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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	mm	millimeter
cP	centipoise	μm	micrometer
g/cm^3	gram per cubic centimeter	m/s	meter per second
kg/mt	kilogram per metric ton	pct	percent
kW•h/mt	kilowatt hour per metric ton	r/min	revolution per minute
min	minute		

FINE GRINDING OF COAL BY THE TURBOMILLING PROCESS

By E. G. Davis[1]

ABSTRACT

As a result of interest by the U.S. Department of Energy, the Bureau of Mines conducted studies on comminution of bituminous coal to the 2-μm particle size range using the Bureau-developed turbomill. Both "plant-grind" size (80 pct minus 75 μm) and microsize (minus 10 μm) coal can be produced in a single step with the Bureau's turbomill. In 15 min, minus 2.4-mm coal milled in water with steel shot was reduced to 65 pct minus 75 μm and 26 pct minus 2 μm, with an energy requirement of 139 kW•h/mt coal. Plant-grind size coal milled in water, with Ottawa sand as the milling medium, was reduced to more than 45 pct minus 2 μm in 15 min, at 175 kW•h/mt. Plant-grind coal milled with steel shot was reduced to 57 pct minus 2 μm in 15 min, at 138 kW•h/mt. When diesel fuel was substituted for water, the milling of the coal was less effective and less energy efficient. Keeping the pulp dispersed was critical. Without an effective dispersant, the slurry became very viscous with increased milling time, resulting in higher energy requirements, low heat dissipation, and poor grinding efficiency.

INTRODUCTION

The Bureau of Mines turbomilling process has been used to fine-grind a wide variety of products (1-2),[2] including, in large-scale continuous tests, kaolin for use as paper-coating clays (2). Autogenous turbomilling has been applied to a North Carolina dunite to produce an olivine foundry sand (3-4) and to a calcium carbonate to produce micrometer-sized particles.

Aware of the Bureau's experience in ultrafine grinding, the U.S. Department of Energy (DOE) indicated an interest in the use of the turbomill to produce a coal slurry in the 1- to 5-μm particle size range. For a number of years, DOE has considered the possible use of microfine coal in water as a substitute for oil in firing steam boilers (5) or as an addition to diesel fuel for use in diesel engines (6). As a result of DOE's interest and the examination and discussion of coal size-reduction systems in the literature (7), and to demonstrate the effectiveness of the Bureau-developed turbomill, the Tuscaloosa Research Center conducted studies on the milling of bituminous coal using the Bureau's turbomilling process (8).

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[1]Metallurgist, Tuscaloosa Research Center, Bureau of Mines, Tuscaloosa, AL.

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

DESCRIPTION OF MATERIALS

Three different coals, typical of coals used in steam plants, were used in the test program (table 1). Sample 1 was from the lower Freeport Seam, and sample 2 was from the Pittsburgh Seam. Both of these are typical coals from Pennsylvania coal fields. A third coal (samples 3A and 3B) came from the Tiger Mine, Clemmons Seam, in Alabama. Samples 1 and 2 were both "plant grind," which is 80 pct minus 75-μm size. A portion of the Alabama coal was dry-ground through 75 μm (sample 3A) to produce a simulated plant-grind sample. Another portion was crushed to minus 2.4 mm (sample 3B) for use in autogenous milling and steel shot grinding tests.

Goulac[3] (Ca-Mg lignin suldonate) and tetrasodium pyrophosphate (TSPP), two standard dispersants, and Lomar D (an organic anionic sulfonate) were used as dispersants in water. Lecithin, a natural food product high in fat, which is soluble in fuel oils, was used as the dispersant in the diesel fuel milling tests. The diesel fuel was a D-2 grade with a specific gravity of 0.85 and an average viscosity of 3.3 cP.

Batch tests were conducted using Ottawa sand (between 840 and 600 μm in particle size), steel shot (between 840 and 600 μm), and autogenous coal (between 2.4 mm and 600 μm) milling media.

