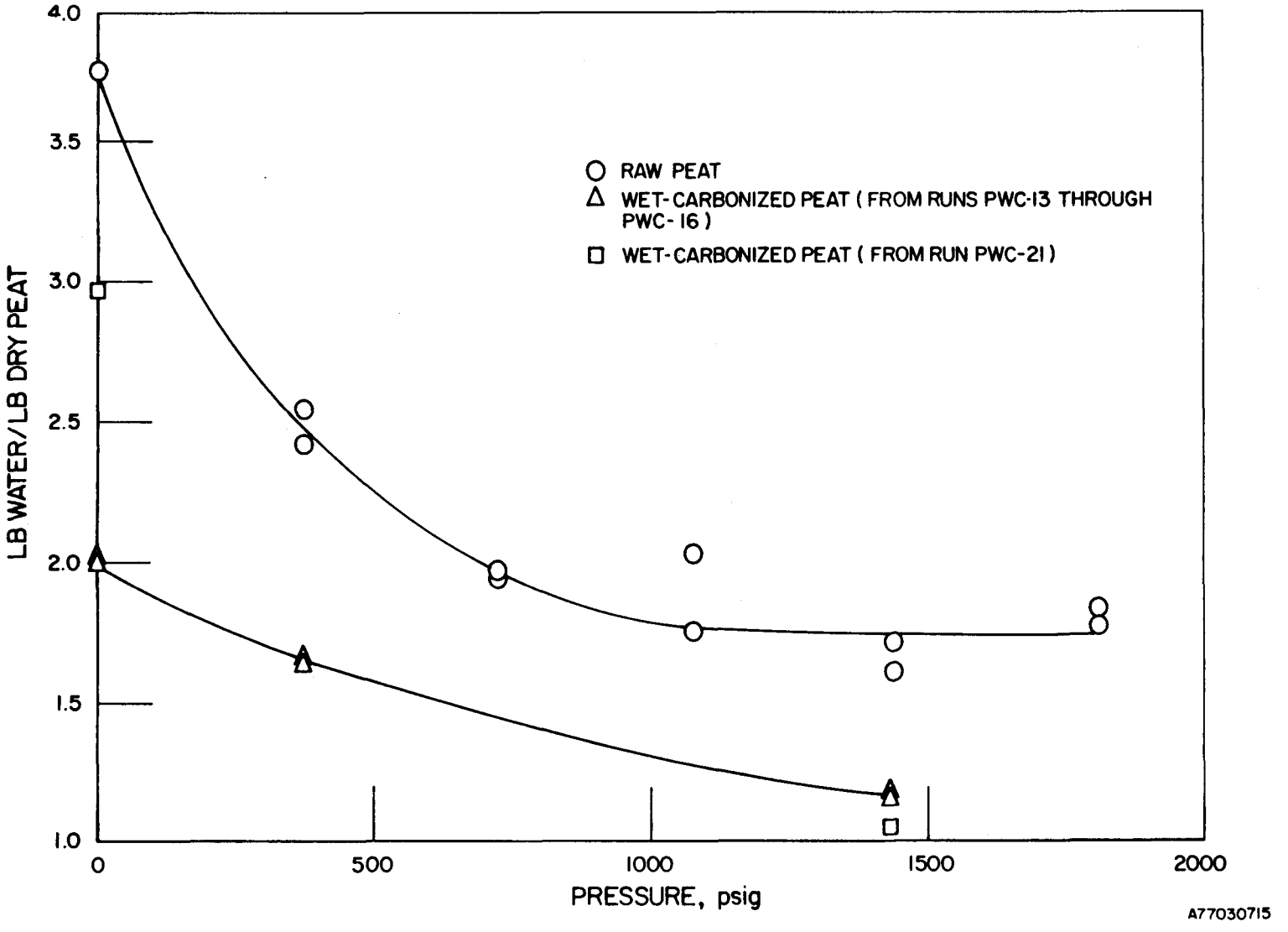

Figure 20. THE EFFECT OF PRESSURE ON WATER REMAINING IN RAW AND WET-CARBONIZED PEAT AFTER COMPACTION

PELLETIZING AND BRIQUETTING

Pelletizing and briquetting are two commonly used processes for handling fine-particle-size materials to improve their flow characteristics. The objective of this subtask was to determine the briquetting and pelletizing characteristics of peat to evaluate the potential of a system for the gasification of peat employing a fixed or moving bed.

