R. I. 3707 | June 1943

UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

BRIQUETTING SUBBITUMINOUS COAL

BY

V. F. PARRY AND JOHN B. GOODMAN

R.I. 3707,
June 1943.

REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

BRIQUETTING SUBBITUMINOUS COAL[1/]

By V. F. Parry[2/] and John B. Goodman[3/]

CONTENTS

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote is used: "Reprinted from Bureau of Mines Report of Investigations 3707."

2/ Supervising engineer, Bureau of Mines Field Office, Golden, Colo.
3/ Associate chemical engineer, Bureau of Mines Field Office, Golden, Colo.

CONTENTS (Cont'd.)

TABLES

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd.)

INTRODUCTION

Review of Previous Work

Many investigators and certain commercial interests have recognized that the briquetting process is a practical method to convert much of what is now considered undesirable fuel into a usable form of domestic fuel. The art of improving the form of solid fuels is ancient, as early records indicate that the Chinese employed crude hand briquetting of combustible materials long before coal was known in Europe and America.

According to Franke,[4] the earliest description of a briquetting procedure employed in the Occident is contained in an English patent dated in 1773. Following this in rapid sequence, many methods and procedures were developed in this country and in Europe. Stillman[5] states that the first attempt to briquet coal in the United States was made by Loiseau[6] at Port Richmond Piers, Philadelphia, in 1872. The American briquetting processes outlined by Stillman comprise an imposing compilation of successes and partial and outright failures.

Early Bureau of Mines work on the problem of briquetting lower-rank coals was fairly extensive. Wright[7] conducted studies on beneficiation of such coals in the Geological Survey fuel-testing plant at St. Louis from 1904 to 1912. The purposes were: (1) to determine the percentage of pitch or other binder necessary to make satisfactory briquets out of the coals tested; (2) to investigate the relative merits of the different binders; (3) to provide briquets from run-of-mine coal for comparative combustion tests. He concluded that, as excessive moisture in fuel causes a waste of useful heat during combustion and is a source of expense to consumers who pay the freight on water, dried-lignite briquets would be worth 50 percent more than the raw fuel. Wright's observations indicated that lignite briquets resisted weathering much better than the raw fuel. The results of the producer-gas

---

4/ Franke, G., Handbuch der Brikettbereitung: Ferdinand Enke, Stuttgart, vol. 1, 1910 (trans. by Lountsberry, Chas., Griffin Co., Ltd., London, 1916).

5/ Stillman, A. L., Briquetting: Chemical Publishing Co., Easton, Pa., 1923, 466 pp.

6/ Loiseau, E. F., On the Manufacture of Artificial Fuel at Port Richmond, Pa.: Trans. Am. Inst. Min. Eng., vol. 6, 1877-78, pp. 214-220. The Successful Manufacture of Pressed Fuel at Port Richmond, Philadelphia, Pa.: Trans. Am. Inst. Min. Eng., vol. 8, 1879-80, pp. 314-320.

7/ Wright, C. L., Fuel-Briquetting Investigation: Bureau of Mines Bull. 58, 1913, 277 pp.

and steaming tests indicated that as gas-producer fuel the briquets were 43 percent more efficient and as boiler fuel 14.5 percent more efficient than raw lignite. Other investigations at the St. Louis fuel-testing plant on briquetting lignite are described in Geological Survey bulletins.8/ When the briquetting investigations were transferred to the Bureau of Mines at Pittsburgh in 1910, additional investigations on lignite were undertaken to determine the following:9/

1. The possibility of briquetting American lignites without binder.
2. The suitability of the German brown-coal-briquet presses for briquetting American lignites.
3. The moisture content necessary for producing good briquets.
4. The approximate cost of briquetting lignite.
5. The comparative weathering qualities of briquets and raw lignites.

The later work at Pittsburgh, reported by Wright,10/ was more extensive. This included studies on oth er coals, commercial briquetting processes, and types of binders, and more complete physical and chemical tests on the briquets, as well as practical combustion and water-gas machine tests. Following this, Babcock and Odell11/ and Hood and Odell12/ conducted briquetting investigations on lignite and lignite char in North Dakota. They concluded that carbonized lignite could be briquetted satisfactorily with

---

8/ Parker, E. W., Holmes, J. A., and Campbell, M. R., Preliminary Report on the Operations of the Coal-Testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904: Geol. Survey Bull. 261, 1905, 172 pp. Report on the Operations of the Coal-Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904: Geol. Survey Prof. Paper 48, 1906, 1492 pp.
Holmes, J. A., Preliminary Report on the Operations of the Fuel-Testing Plant of the United States Geological Survey at St. Louis, Mo., 1905: Geol. Survey Bull. 290, 1906, 240 pp. Report of the United States Fuel-Testing Plant at St. Louis, Mo., Jan. 1, 1906, to June 30, 1907: Geol. Survey Bull. 332, 1908, 299 pp.
Mills, J. E., Binders for Coal Briquets; Investigations Made at the Fuel-Testing Plant, St. Louis, Mo.: Geol. Survey Bull. 343, 1908, 56 pp.
Goss, W. F. M., Comparative Tests of Run-of-Mine and Briquetted Coal on Locomotives, Including Torpedo-Boat Tests and Some Foreign Specifications for Briquetted Fuel: Geol. Survey Bull. 363, 1908, 57 pp.

9/ Wright, C. L., Briquetting Tests of Lignite: Bureau of Mines Bull. 14, 1911, 64 pp.

10/ Wright, C. L., Fuel-Briquetting Investigations: Bureau of Mines Bull. 58, 1913, 277 pp.

11/ Babcock, E. J., and Odell, W. W., Production and Briquetting of Carbonized Lignite: Bureau of Mines Bull. 221, 1923, 82 pp.

12/ Hood, O. P., and Odell, W. W., Investigations of the Preparation and Use of Lignite, 1918 to 1925: Bureau of Mines Bull. 255, 1926, 204 pp.

12 percent binder and that a stable product with desirable weathering properties, comparable with higher-grade fuels, could be obtained.

The problems of briquetting coking and noncoking bituminous coals were studied systematically by Stansfield and Lang.13/ In recent years, these results have been used as a basis for establishing several briquetting plants in Canada.14/ These investigators showed the importance of equipment, binder, technique, and the physical and chemical properties of the coal.

A résumé of the art of briquetting is given in the Canadian publication entitled, "Fuel Briquetting."15/ It presents historical information, the present status of the art, and the results of briquetting tests at the Fuel Research Laboratories of the Canadian Department of Mines and Resources. The most recent American contribution to the subject of briquetting, though in a specialized portion of the field, has been prepared by Piersol16/ of the Illinois State Geological Survey.

Certain factors important in briquetting are summarized by Knight17/; portions are outlined below:

1. Slack for briquetting should be as clean as possible. The lower the ash and volatile content the better.
   - (a) High ash content requires greater percentage of binder, because binder will not adhere well to slate or other refuse materials.
   - (b) Low volatile content is desirable.
2. Binder should be well-dispersed, filling all void spaces of finely graded coal. Good sealing and bonding tend to produce a weatherproof briquet.
   - (a) Asphaltic residuums fill these requirements.
   - (b) Properly compounded briquet mixes require a minimum quantity of asphaltic binder.

13/ Stansfield, E., and Lang, W. A., Principles in the Briquetting of Coking and Noncoking Bituminous Coals: Proc. 20 Internat. Conf., Bituminous Coal, vol. 1, 1928 (November 19-24), pp. 508-526.

14/ Shanks, J., Practical Experience in the Briquetting of Bituminous Coking Coal: Trans. Canadian Inst. Min. and Met., vol. 45, 1942, pp. 15-26.

15/ Strong, R. A., Swartzman, E., and Burrough, E. J., Fuel Briquetting: Canadian Bureau of Mines, Mines and Geology Branch, No. 775, 1937, 100 pp.

16/ Piersol, R. J., Briquetting Illinois Coal without a Binder by Compression and Impact: Illinois State Geol. Survey, Rept. of Investigations 31, 1933, 70 pp. Briquetting Illinois Coal Without a Binder by Impact: Rept. of Investigations 37, 1935, 75 pp. I. Smokeless Briquets: Impacted Without a Binder from Partially Volatilized Illinois Coals. II. Smoke Index: A Quantitative Measurement of Smoke: Report of Investigations 41, 1936, 113 pp.

17/ Knight, J. L., What Factors Are Important in Briquetting: Coal Age, vol. 43, September 1938, pp. 34-35.

3. A good binder should not interfere with the attainment of desirable physical properties in the briquet.

4. Desirable properties of briquets are:
   (a) They should be of maximum density.
   (b) They should be tough to withstand handling shocks.
   (c) Heat value must not be decreased.
   (d) Ash content must not be increased.
   (e) Briquets should be smooth and regular in shape.
   (f) Briquets should retain shape and not disintegrate during storage or burning.
   (g) All desirable characteristics of raw coal should be retained, and actual improvement in quality of fuel should be obtained.

Briquetting Low-Rank Coals Without Binder

The problem of briquetting the low-rank coals is more complex than with the higher ranks. In Europe, the processing of brown coal has been a successful industry for many years; but when the German methods for briquetting brown coal without binder were applied to North American lignites, they did not prove entirely successful because of differences in the characteristics of the two types of lignite. Brown coal can be briquetted without binder because it contains natural bitumen that functions as a binder under elevated temperature and pressure. Most American lignites do not briquet successfully without added binder, though, as Wright[18/] pointed out, certain types from Texas, North Dakota, and California make satisfactory briquets. He found that lignites containing less than 1.5 percent of natural bitumen substance soluble in carbon disulfide could not be briquetted without additional binder. The general opinion is that certain classes of lignites may be briquetted without binder, and the briquets are superior to the raw fuel from which they are made, but they weather and do not remain intact in the fire as well as similar lignite briquets made with binder.

Coal is being briquetted without binder to some extent in the United States and Canada. Processes have been evolved that briquet coking coal heated to the plastic stage, and patent covering such a method has been granted to MacPherson.[19/] Goodrich[20/] describes the British plant of Pure Coal Briquettes, Ltd., which successfully briquetted South Wales steam coal with-

---

18/ Wright, C. L., Work cited in footnote 10.

19/ Mac Pherson, R. G., Compounded Smokeless Fuel: U. S. Patent 2,136,591, November 15, 1938.