EXPERIMENTAL WORK

Previous Bureau milling studies using Ottawa sand had identified the effect of milling medium size, solids content, and medium-to-mineral ratio on the milling of a variety of minerals. Based on this experience, standard batch operating conditions for a sand milling medium, shown in table 2, were used for the batch turbomilling of the coal in both water and diesel fuel. Steel shot was chosen because it was much denser than sand, 7.9 versus 2.65 g/cm^3.

The tests were conducted in a 13-cm-diam turbomill, shown in figure 1. The turbomill consists of three main parts: a rotor composed of vertical bars fixed to an upper disk attached to the drive shaft, a cagelike stator composed of vertical bars attached to rings at the top and bottom, and a frame that holds the

[3]Reference to specific products does not imply endorsement by the Bureau of Mines.

TABLE 1. - Size analyses of coal samples, weight percent

Particle size	1[1]	2[1]	3A[2]	3B[3]	Particle size	1[1]	2[1]	3A[2]	3B[3]
Minus 2.4 plus 1.4 mm...	0	0	0	17	Minus 600 plus 150 μm...	1	1	0	29
Minus 1.4 mm plus 840 μm	0	0	0	28	Minus 150 plus 75 μm....	16	16	11	3
Minus 840 plus 600 μm...	0	0	0	22	Minus 75 μm............	82	82	89	1

[1]Plant grind, which is 80 pct minus 75 μm.
[2]Plant-grind size coal of sample 3.
[3]Coarse size coal of sample 3 used as grinding medium in autogenous turbomilling.

TABLE 2. - Standard batch operating conditions using Ottawa sand as the milling medium

Test conditions	Standard material value or setting
Coal-liquid...............pct solids..	40.0
Coal plus sand-liquid.....pct solids..	70.0
Sand-to-coal weight ratio.............	2.5
Medium size......................μm..	600-840
Peripheral rotor speed...........m/s..	7.45