Pelletizing Tests

Pelletizing tests were conducted in the laboratory of the California Pellet Mill Co., Crawfordsville, Indiana. The equipment used for pelletizing is schematically represented in Figure 21. Loose feed material is fed into the

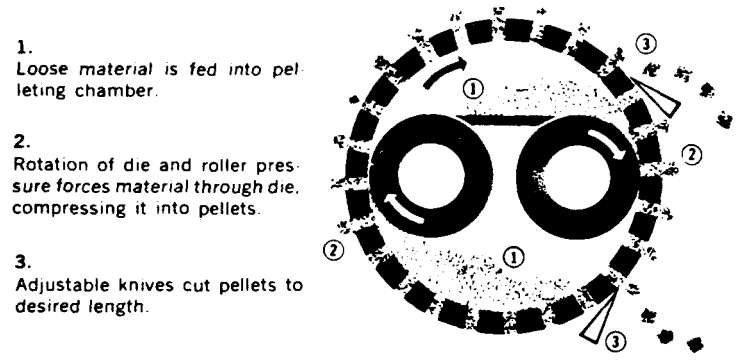

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Figure 21. SCHEMATIC PRESENTATION OF PELLETIZING APPARATUS

rotating pelleting chamber. The motion of the die and roller extrudes the material through the die, compressing it into pellets of a desired length. Eight pelletizing tests were conducted with −4 mesh peat, nominally containing 38, 50, 65, and 78 weight percent moisture.

The diameters and the lengths of the pellet sizes in these tests were varied from 1/16 to 1/2 inch and from 1/8 to 1 inch, respectively. Table 17 is a qualitative assessment of these pellets. All tests were successful except the one conducted with peat containing 78 weight percent moisture. It did not pelletize well. The pellets formed were not distinct pieces, but rather indistinguishable clumps.

The results in Table 17 indicate that peat containing about 38 weight percent moisture pelletizes very well but that peat pellets containing 78 weight

Table 17. RESULTS OF PELLETIZATION OF PEAT SAMPLES THAT HAVE DIFFERENT MOISTURE CONTENTS

Test No.	Pellet Size, in.	Moisture Content Feed[a]	Moisture Content Pellet	Bulk Density Feed	Bulk Density Pellet	Pellet Quality[d]
		wt %		lb/cu ft		
1	3/16 x 3/4	38	38.7	20	41	Very good
2	3/16 x 3/8	50	50.9	23	39	Good
3	3/16 x 3/8	78	73.0	--	--[c]	Very poor
4	1/8 x 1	38	38.4	20	45	Very good
5	1/8 x 1	50	49.9	23	40	Good
6	1/8 x 1	65	64.2	--[b]	34	Poor
7	1/2 x 2	38	38.5	20	42	Good
8	1/16 x 1/4	38	36.3	20	42	Excellent

[a] Moisture determination based on random samples, subject to local variations in moisture content in the bulk sample.

[b] Not determined.

[c] Pellets were not distinct pieces, but rather indistinguishable clumps.

[d] Based on qualitative flow characteristics and strength.

percent moisture cannot retain their shape. The pellets made from peat containing 65 weight percent moisture were weak; whereas, those made from peat containing 50 weight percent moisture were acceptable. Moisture contents and bulk densities of the feed materials and the pellets are also compared in Table 17. The heat generated by the mechanical work during pelletizing raised the temperature of the extruded pellets to about 125°F; however, the amount of dewatering and drying resulting from this generated heat was insignificant, except for the peat sample containing about 78 weight percent moisture.