20/ Goodrich, W. F., Utilization of Low-Grade and Waste Fuels: Ernest Benn, Ltd., London, 1924, p. 152.

out binder. Piersol's[21] recent work in this country may lead to a process for manufacturing briquets from Illinois bituminous coal without binder.

Briquetting Low-Rank Coals with Binder

Binders are used in virtually all American briquetting plants. By employing binders in the raw-coal briquetting mixes, it is possible to employ moderate compacting pressures that contribute to lower maintenance costs. than do high pressures. Probably this accounts for the limited work on the briquetting of low-rank coals at high pressure without binder.

Low-rank coals briquetted with binder have better weathering properties than raw coal because of the sealing action of the binder, which repels water and retards loss of moisture. The ability to withstand transportation shock is also generally improved. Achievement of desirable burning properties depends to some extent upon the choice of binder, but even the best binders do not eliminate deterioration in the fuel bed. During combustion the binder should not contribute much additional smoke to that produced by the coal, and it should be of such a nature as to retard disintegration of the briquet into fine coal during combustion. Numerous articles and papers have been written on the properties of binders for briquets. The Bureau's work as reported by Mills,[22] Pratt,[23] and Wright,[24] covering a number of types of materials, may be mentioned. The subject of binders has been reviewed more recently in the Canadian publication, Fuel Briquetting.[25]

Scope of Present Report

Briquetting investigations were undertaken at the Bureau of Mines, Field Office, Golden, Colo., during 1940-41 to determine the difference in properties of briquets made from steam dried and raw subbituminous coal and to study the briquetting of low-rank fuels. Fairly extensive work on the briquetting of low-rank coals had been done earlier by the Bureau; but at the time those investigations were undertaken, steam-dried coals were not considered, and modern petroleum-residuum binders were not employed.

21/ Piersol, R. J., Method of Briquetting Coal: U. S. Patent 2,021,020, November 12, 1935; See also footnote 16.

22/ Mills, J. E., Binders for Coal Briquets: Bureau of Mines Bull. 24, 1911, 56 pp. (reprint of Geol. Survey Bull. 343).

23/ Pratt, J. H., Acknowledgment to work in Bureau of Mines Bull. 24, p. 5.

24/ Wright, C. L., Work cited in footnote 10.

25/ Strong, F. A., Swartzman, E., and Burrough, E. J., Work cited footnote 15.

Investigations by the Bureau of Mines,[26] in cooperation with the University of North Dakota, have indicated that drying low low-rank coals with high-pressure steam might have advantages in briquetting. This process reduces the moisture of a typical lignite to about 8 percent; and the moisture in a subbituminous coal can be reduced to about 3 percent, improving the physical properties to some extent. The ability to absorb moisture is reduced, which in turn retards slacking. As this process removes moisture, thus stabilizing the coal, and delivers it heated to about 140°F., it was felt that steam drying could be used advantageously in briquetting subbituminous coal.

At the beginning of the study it was recognized that only small-scale laboratory research could be conducted with the funds and facilities available; therefore, the program of research on raw and steam-dried subbituminous coal was limited to the following objectives:

1. To determine the properties of cylindrical briquets made from raw and steam-dried coal, using four representative asphaltic binders.
2. To determine the properties of briquets made with different amounts of binder and to determine an optimum binder: coal ratio.
3. To determine the weathering properties of briquets made from raw and steam-dried subbituminous coal.
4. To determine the properties of briquets made from steam-dried and raw subbituminous coal after exposure to controlled accelerated weathering; to determine the effects of paraffin coatings.
5. To determine the comparative properties of briquets made from air-dried and steam-dried subbituminous coal.
6. To compare the properties of briquets made from subbituminous coal and from Pocahontas coal.
7. To determine certain physical and chemical properties of commercial briquets.

ACKNOWLEDGMENTS

The authors acknowledge the cooperation of D. H. Pape, president of the Sheridan-Wyoming Coal Co., from whose Monarch No. 45 mine the coal samples were taken; of L. C. Krchma of the Socony-Vacuum Oil Co. and E. Prostel of the Lehigh Briquetting Co. in supplying commercial binders;

26/ Harrington, L. C., Parry, V. F., and Koth, A., A Technical and Economic Study of drying Lignite and Subbituminous Coal by the Fleissner Process: Bureau of Mines Tech. Paper 633, 1942, 84 pp.
Parry, V. F., Harrington, L. C., and Koth, A., The Preparation of Stable Non-slacking Fuel by Steam-Drying Subbituminous Coal and Lignite: Trans. Am. Soc. Mech. Eng., August 1, 1941, 7 pp.

and of Dean L. C. Harrington of the University of North Dakota for assistance in steam-drying the coal samples. E. C. Beatty and J. D. Buhler, junior engineering aids, Bureau of Mines, Golden, Colo., assisted in making and testing briquets.

SOURCE OF MATERIALS

Binders - Through the cooperation of the Socony-Vacuum Oil Co. of Casper, Wyo., and the Lehigh Briquetting Co. at Dickinson, N. Dak., four commercial asphaltic binder materials were obtained for comparative tests. The chemical and physical properties of these binders are summarized in table 1. The first three binders listed are petroleum-residuum pitches that have been blended and processed to give desirable binder properties; the fourth is a commercial product used in North Dakota and is a blend of petroleum-residuum pitch with coal-tar pitch obtained from the carbonization of a North Dakota lignite. The exact proportions of the blend have not been revealed by the briquetting company, although it is stated that approximately two-thirds petroleum residuum and one-third lignite pitch are used; but these proportions are varied during different seasons.

Coal - The subbituminous-coal samples used in the briquetting investigations were obtained from the Monarch No. 45 mine of the Sheridan-Wyoming Coal Co. A standard seam sample and a large sample for steam drying and briquetting were taken from the same working face in the mine. A portion of the fresh coal was sent to Golden in sealed containers, and the balance was sent to the University of North Dakota for steam drying at 400 p. s. i. steam pressure. Table 2 gives the analysis of the fresh and steam-dried coal.

TABLE 1. - Properties of briquetting binders used in the investigation

Property 1/	Binders 2/			
	A	B	C	D
Viscosity at S.F. 275°F.........	74	330		
Penetration - 100/5/77	18	18	21	4
Softening point - ring and Ball, ... °F.	133	141	154	176
Flash - Cleve.Open Cup, .. °F.	470	610	650	
Ductility at 77°F./50 mm/min.	196+	194+	5.8	
Solubility in CCl_4.....percent	98.99	99.68		
Sp. gravity - 77°/77°............	1.1030	1.047	1.0331	
Proximate analysis, percent: - 3/				
Moisture	0.0	0.0	0.0	0.0
Volatile matter	71.30	76.30	72.30	73.80
Fixed carbon	28.63	23.66	27.40	25.50
Ash	.07	.04	.30	.70
	100.00	100.00	100.00	100.00

See footnote p. 8

TABLE 1. - Properties of briquetting binders used in the investigation (Cont'd.)

Property[1]	Binders[2]			
	A	B	C	D
Residue from volatile determination	Hard, coherent, brittle.	Flaky, thin plates, not dense or compact.	Hard, brittle, coherent.	Hard, glassy, compact.

1/ Physical properties of pitches supplied by Socony-Vacuum Co. and Lehigh Briquetting Co.
2/ A and B are asphaltic pitch binders, Wyoming refinery.
C is asphaltic pitch binder, Kansas refinery.
D is binder used for briquetting carbonized lignite in North Dakota.
3/ Proximate analysis of pitches made at Golden, Colo. Field Office, Bureau of Mines.

TABLE 2. - Analyses of raw- and steam-dried coal used in investigation

	Raw coal[1]		Steam-dried[1]	
	As received	Moisture-and ash-free	As received	Moisture-and ash-free
Moisture.......... percent	25.5		5.8	
Volatile matter.. Do	31.9	45.2	38.6	43.6
Fixed carbon .... Do	38.6	54.8	49.9	56.4
Ash .... Do	4.0		5.7	
B.t.u.	9,200	13,020	11,500	13,000

1/ Analyses made at Golden on freshly prepared samples just before briquetting. B.t.u. calculated from Pittsburgh analysis B-38443.

EQUIPMENT AND TECHNIQUE

At the start of the investigation no standardized techniques had been established for small-scale laboratory research on briquetting, and it was necessary to develop certain procedures. The following methods and testing techniques were adopted:

Preparation of Coal Samples and Binder

All coal samples were stored in sealed drums to avoid change in physical properties due to gain or loss of moisture. This precaution is necessary when the lower-rank fuels are handled. The coal was crushed to pass an 8-mesh Tyler, square-hole screen, and the size consist for briquetting was adjusted to meet the ideal Tyler-screen grading described in table 3:

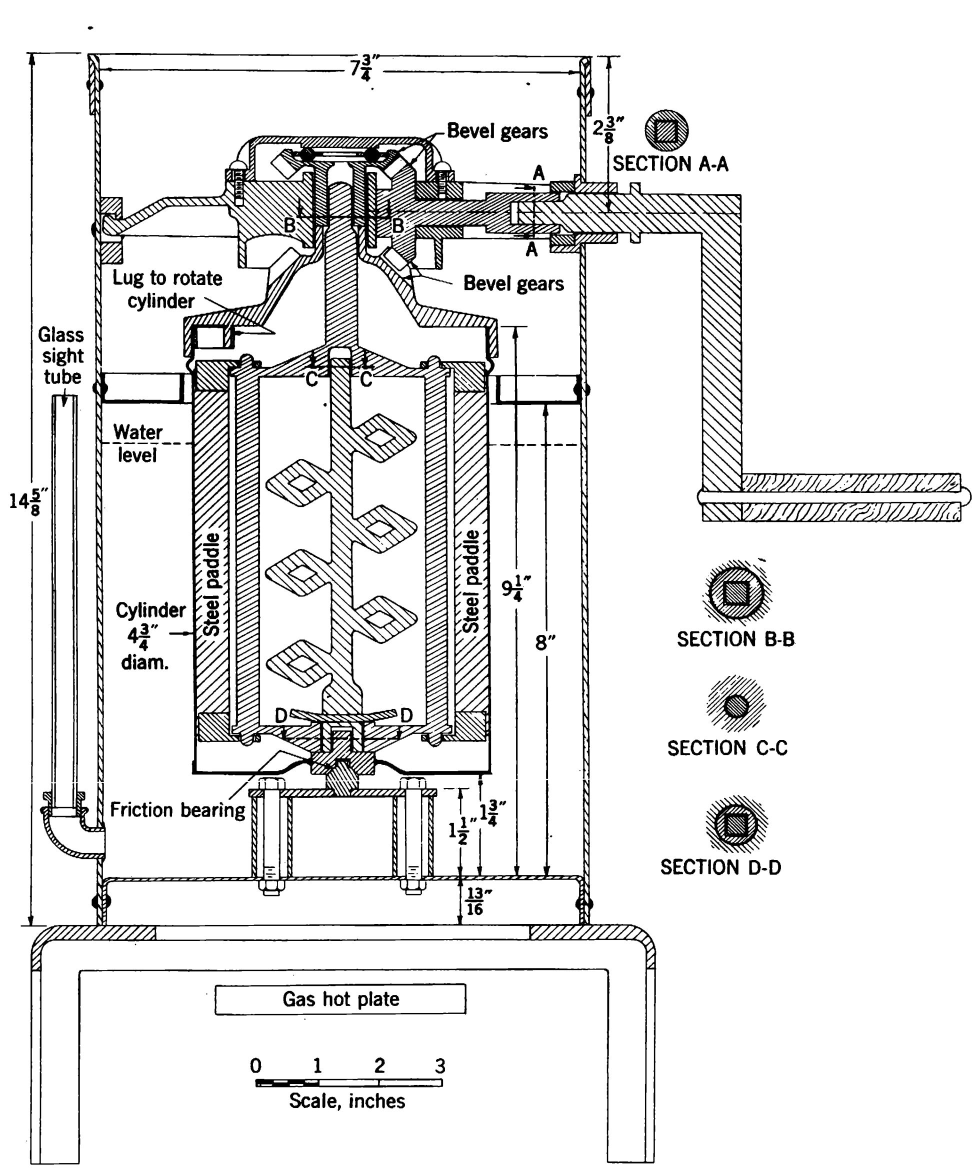


Figure 1.—Steam-jacketed mixer for fluxing briquet binder.

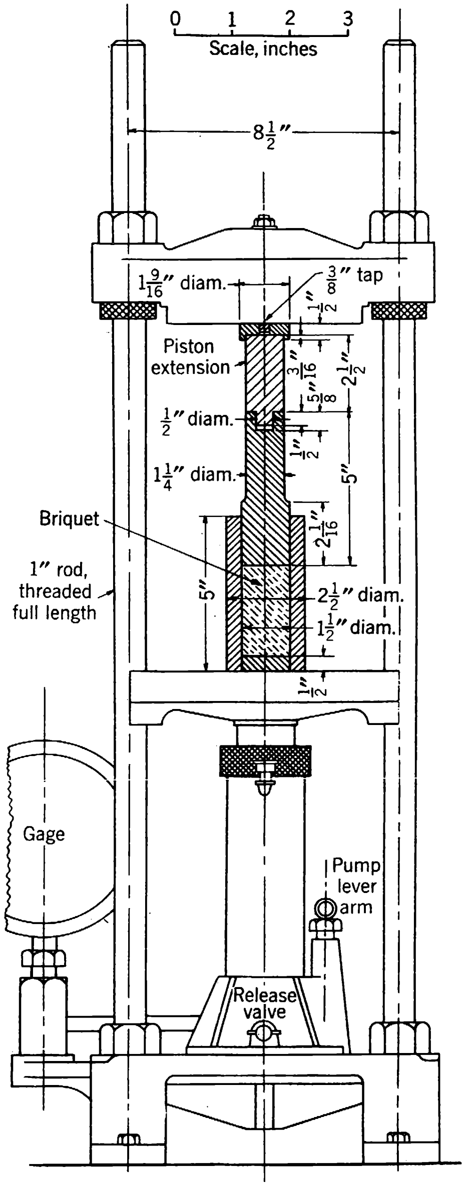


Figure 2.—Hydraulic press with cylinder and piston for forming cylindrical briquets.

TABLE 3. - Size consist of coal samples for briquetting tests

Tyler-screen scale	Percentage retained	Cumulative percentage retained
Passing 8 - retained on 14	50.0	50.0
Passing 14 - retained on 28	25.5	75.5
Passing 28 - retained on 48	12.5	88.0
Passing 48 - retained on 100	6.1	94.1
Passing 100	5.9	100.0

The binders were pulverized to pass 60-mesh Tyler, and the desired quantity was added to the coal by rolling and cutting with a knife.

Mixing Coal and Binder

The hot-water-jacketed mixer shown in figure 1 is of sufficient capacity to handle 600 grams of briquet mix. The inner container, with the mixing paddle and scraper, is easily removed from the jacket for charging and cleaning. A gear drive rotates the container in one direction, and mixing paddles and scrapers rotate in the opposite direction.

In preparing a briquet batch, the ingredients are heated and mixed at the temperature of boiling water for 15 minutes. During this operation, the crank is turned at a speed of about 40 revolutions per minute. When the operation is complete the paddle is removed, and the mixture is allowed to remain in the heated container until briquetted.

Making a Briquet

The plunger and mold used for forming the briquet are made from mild steel. The mold is a piece of seamless tubing (1-1/2 inches inside diameter and 2-1/2 inches outside diameter) equipped with a removable base plug, as shown in figure 2. The inside of the mold and the plunger were finely machined and polished to fit with 0.005-inch clearance. The mold and plunger as designed can make 1-1/2-inch-diameter briquets up to 4 inches in length.

The experimental briquets are approximately 2 inches long and weigh 70 grams (2-1/2 ounces). The heated mixture is placed in the hot mold with the aid of a short funnel and lightly compacted with a wooden plunger. The steel plunger is fitted, and forming pressure is applied by pumping up the hydraulic press to reach 10,600 pounds total pressure in 15 seconds, result-in a pressure of 6,000 pounds per square inch on the briquet. The pressure is maintained for 1 minute and then released slowly to avoid rupture of the briquet by expansion of compressed gases. The briquet is removed without damage by inverting the mold unit and piston extension, placing a 3-inch length of 2-inch pipe on the top of the mold, and forcing the briquet and plug into the free space of the pipe. The time required to make a briquet is about 3 minutes, and a batch of 50 can be made in 3 hours, including the weighing, mixing, and pressing. After each briquet is removed from the press, the inside of the hot mold and the piston surface are lubricated with a paraffin-saturated pad. Both the mold and piston are kept hot during operations by immersion in boiling water. Usually a batch of 50 briquets is required to provide enough for the several small- scale tests. The briquets are cooled at room temperature for 24 hours before testing.

Compressive Strength

These tests were made with the hydraulic press shown in figure 3. This equipment employs a converted automobile hydraulic jack, and bearing plates are attached to adapt to the sample. The top plate is fitted with a ball bearing to permit adjustment to minor differences in briquet dimensions. The compressive strength is indicated by hydraulic gages equipped with maximum hands. One gage measures pressure up to 750 pounds, and the other measures up to 2,500 pounds; each has a precision of 1/2 percent of total load. The gages are connected to the pressure cylinder by a 1/16-inch-diameter copper tube 18 inches long. This acts as a buffer and prevents injury to the gage when the briquet breaks. In making compressive strength tests, it was found desirable to test at least five briquets and report the average strength.

Apparent Specific Gravity

The apparent specific gravity was determined by using the buoyancy method of weighing a paraffin-coated briquet first in air and then in water. The weight of the uncoated briquet was initially determined, and the weight was then redetermined after lightly coating the briquet with molten paraffin by dipping. The density of the paraffin was determined to be 0.9. The following formula for apparent specific gravity was then used:

$$\text{App. sp. gr.} = \frac{Wa}{Wap - Wwp - \left(\frac{Wap - Wa}{0.9}\right)};$$

where Wa = weight of uncoated briquet in air,
Wap = weight of paraffin-coated briquet in air,
Wwp = weight of paraffin-coated briquet in water.

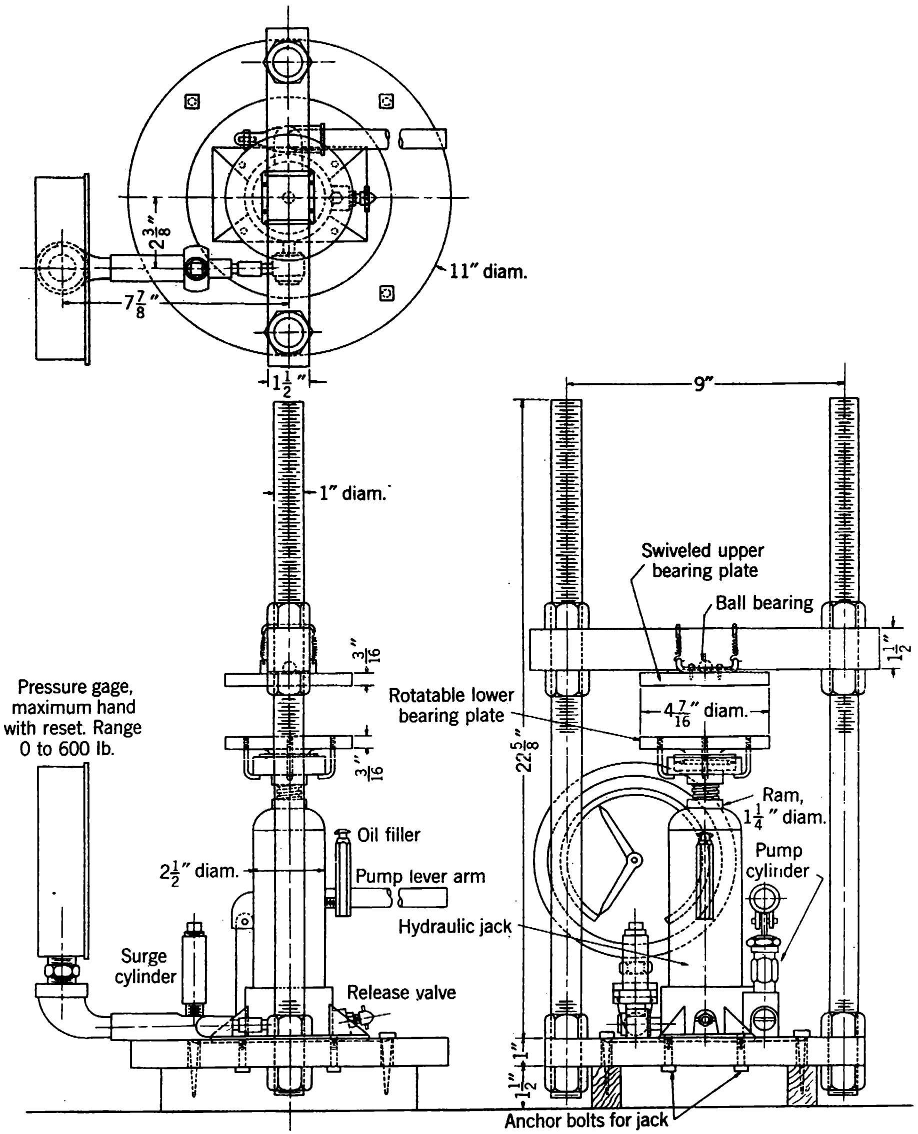


Figure 3.—Hydraulic compression briquet-testing machine.