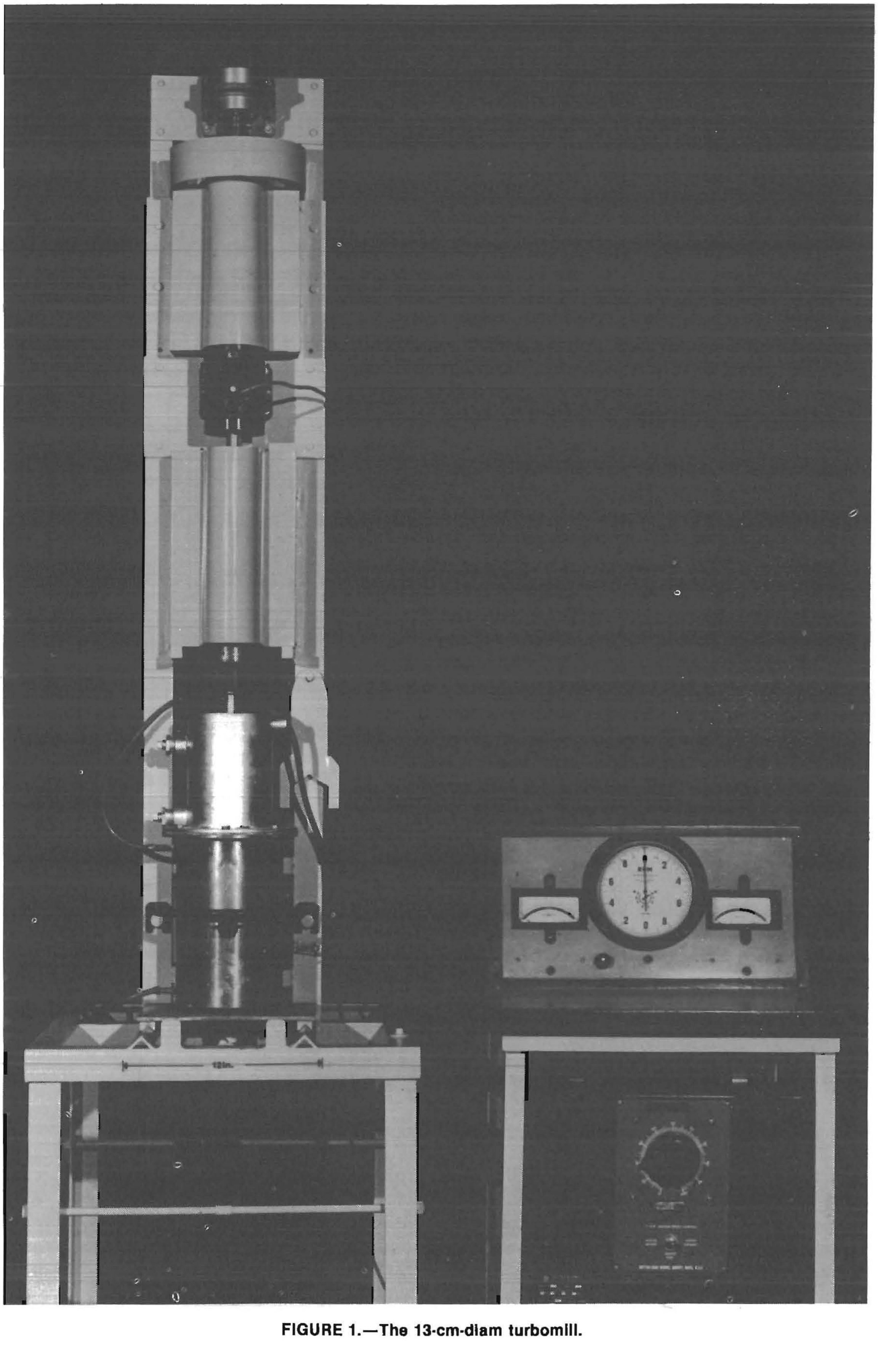

FIGURE 1.—The 13-cm-diam turbomill.

motor and machine components. Figure 2 is a schematic drawing of the mill.

The following procedure was employed for each of the milling tests. First, the liquid and dispersant were added to the turbomill. Then the rotor was turned slowly as the medium (sand or steel shot) and coal were added to the turbomill. After all the coal was charged, the rotor speed was increased to a peripheral speed of 7.45 m/s (equivalent to 1,600 r/min for the 8.8-cm-diam rotor). Power measurements were obtained from a torque meter attached to the shaft of the rotor. The torque on the rotor as it stirs the slurry in the grinder is directly related to the power used by the grinder and can be converted to energy consumption. This measurement technique effectively excludes the power used by the motor and bearings supporting the shaft. After an assigned grinding time, the slurry was drained, screened to remove the grinding medium, and sampled for size analysis. Size analyses of the ground coal was determined by a sedimentation method, using a modified ASTM method for grain-size analysis of soils (9). The degree of milling required for microsized coal varies with its intended application. In the most extreme cases, where the microsized coal is used to fuel an internal combustion engine, the coal must be smaller than 3 μm and in some cases, 1 μm. For this study, 2 μm was selected as an acceptable particle size for microsized coal.

Autogenous turbomilling was also tested as a method for micromilling coal in the turbomill. Here, the coarse coal in the feed (sample 3B, minus 2.4 mm plus 600 μm) serves as the milling medium. This technique has the advantage that the milled product is not contaminated with material abraded from the milling medium.