Tests were also conducted to determine the effects of moisture content and pellet size on the strengths of pellets for axial (compression) and cross (splitting) loads. These tests were conducted in the materials testing laboratory at IITRI using a standard Instron Tester (Model TTC-M6). The results of the tests (Table 18) show that decreasing the moisture content from 65 to 38 weight percent increases the pellet strength almost 6 times. The results also show that, generally, the smaller-sized pellets are stronger.

Table 18. RESULTS OF COMPRESSION AND SPLITTING STRENGTH TESTS ON PELLETIZED SAMPLES OF REED SEDGE PEAT

Original Moisture Content, wt %	38	50	65	38	50	65
Strength	Compression			Splitting		
Nominal Pellet Size, in.	psig					
1/16 x 1/4	--	--	--	135.4 ± 37.9	--	--
1/8 x 1	275.2 ± 35.1	133.2 ± 39.0	39.2 ± 0.9	135.2 ± 29.4	43.8 ± 11.4	22.0 ± 5.8
3/16 x 3/8	--	114.2 ± 22.6	--	--	36.0 ± 13.0	--
3/16 x 3/4	467.2 ± 99.3	--	--	104.4 ± 44.8	--	--
1/2 x 2	200.4 ± 36.3	--	--	61.8 ± 12.7	--	--

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Five samples of peat pellets were tested to determine the effects of pellet size and moisture content on attrition resistance. The attrition tests were conducted in a rotating-ball tumbler consisting of an 11-1/8 inch long, 1-1/4 inch diameter cylinder. The sample was placed in the tumbler, which was allowed to rotate about a horizontal axis going through the center of its long axis (about the cylinder midpoint). The tests were conducted for 2100 revolutions. At the end, the product was screened to determine the quantity of undersized (smaller than the feed) material. The results are presented in Table 19, which shows that pellets made from peat containing 50 weight percent moisture have a higher attrition tendency (lower attrition resistance) than pellets made from 38 weight percent moisture peat because the former generate more undersized material than the latter. There seems to be no definite effect of pellet size on attrition resistance. However, at a constant moisture content, the pellets that have a higher splitting strength also have higher attrition resistance.

Briquetting

Some small-scale briquetting tests were conducted in the laboratory of K&G Industries (a division of Bepex Corp., Rosemont, Ill.). A small (Carver) hand press was used to prepare eight briquettes (1-1/8 inch diameter and 3/8- to 1/2-inch thick) containing 35 weight percent moisture. The tests were conducted with both −6 mesh and with finely ground peat at pressures of about 30,000 and 38,000 psig. Results of these tests are shown in Table 20. The finely ground peat briquetted better than the −6 mesh size peat, which tended to expand upon removal from the die. The conventional briquetting process will probably not be able to handle the peat containing more than 35 weight percent moisture, and no dewatering can be expected during briquetting without first making major equipment modifications.

Table 19. RESULTS OF ATTRITION TESTS CONDUCTED WITH SEVERAL VARIETIES OF PEAT PELLETS

Moisture Content, wt %	38		50		38		38		38	
Nominal Pellet Size, in.	− 3/16 x 3/4 —		− 3/16 x 3/8 —		— 1/8 x 1 —		— 1/2 x 2 —		− 1/16 x 1/4 —	
Sample	Feed	Residue	Feed	Residue	Feed	Residue	Feed	Residue	Feed	Residue
Screen Size, U.S.S., wt %										
−3/4+1/2	--	--	--	--	--	--	100.0	52.4	--	--
−1/2+1/4	--	--	--	--	--	--	--	44.8	--	--
−1/4+4	100.0	77.1	100.0	60.3	--	--	--	--	--	--
−4+6	--	20.5	--	38.3	100.0	51.2	--	--	--	--
−6+8	--	--	--	--	--	47.7	--	--	--	--
−8+10	--	--	--	--	--	--	--	--	--	--
−10+12	--	--	--	--	--	--	--	--	100.0	37.7
−12+14	--	--	--	--	--	--	--	--	--	61.8
−14+16	--	--	--	--	--	--	--	--	--	--
−16	--	2.4	--	1.4	--	1.1	--	2.8	--	--
−20	--	--	--	--	--	--	--	--	--	0.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total Material Smaller Than Feed, wt % of total		22.9		39.7		48.8		47.6		62.3
Pellet Strength,* psig		467		114		275		200		--

* Determined by compression-loading results presented in Table 18.