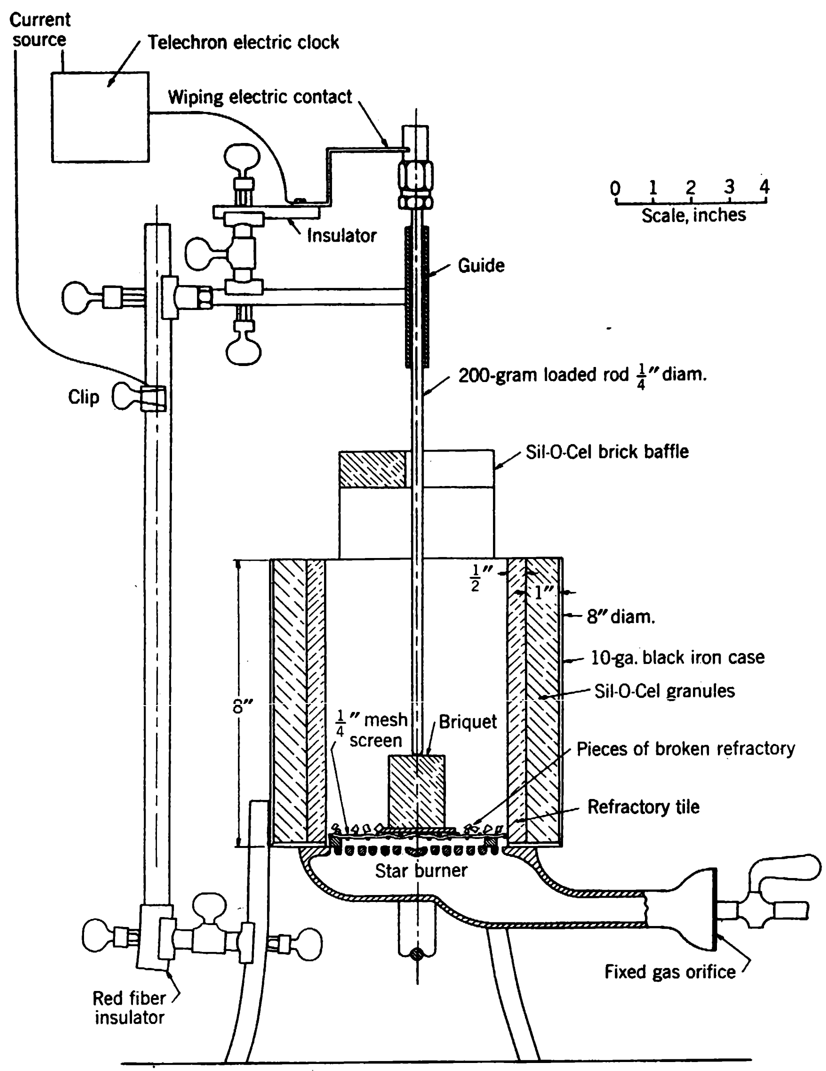


Figure 4.—Furnace for burning observations on coal briquets.

By careful weighing on a sensitive scale, the apparent specific gravity values so obtained are significant to the third figure.

Accelerated Slacking Test

During the early phases of the investigation, the accelerated slacking-test equipment 27/ was used to determine the improvement in slacking resistance resulting from briquetting. In this test, five briquets are dried for 24 hours in an oven held at 33°C. The air in the oven is circulated by a fan, and the relative humidity is maintained at 33 percent by means of a saturated solution of magnesium chloride. After 24 hours drying, the briquets are immersed in water for 1 hour and then returned to the oven to dry for another 24 hours. Following this, the samples are screened in a revolving trommel screen having 0.263-inch square-mesh openings. The screen is revolved 50 times during 1 minute, and the amount of material passing the openings (expressed as a percentage corrected for blank screening) is the slacking index.

Average subbituminous coal has a slacking index of 51, and it was expected that subbituminous-coal briquets would show some indications of slacking in the accelerated test. However, after extensive tests it was found that no significant effect could be observed until the binder content was reduced to about 4 percent. The test was abandoned for briquetted coal, and other tests to determine abrasion resistance were substituted.

Tumbler Tests

The standard tumbler test28/ for coal was found to be too severe. In this test, five briquets were tumbled for 1 hour (2,400 revolutions) in an 8-inch ball mill equipped with four lifters. The briquets suffered severe abrasion under this treatment, and the results were not significant. The number of revolutions was cut to 1,200 for 30 minutes. The amount of abrasion was first expressed as a percentage of material passing a 0.263-inch square-hole screen, but it was decided that this figure is not as significant for laboratory briquets as a figure expressing percent reduction in average size determined by a screen analysis. The latter figure is determined by screening the tumbled sample on 1.06-, 0.263-, and 0.047-inch square-hole screens. The average size of the briquets before tumbling was considered to be 1-1/2 inches. The average size after tumbling is the fraction held on 1.06 times

---

27/ Parry, V. F., and Goodman, J. B., Friability, Slacking Characteristics, and Low-Temperature Carbonization Assays of Subbituminous Coals of the Denver (Colo.) Region: Bureau of Mines Rept. of Investigations 3457, 1939, 12 pp.

28/ American Society for Testing Materials, Tumbler Test for Coal (D441-37T): A. S. T. M. Standards, 1939, pt. 3, Nonmetallic Materials, pp. 576-579.

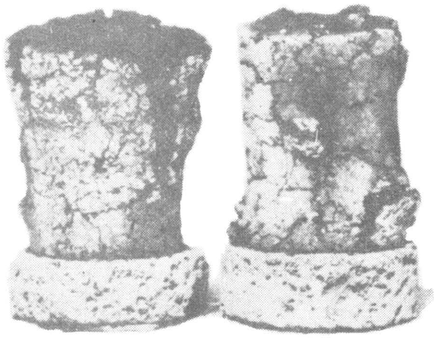
(1.06 + 1.5)/2, plus the fraction held between 1.06 and 0.263 times (1.06 + 0.263)/2, plus the fraction held between 0.263 and 0.047 times (0.263 + 0.047)/2, plus the fraction passing 0.047 times 0.047/2. Photographs of the abraded briquets were taken in some instances to reveal differences in briquets. A typical photograph of tumbled briquets is shown in figure 23.

Two variations of the tumbler test have been used by Canadian investigators.[29] The abrasion test (Sheffield) is made by revolving 2 cubic feet of briquets in a drum 18 inches in diameter by 18 inches in length for 30 minutes at a speed of 23 r. p. m. The material retained on a 1-1/2 inch square-hole screen is reported as the abrasion index, and the material passing through a 1/16-inch square-hole screen is reported as the dust due to abrasion. The test is an adaption of the Midland Coke Research Committee method of testing coke for abrasion. Its main disadvantage in testing laboratory briquets lies in the very large quantity required. The Fuel Research Laboratory ball-mill test is virtually the same as the A. S. T. M. tumbler test for coal and was used by the Fuel Research Laboratory for comparing briquets. The essential difference is found in the number and size of the screens employed to make the size separation after tumbling. The test was found to be more adaptable to small quantities of briquets.

Devolatilization - Burning Test

Conditions existing above a hot fuel bed were simulated with the apparatus shown in figure 4, which furnished information on (1) the initial devolatilization action, (2) the relative amount of volatile matter and loss due to spalling, (3) the physical structure of a devolatilized briquet, and (4) the time taken for a briquet to disintegrate under a fixed load when burning in air. The reason for adopting this test was to obtain information on the behavior of a noncoking briquet when exposed to conditions simulating those at the top of a glowing fuel bed. It was known that coking-coal briquets swell and burst like popcorn under these conditions, whereas noncoking briquets may disintegrate by pressure caused by volatilization of combustible matter (see fig. 5). It was also known that a briquet made from noncoking coal, such as subbituminous B, would disintegrate when small amounts of binder or improper binders were employed, whereas a briquet made with excess binder may disintegrate through forces resulting from devolatilization. The heating test devised is a practical method for studying the behavior of a briquet in a fire. It is not a precise test, and no scientifically accurate conclusions can be drawn from observations. It was valuable in comparing briquets under conditions simulating combustion or devolatilization.

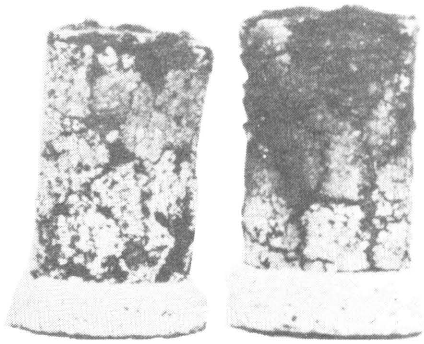
29/ Strong, F. A., Swartzman, E., and Burrough, E. J., Work cited in footnote 15.



Burning Until Volatile Matter
Is Driven Off

Monarch Raw Coal - 92%
S.V. Regular No. 17 Binder- 8%

11-Days Accelerated Weathering

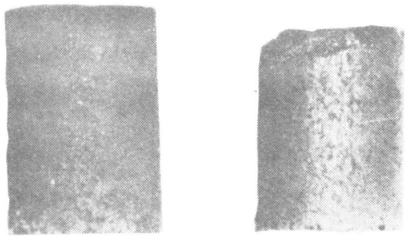


Burning Until Volatile Matter
Is Driven Off

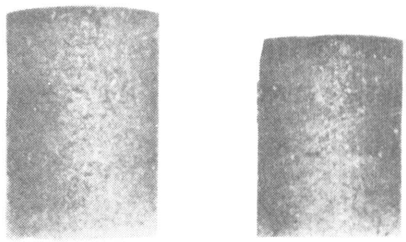
Monarch Steam-Dried Coal - 92%
S.V. Regular No. 17 Binder- 8%

11-Days Accelerated Weathering

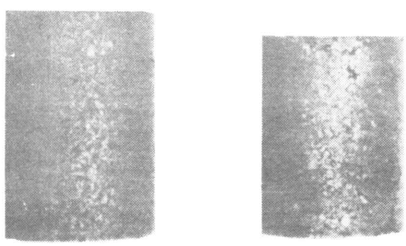
Figure 5.—Typical appearance of samples after devolatilization-burning test.