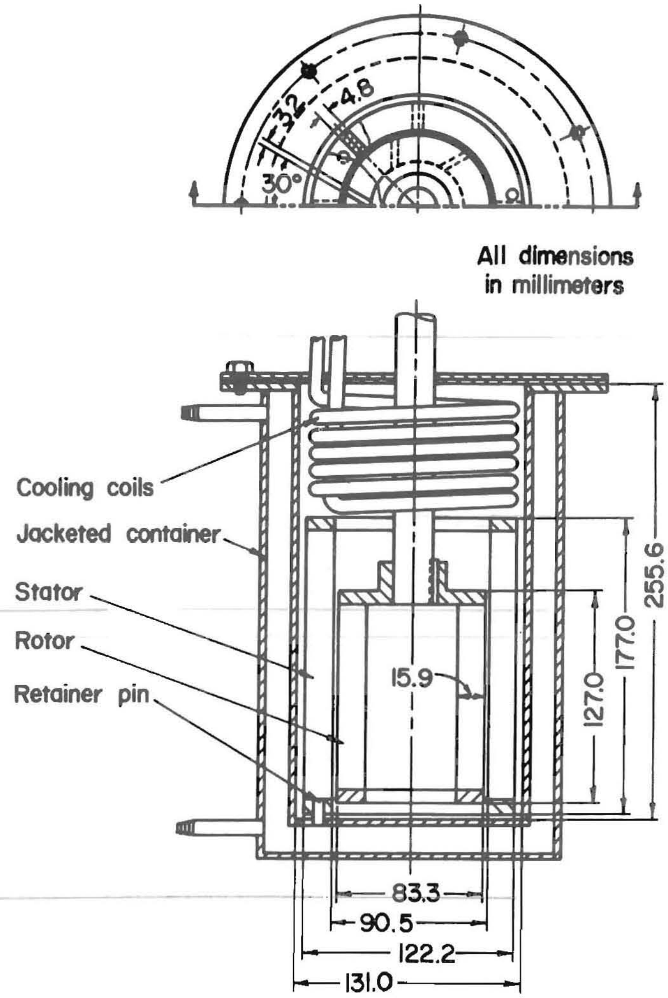

FIGURE 2.—Schematic drawing of turbomill.

To maintain the same volume of medium, the 2.5:1 ratio of Ottawa sand to coal was replaced with a 1.1:1 ratio of coarse coal to the remaining coal. The coal was only 44 pct as dense as Ottawa sand. Roughly, 52 pct of the coal in the grinder was plus 600 μm and acted as the turbomilling medium. All of the other parameters remained the same for these tests.

RESULTS

OTTAWA SAND AS THE GRINDING MEDIUM

Table 3 shows the size analysis of the coal after milling with Ottawa sand in water, and table 4 shows the size after milling in diesel fuel. After milling in water for 15 min, 45 to 74 pct of the plant-grind coal was finer than 2 μm. The production rate of the minus 2-μm coal, as shown in figure 3, decreased as the milling time increased. For example, after the first 15 min, sample 1 was milled to 74 pct minus 2 μm using 160 kW•h/mt energy. During the next 15 min,

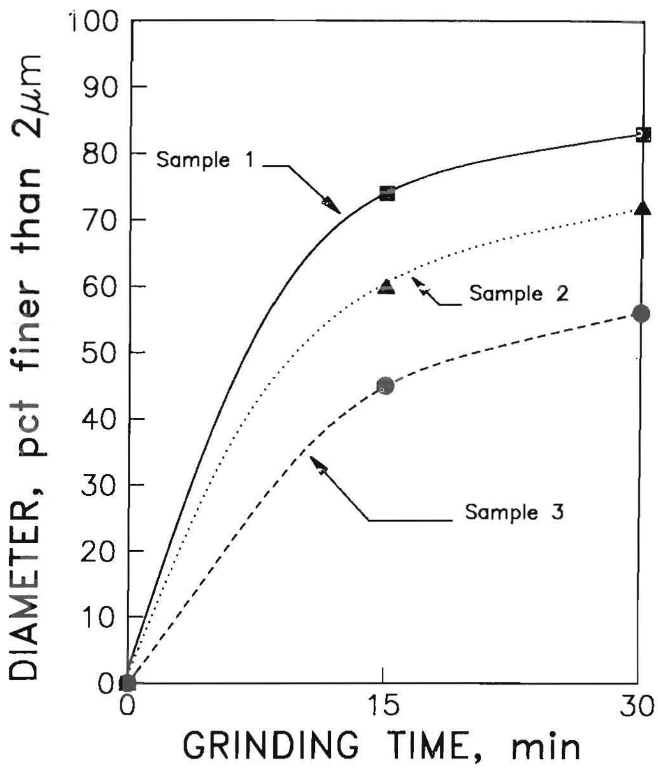

FIGURE 3.—Turbomilling results of plant-grind coal samples using Ottawa sand in water.

the percentage of minus 2-µm coal increased to only 83 pct, but an additional 150 kW•h/mt energy was required. The milling effectiveness and energy efficiency decreased significantly as the milling time lengthened. A size classification step should therefore be included in a continuous milling circuit to remove the minus 2-µm material and return the plus 2-µm fraction to the turbomill for further size reduction.