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Table 20. EFFECT OF PARTICLE SIZE AND BRIQUETTING PRESSURE ON THE SPLITTING STRENGTH (Crossload) OF PEAT BRIQUETTES AND THEIR BULK DENSITY

Sample No.	Briquetting Pressure, psig	Feed Size	Bulk Density, lb/cu ft	Splitting Strength, psig
1	30,000	−6	55.2	40
2	30,000	Fine†	63.0	103
3	38,000	−6	58.7	23
4	38,000	−6	56.2	76‡
5	38,000	−6	56.2	28
6	38,000	Fine†	71.5	180
7	38,000	Fine†	63.7	71
8*	38,000	Fine†	70.3	230

* Heated to 200°F prior to briquetting.

† Ground in a mortar and pestle.

‡ A punch-shear test was conducted on this sample to determine its strength in shear.

The strengths of various peat briquettes were measured to determine the effect of particle size and briquetting pressure on the strength of the briquettes in cross loading (splitting). Briquette strength was also tested in the materials testing laboratory at IITRI. A standard Instron Universal Tester (Model TTC-M6) was used for all tests. The results show that the smaller-particle-size peat makes stronger briquettes. Heat pretreating the feed material also appears to strengthen the briquettes.

One of the briquettes was also tested for strength in shear. For measuring strength in shear, the briquette was laid flat on a die with a 1/2-inch diameter hole. A 1/2-inch diameter rod was then positioned axially over the briquette (over the hole) and loaded. The force required to punch a hole in the briquette is a measure of its strength in shear.

There was no definite effect of briquetting pressure on briquette strength. For coarse feed material, increasing the briquetting pressure decreases briquette strength. For finely ground feed material, an increased briquetting pressure results in an average increase in strength. Larger numbers of briquettes will have to be tested to yield statistically significant data.

FLOW CHARACTERISTICS OF PEAT

Many separate tests were conducted to determine the effects of moisture content and particle size on the flow characteristics of peat. Four important parameters useful in designing and sizing the hoppers are the angles of internal friction (α), repose (β), rupture (ω), and the angle of slide (δ).

The angle of internal friction is necessary to determine what wall angle is required for a hopper to discharge its entire contents. The angle of internal friction is the angle of the interface between the cone of flowing solids and the stationary solids around the cone. The angle of repose is essential in determining the capacity of a bin filled by pouring material. It is defined as the internal angle of the cone formed by pouring solids.

The angle of slide is the minimum angle of inclination of the surface on which the sample is resting necessary to make the sample slide down on its own. An angle of rupture is the angle formed by the material that flows from a container when a restraining wall is removed. All of these angles are measured from the horizontal. A schematic diagram of the equipment and definitions of the angles of internal friction, repose, and rupture are shown in Figures 22 and 23. The sample container is a 20 inch x 14-3/4 inch x 7-3/4 inch wooden box. A plastic window was built into the large front panel for observation. Sliding doors on the bottom of the box allow for variable-sized port openings for testing.

The tests were conducted with —2 inch, —1/2 inch, —10+20 mesh, and —20+40 mesh size fractions of peat containing 0, 41, and 75 weight percent moisture. Size distributions of the various fractions of peat, bituminous, and lignite coal used in these tests are shown in Table 21.

The results of these tests are presented in Tables 22 and 23, which show that increasing the moisture content from 0 to 75 weight percent increases the angles of internal friction from 47 to 74 degrees. The angle of repose of peat is about 34 degrees and is not significantly affected by moisture content. The angles of internal friction and repose for —20 mesh dry bituminous coal were 60 and 33 degrees, respectively.