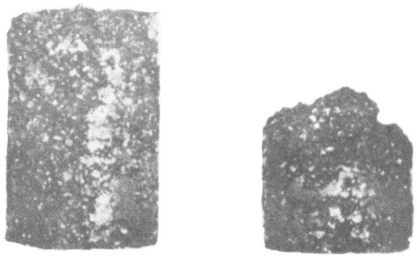
Steam-Dried Coal Raw Coal
10-Percent S.V. Reg.
No. 17 Binder



Steam-Dried Coal Raw Coal
10-Percent S.V. Spec.
No. 17 Binder



Steam-Dried Coal Raw Coal
10-Percent S.V.
Lignite Binder



Steam-Dried Coal Raw Coal
10-Percent Lehigh
(Comm.) Binder

Figure 6.—Weathered subbituminous-coal briquets made with commercial binders after 6 months outside exposure (see table 1 for properties).

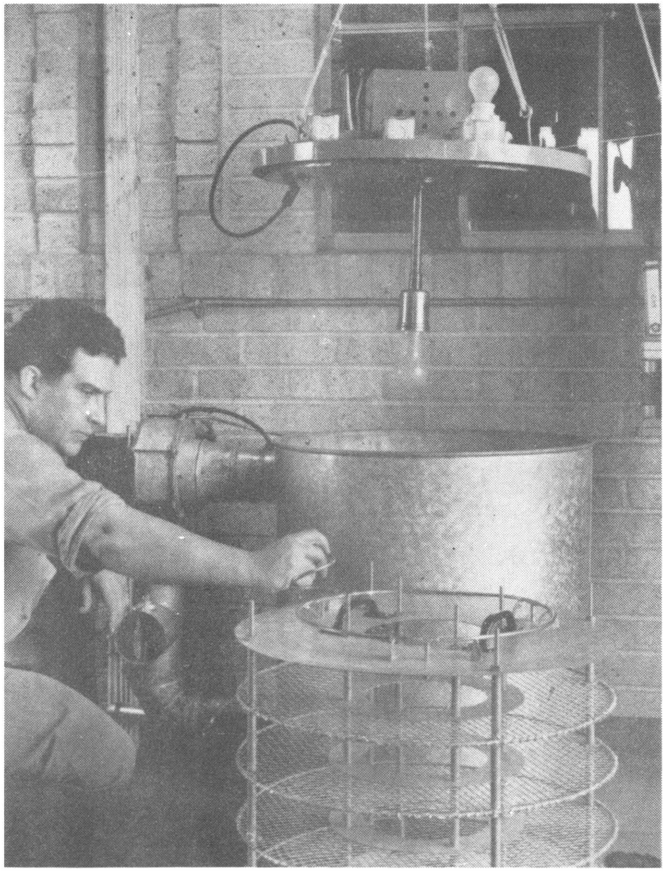


Figure 7.—Disassembled accelerated weathering apparatus.

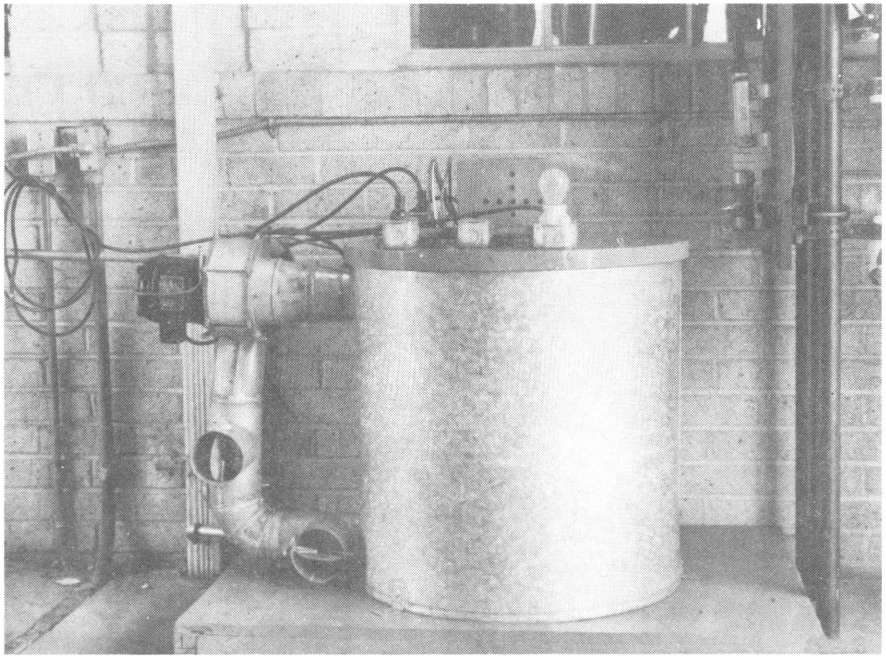


Figure 8.—Assembled accelerated weathering apparatus.

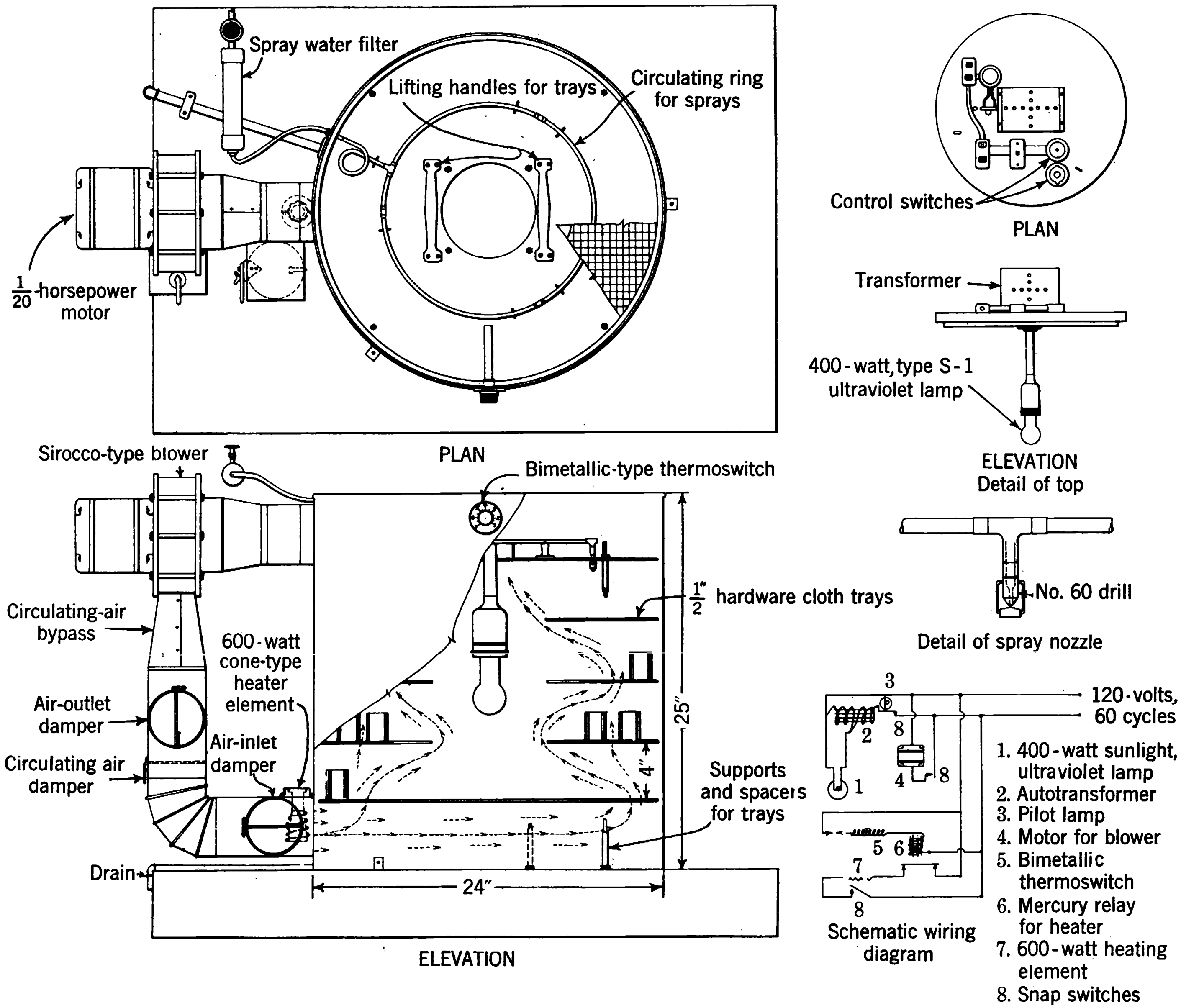


Figure 9.—Accelerated weathering apparatus for briquets.

The furnace walls and hearth are raised to a bright incandescent heat by burning a fixed quantity of gas for 1/2 hour. A weighed briquet is placed upon the hearth in the center of the refractory pot, and the time is noted. The volatile products in the briquet immediately begin to distill and burn with a luminous flame. The devolatilizing process and the accompanying smoke are observed until the luminous flame disappears. The time is noted, and the briquet is immediately removed and quenched in an atmosphere of CO_2. When cool, the devolatilized briquet is reweighed to estimate total loss, consisting of volatile matter, water, carbon, and spalling. Photographic records are made of the appearance of a briquet after this test. These provide a good comparison and show the expansion, fissuring, and spalling that may occur during devolatilization. Figure 5 shows a typical set of samples treated in this manner.

Observations were made on the action occurring when the briquet was allowed to burn in the furnace under a fixed load until disintegration. The primary heating or devolatilization was conducted in the same manner as outlined above; however, the briquet was not extracted and quenched but was left under load in the hot furnace in an atmosphere of hot air until it disintegrated. The time required for disintegration under these conditions is a rough measure of the quality of the briquet.