Turbomilling coal in diesel fuel was not as effective as milling the coal in water. In 15 min, only about a third of the coal was minus 2 µm. After 30- and 60-min milling times, very little additional minus 2-µm coal was produced.

Keeping the pulp dispersed during turbomilling was critical. TSPP did not work well for dispersion of the coal slurry in water because as the milling time increased, the slurry became viscous. Goulac was used in most of the water milling tests; however, during the 60-min runs, the coal slurry also became viscous. This increased the energy required to maintain the proper rotor speed and hindered heat dissipation, causing the slurry to become very hot. Lomar D was found to be effective for dispersing the coal even during the 60-min tests.

TABLE 3. - Particle size distribution of coal turbomilled in water[1] using a sand medium

Grind time, min	Diameter, pct finer than--			Energy, kW•h/mt feed
	10 µm	5 µm	2 µm	
Sample 1:				
15.........	99	94	74	160
30.........	100	97	83	310
Sample 2:				
15.........	100	91	45	175
30.........	100	94	56	360
Sample 3A:				
15.........	100	92	60	190
30.........	100	97	72	370

[1]Goulac (Ca-Mg lignin sulfonate) used as dispersant.

TABLE 4. - Particle size distribution of coal turbomilled in diesel fuel using a sand medium

Turbomill time, min	Diameter, pct finer than--					Energy, kW•h/mt feed
	75 µm	20 µm	10 µm	5 µm	2 µm	
Sample 1:						
15.....	100	96	85	70	32	230
30.....	100	98	92	72	42	510
60.....	100	95	86	71	44	1,150
Sample 2:						
15.....	100	98	95	78	30	260
30.....	100	98	92	77	30	495
60.....	100	100	92	80	58	1,130

Table 5 compares the effect of the dispersants Goulac and Lomar D on turbomilling coal sample 2. As shown, the 15-min test using Lomar D produced a product which was not significantly different than that produced by the 30-min test using Goulac. In addition, twice as much Goulac as Lomar D was required to maintain fluidity.

Lecithin appeared to be an effective dispersant for the diesel fuel tests.

STEEL SHOT AS THE GRINDING MEDIUM

Results are shown in table 6 of milling plant-grind coal (sample 2) with a steel shot medium, as compared with milling the same coal sample with the same volume of Ottawa sand. Since the steel is roughly three times denser than the Ottawa sand, the weight ratio of steel shot to coal was 7.5:1. The number of milling medium particles was virtually the same for both the steel shot and Ottawa sand tests. The steel shot turbomilling system produced more minus 2-µm coal with less energy than did the Ottawa sand turbomilling system. In the first 15 min of the steel shot milling test, 57 pct of the coal was minus 2 µm at an energy cost of 138 kW.h/mt. This was 21 pct more minus 2-µm coal with 20 pct less energy.

Coarse coal (sample 3B) was also milled with steel shot. These tests were made to determine how well a coarse coal could be milled and to see what size material would be produced. In addition to the 7.5:1 ratio of steel shot to coal, ratios of 5:1 and 2.5:1 were also tested; table 7 shows the results from these tests.

TABLE 5. - Effect of dispersing agents on size of coal sample 2 turbomilled in water using a sand medium

Turbomill time for dispersants, min	Diameter, pct finer than--		
	10 µm	5 µm	2 µm
Goulac:[1]			
15	100	91	45
30	100	94	56
Lomar D:[2]			
15	100	97	47
30	100	98	68

[1] Ca-Mg lignin sulfonate.
[2] Organic anionic sulfonate.

TABLE 6. -- Particle size distribution of plant-grind (minus 75-µm) coal sample 2 using sand and steel shot media

Turbomill time for media, min	Diameter, pct finer than--			Energy, kW•h/mt feed
	10 µm	5 µm	2 µm	
Sand:[1]				
15	100	91	45	175
30	100	94	56	360
Steel shot:[2]				
15	100	95	57	138
30	100	98	77	275

[1] Sand-to-coal weight ratio, 2.5:1.
[2] Steel-shot-to-coal weight ratio, 7.5:1.