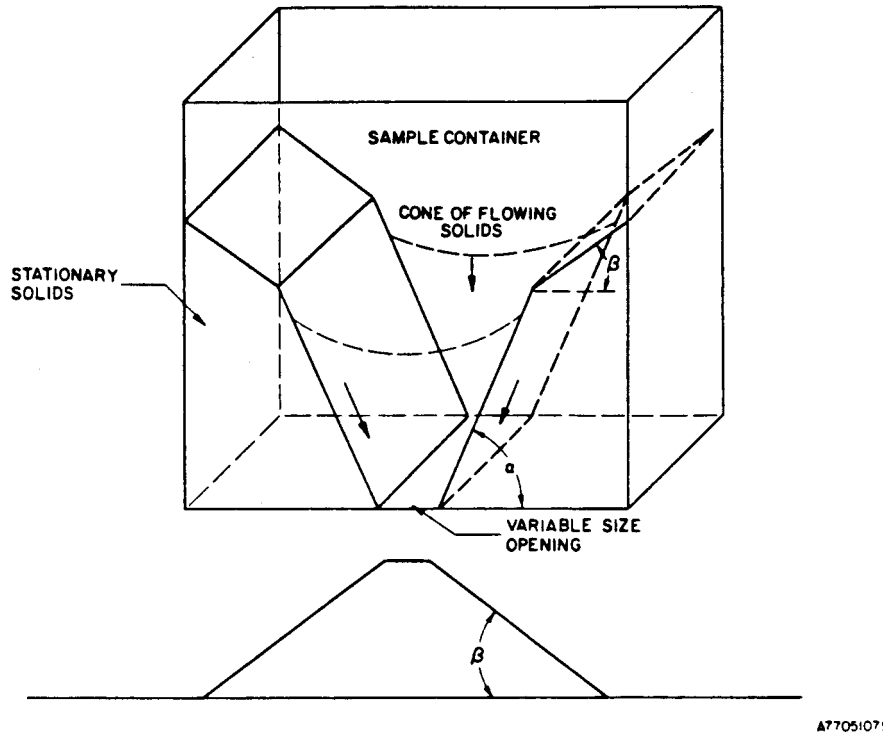

Figure 22. SCHEMATIC OF APPARATUS USED FOR DETERMINING ANGLES OF REPOSE, β, AND INTERNAL FRICTION, α

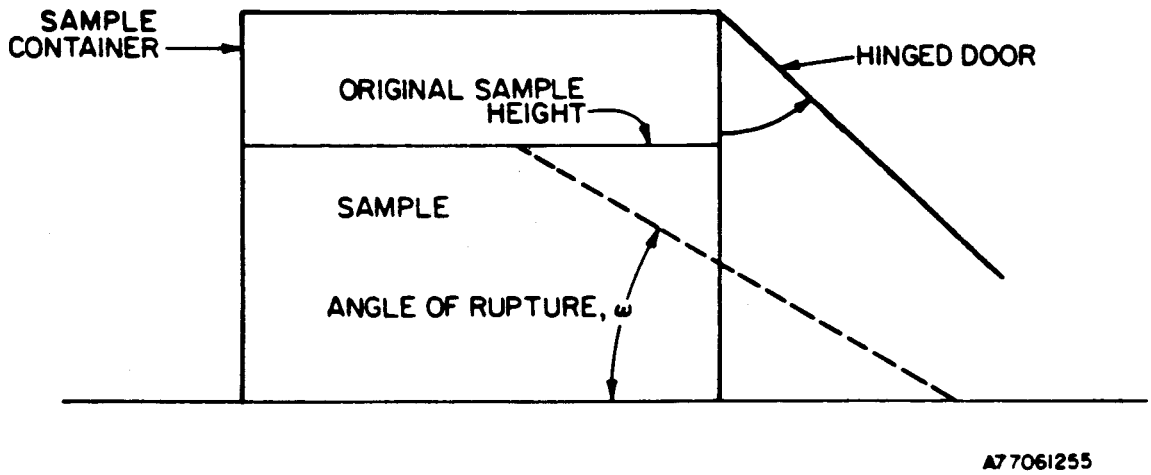

Figure 23. PICTORAL REPRESENTATION OF ANGLE OF RUPTURE, ω

Table 21. PARTICLE-SIZE DISTRIBUTION OF PEAT AND COAL SAMPLES USED IN TESTS TO DETERMINE ANGLES OF INTERNAL FRICTION, REPOSE, SLIDE, AND RUPTURE

Sample	Peat						Coal		
							Bituminous	Lignite	
Nominal Size, in.	−2	−1/2	−2	−1/2	−2	−1/2	−20	−1	−1/2
Moisture Content, wt %	0		41		75		0	0	
Sieve Size, U.S.S., wt %									
−2+1 in.	13.6	0.0	4.1	0.0	15.1	0.0	0.0	0.0	0.0
−1+3/4 in.	5.6	0.0	4.8	0.0	16.4	0.0	0.0	0.0	0.0
−3/4+1/2 in.	8.6	0.0	11.1	0.0	10.9	0.0	0.0	6.3	0.0
−1/2+1/4 in.	28.3	11.7	20.0	20.5	14.8	14.9	0.0	18.2	13.7
−1/4+10 in.	21.4	32.6	19.4	22.3	17.1	32.4	0.0	31.1	30.6
−10+20 mesh	9.0	23.9	11.7	16.5	21.4	44.1	0.0	16.0	20.9
−20+40 mesh	4.6	15.4	8.3	14.0	4.1	8.3	26.9	9.8	13.6
−40+60 mesh	2.4	9.3	5.0	7.4	0.2	0.3	16.0	5.8	7.4
−60+80 mesh	1.0	1.1	2.7	4.3	0.0	0.0	8.7	1.7	3.4
−80+100 mesh	0.9	1.0	2.2	2.5	0.0	0.0	6.8	2.0	1.1
−100+140 mesh	1.2	1.3	4.0	4.6	0.0	0.0	12.6	1.7	2.4