Normal and Accelerated Weathering

Satisfactory briquets must be able to stand the weather for a reasonable period, long enough to get them to consumers' bins. In some instances, briquet plants must store large quantities during the summer to meet winter demands or to maintain economical operation of the plant, and at times the briquets are exposed for 6 or 8 months. Subbituminous coal or lignite disintegrates rapidly in the raw state when exposed to the weather; hence, briquets made from these fuels are liable to have the same weakness, and a weathering test is desirable.

During the early part of the investigation, samples of briquets were exposed to normal outside weathering to find their weathering resistance. Small sheet-iron trays were constructed to hold eight briquets, and the samples were exposed on the roof of the laboratory. It was found that variable conditions and actual mechanical loss of dust by high winds affected the significance of weathering observations. The weathering test proved to be important, but further observations were confined to controlled accelerated weathering in special equipment.

The accelerated weathering apparatus shown in figures 7, 8, and 9 was devised. It supplies dry air, heat, ultraviolet radiation, and wetting under any cycle desired but does not include the effect of freezing. The ultraviolet radiation from a type S-1 mercury-vapor lamp at a distance of 15 inches is approximately nine times the intensity of a normal, midday, midsummer sun. The infrared radiation from the lamp, combined with the heat from a 500-watt heating coil, maintains a temperature of 130°F. during the heating cycle. A sirocco-type fan blower circulates air at the rate of 42 cubic feet a minute, giving a complete change of air every 9 seconds. The three atomizing spray heads in the top provide a fine mist of water, which wets all specimens on the shelves.

PHASES OF INVESTIGATION

When the study of briquetting subbituminous coal was begun, it was impossible to outline in detail all the phases to be investigated. As experience was gained and new techniques developed, it became necessary to repeat some work and to add new studies. Occasionally, it was impractical to repeat certain observations owing to the expense and time involved in preparing fresh samples and in making up new batches of briquets from limited base samples. Therefore, the different phases of the work were more or less independent of the others, and they constitute units of study. The experimental work covered about 1 year and was divided into seven phases of study:

1. Comparative Briquetting Properties of Steam-Dried and Raw Subbituminous Coal, Using Various Commercial Binders

The object of this series of tests was to select the most satisfactory binder of the four described in table 1. Fresh and steam-dried subbituminous coals of uniform screen analysis, meeting the Tyler ideal grading, were briquetted with 10 percent of each binder.

The properties of the freshly made briquets were determined, and 10 briquets of each coal and type of binder were subjected to the accelerated-slacking test. Five of these were used to determine the slacking index, and five were used for compressive strength tests.

Five briquets of each coal and type of binder were subjected to normal outside weathering for 6 months. During the early part of the period, the temperature was sometimes below freezing, but in the latter part it was quite warm, with occasional rains.

Considering the experimental data presented in table 4 and figure 10, it appears that the properties of the steam-dried and raw coal briquets prepared with binder A generally are superior to those made from the other binders. The compressive strength of fresh briquets made from raw coal with binder A is 60 percent greater than the average strength of briquets made with the

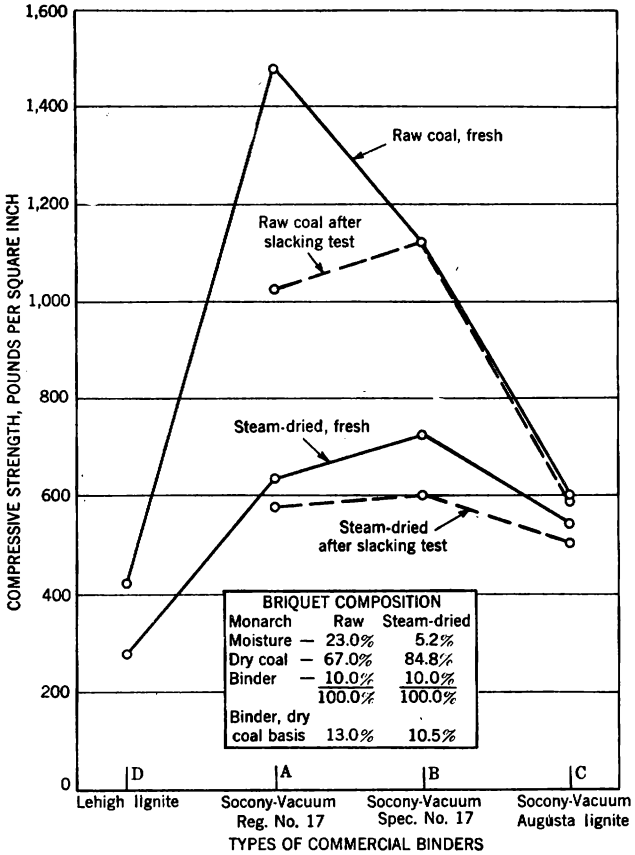


Figure 10.—Compressive strength of briquets made with four commercial binders before and after exposure to accelerated slacking test.

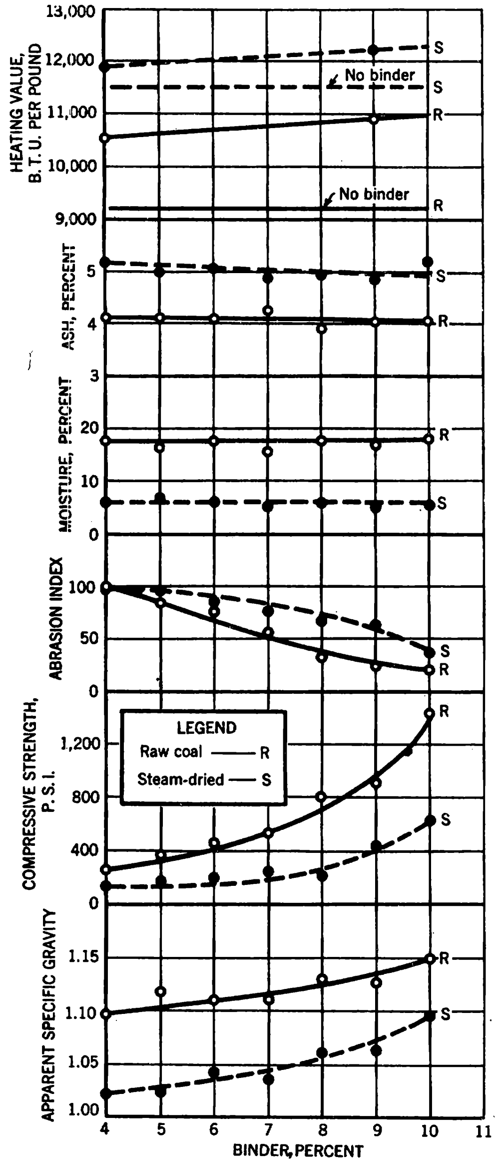


Figure 11.—Properties of fresh briquets made from raw and steam-dried subbituminous coal.

four binders, and the compressive strength of the original fresh steam-dried briquets made with binder A is 17 percent greater than the average. Similarly, the compressive strength of the raw-coal briquets after slacking is 12 percent greater than the average, and the strength of the steam-dried coal briquets is about 3 percent greater. However, briquets made in batches 5 and 6 with binder B, except for the fresh raw briquets, have compressive strengths higher than the corresponding values for briquets made with binder A. The appearance of weathered briquets prepared from the four binders is shown in figure 6. Although the appearance of those made with binder B was better after 6 months' outside exposure, the properties of unweathered briquets were not superior to those made with binder A. Binder B is especially compounded; it is more viscous and has a higher melting point than binder A. Considering all factors, including its easier procurement, binder A was judged the best and was chosen as the standard for all succeeding briquetting tests.

2. Amount of Binder Required

Briquet mixtures were prepared, using raw and steam-dried subbituminous coal in the as-received condition with proportions of binder A ranging from 4 to 10 percent. All briquets were made under the standardized conditions previously described.

Less than 4 percent of binder A did not make coherent briquets, while quantities exceeding 10 percent were not considered advisable despite probable improvement in some physical characteristics. Furthermore, a high concentration of binder might mask characteristic differences of the raw and steam-dried coal. Therefore, observations were confined to binder concentrations ranging from 4 to 10 percent.

The results of the tumbler, compression, burning, and weathering tests were the basis for judging the effects of binder concentration. Figure 14 indicates that 8 percent of binder is the minimum that gives good resistance to weathering. The briquets containing 9 and 10 percent of binder show some weathering, while those containing less than 8 percent are inferior in weathering resistance. The residues from the tumbler tests indicate that less than 8 percent binder weakened the briquet structure, while the improvement derived from more than 8 percent was minor. There is no sharp change in properties as binder concentration increased, but it appeared from all observations that about 8 percent of binder is required to make satisfactory briquets from either steam-dried or raw subbituminous coal.

TABLE 4 - Properties of 1-1/2-inch by 2-inch cylindrical briquets made from steam-dried and raw subbituminous coal, using 10 percent of various asphaltic binders

Binder used 1/	A		B		C		D	
Batch number	3	4	5	6	7	8	1	2
Coal	St.-dried	Raw	St.-dried	Raw	St.-dried	Raw	St.-dried	Raw
Apparent specific gravity of briquet	1.10	1.16	1.09	1.165	1.101	1.166	1.025	1.15
Compressive strength of fresh briquet ... p.s.i.	638	1,435	724	1,121	543	603	279	428
Compressive strength of briquet after slacking test, ... p.s.i.	578	1,025	602	1,120	508	588	-	-
Corrected slacking index 2/	.00	.03	.00	.00	.00	.00	.0	2.4
Time for devolatilization ... minutes	23	25	20	22	18	21	21	20
Time for burning briquet to break under 200-gram load ... hours	.10	2.1	.25	.22	.06	.16	2.5	2.6
Loss during burning test ... percent	43.8	55.9	46.0	57.5	46.7	55.2	45.9	55.9
Volatile matter ... Do	42.8	36.9	43.0	38.6	42.6	39.1	42.8	39.3
Moisture ... Do	5.6	18.4	4.9	17.7	5.0	15.5	5.1	16.4
Ash ... Do	5.3	4.1	4.8	4.2	4.9	4.1	5.3	4.0

1/ Refer to table 1 for properties.
2/ See Report of Investigations 3457.