TABLE 7. - Particle size distribution of coal sample 3B turbomilled with steel shot

Milling time,[1] min	Diameter, pct finer than--					Energy, kW•h/mt feed
	2.4 mm	600 µm	75 µm	5 µm	2 µm	
7.5:1 ratio:						
15	100.0	60.4	45.6	43.1	26.6	145
30	100.0	64.8	53.9	50.1	37.8	281
60	100.0	67.5	55.9	54.6	44.9	466
5:1 ratio:						
15	100.0	79.1	65.4	56.8	26.5	139
30	100.0	80.1	70.9	67.3	42.2	253
60	100.0	82.2	75.5	68.0	50.6	420
2.5:1 ratio:						
15	100.0	60.6	56.4	49.6	23.7	106
30	100.0	81.4	73.0	62.8	38.1	226
60	100.0	83.9	78.0	69.1	44.6	323

[1] By ratio of steel shot to coal.

TABLE 8. - Particle size distribution of autogenous turbomilled coal[1]

Milling time, min	Diameter, pct finer than--					Energy, kW·h/mt feed
	2.4 mm	600 μm	75 μm	5 μm	2 μm	
0 (feed)......	100	48	31	0	0	NAp
30.............	100	49	41	33	20	155
60.............	100	51	42	38	31	300

NAp Not applicable.
[1]Coal sample 3A; Goulac (Ca-Mg lignin sulfonate) used as dispersant.

These tests show that both a plant-grind size and microsize coal could be produced by milling coarse coal with a steel shot. The best results were obtained using a ratio of 5:1 where, in 15 min, 65.4 pct of the coal was minus 75 μm size and 26.5 pct of the coal was minus 2 μm size, and only 139 kW·h/mt of energy was consumed.

COURSE COAL AS THE GRINDING MEDIUM

Autogenous turbomilling of coal was tested by using coal sample 3B as the milling medium and sample 3A as the material to be ground, in a ratio of 1.1:1. The results after 30 and 60 min of milling are shown in table 8. The amount of the coal milling medium (plus 600-μm size) decreased from 52 to 51 pct and then to 49 pct over the two milling periods. This indicates that the plus 600-μm size coal was a fairly persistent turbomilling medium. However, the autogenous turbomilling of coal was the least effective and least energy efficient of the techniques studied. The low density of the coal milling medium particles significantly reduced its effectiveness as a milling medium.

CONCLUSIONS

Based on test data obtained by turbomilling coal with Ottawa sand, steel shot, and coarse coal media, the following conclusions were made.

1. Bituminous coal can be fine-ground to microsizes (minus 10 μm) using the Bureau's turbomilling process. In 15 min, plant-grind coal samples (80 pct minus 75 μm) were milled using Ottawa sand or steel shot milling media to produce products containing 45 to 74 pct minus 2-μm material. Beyond 15 min, the production rate of minus 2-μm size coal significantly declined.

2. The high-density steel shot medium produced more minus 2-μm size coal for less energy than did the Ottawa sand: steel shot produced 57 pct minus 2 μm at 138 kW·h/mt in 15 min, and Ottawa sand produced 45 pct minus 2 μm at 175 kW·h/mt.

3. Both plant-grind size and microsize coal can be produced in a single step with the Bureau's turbomill. In 15 min, a coarse coal sample (less than 2.4 mm) was milled to 65 pct minus 75 μm and 26 pct minus 2 μm with steel shot, with 139 kW·h/mt energy used.

4. Diesel fuel with Lecithin as a dispersant could be substituted as the milling medium for water, but the turbomilling was less effective and less energy efficient.

5. Autogenous turbomilling can produce microsize coal; however, it was the least effective and least energy efficient of the techniques studies.

6. Without an effective dispersant, the pulp became very viscous, which increased energy requirements and reduced grinding efficiency.

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