−140+170 mesh	0.4	0.6	1.6	1.0	0.0	0.0	3.5	0.8	0.6
−170+230 mesh	0.8	0.6	3.2	4.2	0.0	0.0	6.9	1.2	1.2
−230+325 mesh	1.0	1.2	1.5	2.4	0.0	0.0	8.0	1.8	1.7
−325 mesh	1.2	1.3	0.4	0.3	0.0	0.0	10.6	3.6	3.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average Particle Size, mm	0.778	0.531	0.481	0.380	3.093	1.676	0.107	0.361	0.347

Table 22. THE EFFECT OF PARTICLE SIZE AND MOISTURE CONTENT ON THE ANGLE OF INTERNAL FRICTION FOR PEAT AND COAL SAMPLES

Sample	Peat			Coal	
				Lignite	Bituminous
Moisture Content, wt %	0	41	75	0	0
Particle Size	Angle of Internal Friction (α), degrees				
−2 in.	54	71	76	49	--
−1/2 in.	52	67	68	43	--
−10+20 mesh	41	74	78	35	--
−20+40 mesh	40	69	--	34	--
−20+Pan	--	--	--	--	60
Average	47	70	74	40	--
Standard Deviation	15	6	10	14	--

Table 23. THE EFFECT OF PARTICLE SIZE AND MOISTURE CONTENT ON THE ANGLE OF REPOSE FOR PEAT AND COAL SAMPLES

Sample	Peat			Coal	
				Lignite	Bituminous
Moisture Content, wt %	0	41	75	0	0
Particle Size	Angle of Repose (β), degrees				
−2 in.	27	31	34	31	--
−1/2 in.	35	32	34	31	--
−10+20 mesh	32	37	32	32	--
−20+40 mesh	38	37	--	34	--
−20+Pan	--	--	--	--	33
Average	33	35	33	32	--
Standard Deviation	9	6	2	3	--