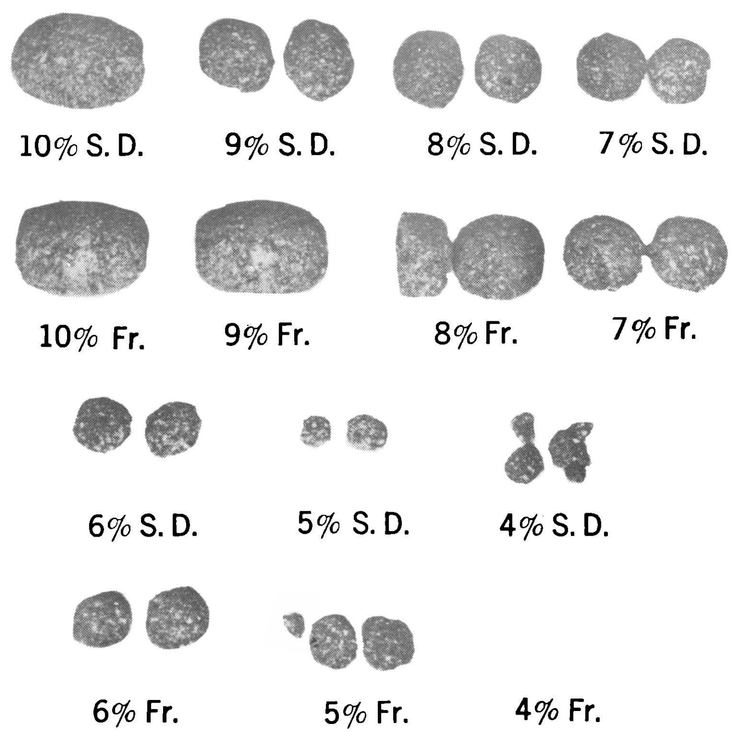


Figure 12.—Appearance of steam-dried and raw-coal briquets after tests in standard tumbler apparatus (2,400 revolutions in 1 hour); binder A, 4 to 10 percent.

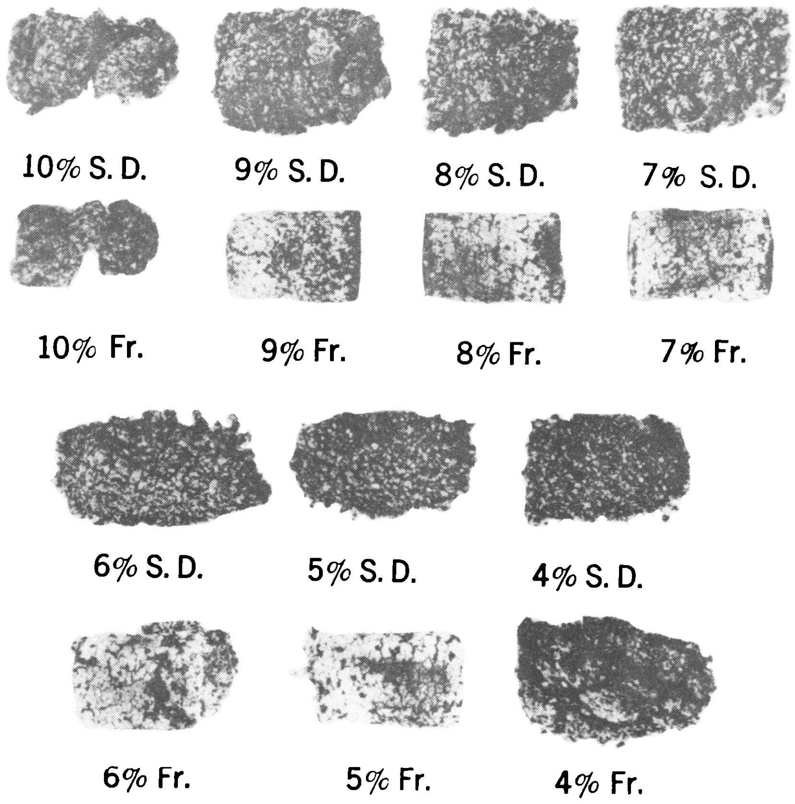


Figure 13.—Residues of steam-dried and raw-coal briquets after burning tests; binder, 4 to 10 percent.

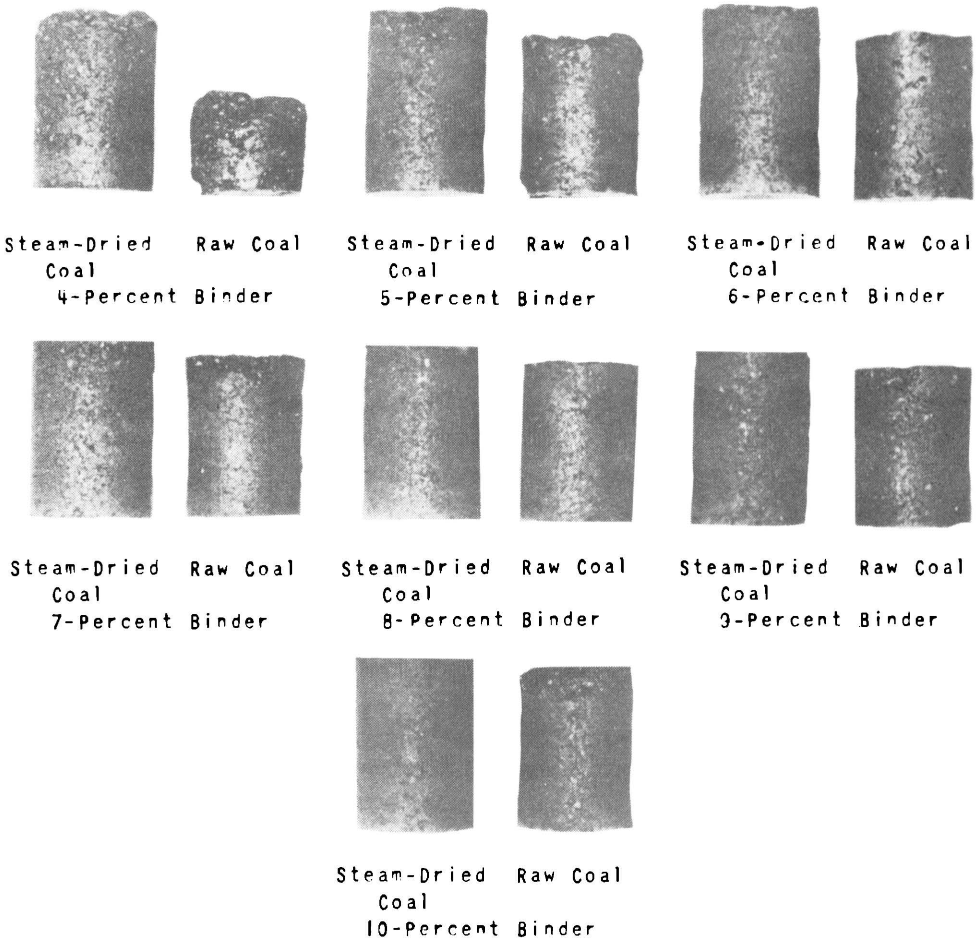


Figure 14.—Effect of outside weathering on steam-dried and raw-coal briquets after 6 months exposure.

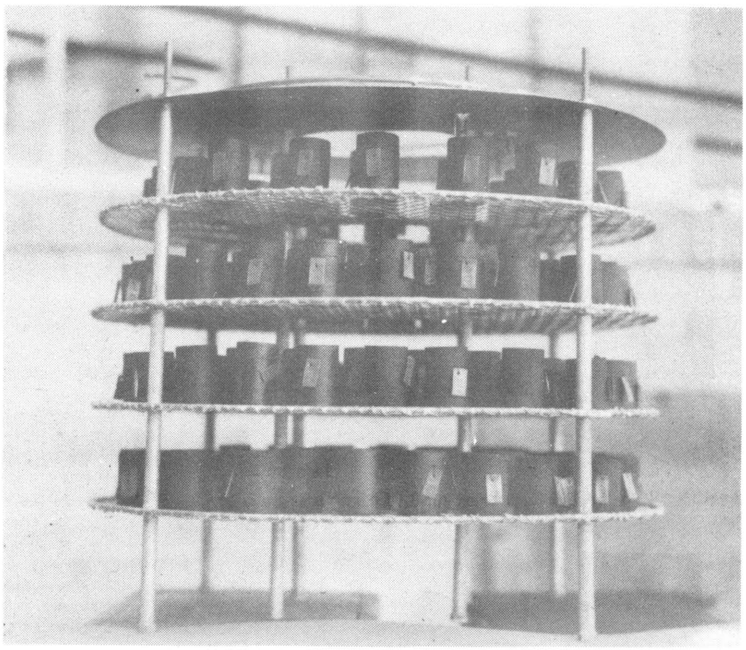


Figure 15.—Arrangement of raw and steam-dried coal briquets on shelves of accelerated weathering apparatus.

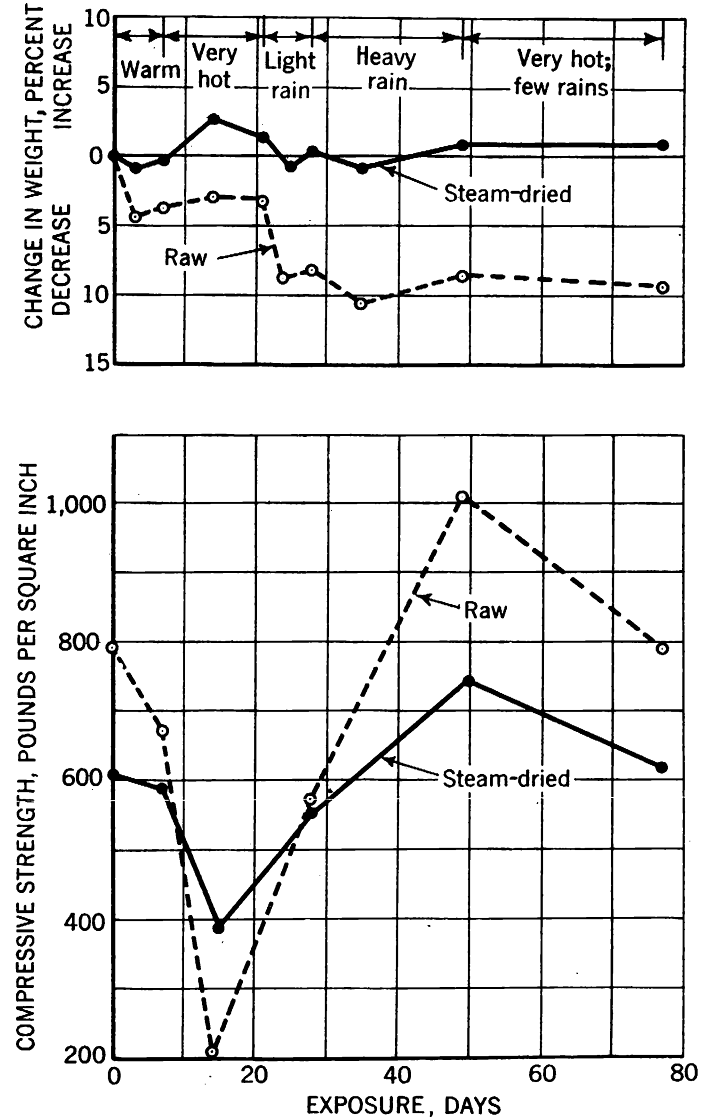


Figure 16.—Influence of 77 days continuous weathering of briquets from May 26 to August 11, 1941.