Results of measurements for the angles of slide and rupture are presented in Tables 24 and 25. They show that increasing the moisture content from 0 to 75 weight percent increases the angle of slide from 28 to 39 degrees, and that increasing the moisture content from 0 to 41 weight percent increases the angle of rupture from 31 to 41 degrees. The angle of rupture for peat containing 75 weight percent moisture is about 90 degrees, therefore, the material will not flow, except when vibrating the container. The angles of slide and rupture for lignite and bituminous coals are also quite close to those of peat. There is no definite or significant effect of particle size on any of these flow parameters.

The results show that except for the angle of internal friction (47 degrees for peat and 40 degrees for lignite), the flow parameters for dry peat and dry lignite are very similar. This indicates that the design of solids-handling equipment for a peat gasification plant will not differ significantly from that for a lignite gasification plant.

Table 24. THE EFFECT OF PARTICLE SIZE AND MOISTURE CONTENT ON THE ANGLE OF SLIDE (on Steel Plate) FOR PEAT AND COAL SAMPLES

Sample	Peat			Coal	
				Lignite	Bituminous
Moisture Content, wt %	0	41	75	0	0
Particle Size	Angle of Slide (δ), degrees				
−2 in.	27	35	38	28	--
−1/2 in.	27	33	38	25	--
−10+20 mesh	30	37	41	32	--
−20+40 mesh	29	37	--	28	--
−20+Pan	--	--	--	--	30
Average	28	36	39	28	30
Standard Deviation	1.5	2	0.5	3	1

Table 25. THE EFFECT OF PARTICLE SIZE AND MOISTURE CONTENT ON THE ANGLE OF RUPTURE FOR PEAT AND COAL SAMPLES

Sample	Peat			Coal	
				Lignite	Bituminous
Moisture Content, wt %	0	41	75	0	0
Particle Size	Angle of Rupture (ω), degrees				
−2 in.	30*	35	∿90	36	--
−1/2 in.	30	40*	∿90	35	--
−10+20 mesh	27	42*	∿90	31	--
−20+40 mesh	36*	45*	--	34	--
−20+Pan	--	--	--	--	32
Average	31	41	90	34	32
Standard Deviation	4	4	--	2	1.5

* Standard deviation of 11 to 14.

CONCLUSIONS

- The results of size-reduction tests indicate that air-dried peat can be ground in a standard hammer mill and that its grinding characteristics are similar to those of lignite and bituminous coals.
- The results of fluidization tests show that the fliudization characteristics of peat are similar to those of coal char. Peat, with a lower particle density, has higher minimum and complete fluidization velocities than the char for the same average particle size. This indicates that peat probably does not fluidize as discrete particles but as a conglomerate of particles. Elutriation of fines from a fluidized bed of peat will be less than expected on the basis of feed-particle-size distribution.
- Moisture content and particle size distribution of the peat sample significantly affect the TRC and the slurry viscosity. A pumpable slurry can be prepared from peat containing about 8 weight percent moisture and a toluene concentration of 2.4 pounds of toluene per pound of dry peat.
- Wet-carbonized peat samples can be dewatered from about 67.0 to 50-55 weight percent moisture (1.0 to 1.2 pounds of water per pound of dry peat) at compaction pressures of 1450 psig.
- The results of high-pressure compaction tests show that increasing compaction pressure to 1100 psig effectively reduces the moisture content of raw peat from 78.9 down to 60 to 65 weight percent (1.5 to 1.86 pounds of water per pound of dry peat). Compaction pressures greater than 1100 psig do not significantly reduce peat moisture content.
- Air-dried peat containing 35 weight percent moisture can be pelletized and briquetted without the use of binders.
- The flow characteristics of dry peat are very similar to those of dry lignite (except the angle of internal friction). The solids-handling equipment for a peat gasification plant will not differ significantly from that for a lignite gasification plant. There is no definite or significant effect of particle size on any of these flow parameters.

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