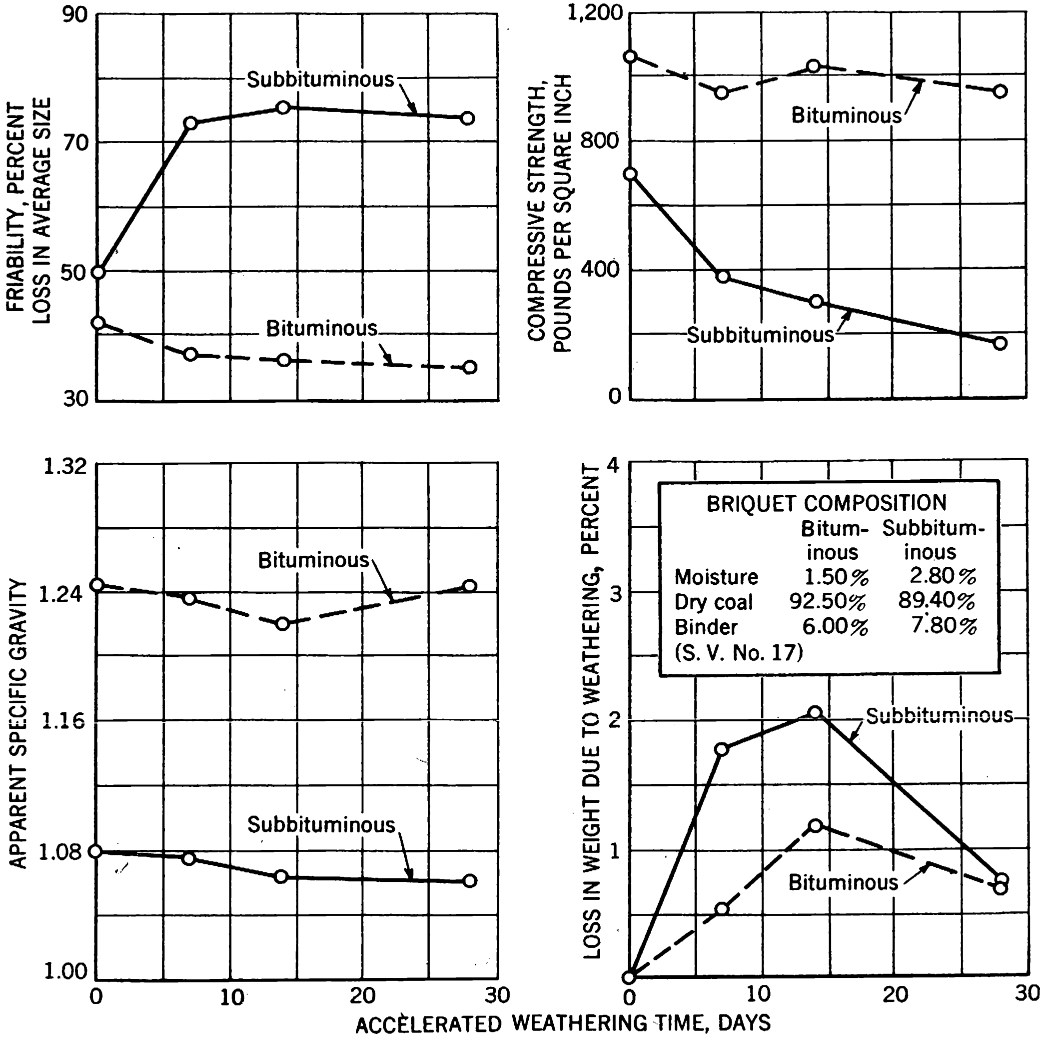


Figure 17.—Physical properties of air-dried Monarch (Wyo.) subbituminous-coal briquets and Pocahontas No. 4 bituminous-coal briquets as influenced by 28 days accelerated weathering.

Tables 5 and 6 give properties of the briquets made in this series. The abrasion test used in the first study was replaced by a modified tumbler test for coal. Five briquets, weighing approximately 350 grams, were used, and the index is expressed as the percentage of material passing the 0.263-inch square-hole screen after 2,400 revolutions of the tumbler.

Figure 11 shows the properties of fresh briquets made with different amounts of binder. The appearance of the briquets after the tumbler test is shown in figure 12, and figure 13 compares them after the devolatilization test. The effect of 6 months outside weathering is shown in figure 14. It was concluded that 8 percent binder is required to briquet subbituminous coal.

3. Properties of Subbituminous-Coal Briquets after Exposure to Normal Weathering

The purpose of this phase of the investigation was to study the weathering of a number of briquets over a prolonged period, using a larger sample than was previously employed. The briquetting material was taken from the base samples of raw and steam-dried coal and prepared in the standardized manner. Weights of two groups, each consisting of 10 briquets made from raw and steam-dried subbituminous coal with 8 percent of binder A, were determined at 10 intervals over a 77-day weathering period. Paralleling the weight-loss measurements during this period, samples were removed weekly for a determination of the compressive strength.

From the data in table 7 and figure 16, several interesting trends appear. The percentage change in weight of raw-coal briquets, from loss of moisture, probably is due to the high initial moisture content of the raw coal (24.8 percent compared with 7.6 percent for steam-dried coal). Even though the density of the raw briquets was higher than that of the steam-dried (1.133 compared with 1.061), the fissuring and cracking due to weathering were more pronounced and provided a freer passage for moisture. The weight of the steam-dried coal briquets fluctuated during the weathering period but was essentially constant at the end of 77 days. The appearance of these briquets confirmed this, as they showed a minimum of surface cracking or spalling.

During the hot periods the compressive strength decreases, and during the wet periods it tends to increase. The average compressive strength of raw-coal briquets was 735 p.s.i. during the weathering period, and the compressive strength of steam-dried coal briquets was 620 p.s.i., obtained by integrating the areas under the compressive strength curves in figure 16.

It was concluded from all observations during this period that steam-dried coal briquets withstand outside weathering better than do raw-coal briquets.

TABLE 5. - Properties of cylindrical briquets made from steam-dried and raw subbituminous coal with different amounts of binder 1/

Batch number	3	4	9	10	11	12	13	14
Coal 2/	St.-dried	Raw	St.-dried	Raw	St.-dried	Raw	St.-dried	Raw
Coal ....percent	90	90	91	91	92	92	93	93
Binder .... Do	10	10	9	9	8	8	7	7
Apparent specific gravity of briquet	1.098	1.151	1.066	1.130	1.061	1.133	1.036	1.113
Compressive strength of briquet .... p.s.i.	638	1435	448	949	225	810	267	552
Compressive strength of briquet after slacking test.... p.s.i.	578	1025	336	711	182	544	250	526
Abrasion loss .... percent, A.S.T.M. 3/	39.8	23.3	63.4	27.0	68.9	34.8	77.2	50.3
Corrected slacking index	.00	.03	.00	.00	.00	.00	.00	.10
Time for devolatilization .... minutes	23	25	19	22	19	22	18	21
Time for burning briquet to break under 200-gram load .... hr.	.10	2.1	.16	2.83	.20	3.33	.17	2.33
Loss during devolatilization....percent	43.8	55.9	45.1	54.3	45.3	53.1	44.6	53.0
Volatile matter .... Do	42.8	36.9	41.8	37.6	40.4	37.1	40.5	37.6
Moisture .... Do	5.6	18.4	5.4	17.2	5.6	17.5	5.6	15.5
Ash .... Do	5.3	4.1	4.6	4.1	4.8	3.8	4.6	4.5

1/ Binder A used, Wyoming refinery.

2/ Coal from Monarch mine, Sheridan-Wyoming Coal Co. All coal samples graded to Tyler ideal screen analysis, described in table 3.

3/ Percentage of material passing 0 263-inch screen after tumbling in A.S.T.M. tumbler apparatus for 1 hour (2,400 revolutions).

TABLE 5. - Properties of cylindrical briquets made from steam-dried and raw subbituminous coal with different amounts of binder (cont'd.)1/

Batch number	15	16	17	18	19	20
Coal 2/	St.-dried	Raw	St.-dried	Raw	St.-dried	Raw
Coal ... percent	94	94	95	95	96	96
Binder ... Do	6	6	5	5	4	4
Apparent specific gravity of briquet..	1.044	1.106	1.026	1.118	1.024	1.097
Compressive strength of briquet ... p.s.i.	199	474	180	390	135	252
Compressive strength of briquet after slacking test... p.s.i.	138	448	155	342	68	135
Abrasion loss... percent, A.S.T.M.3/	87.0	75.4	96.0	85.0	98.6	100.0
Corrected slacking index ...	.00	.00	.90	2.30	2.60	8.80
Time for devolatilization ... minutes	18	21	19	23	20	24
Time for burning briquet to break under 200-gram load ... hr.	.33	2.0	.20	2.5	.15	1.83
Loss during devolatilization..percent	44.5	53.3	43.2	52.4	41.5	52.9
Volatile matter ... Do	40.6	35.9	40.5	36.7	40.2	36.8
Moisture... Do	5.7	17.3	6.3	16.2	6.2	17.3
Ash ... Do	5.1	4.1	5.0	4.2	5.3	4.2

1/ Binder A used, Wyoming refinery.
2/ Coal from Monarch mine, Sheridan-Wyoming Coal Co. All coal samples graded to Tyler ideal screen analysis, described in table 3
3/ Percentage of material passing 0.263-inch screen after tumbling in A.S.T.M. tumbler apparatus for 1 hour(2,400 revolutions).

TABLE 6. - Effect of varying percentage of binder on physical properties of cylindrical briquets made from raw and steam-dried coal

Percentage of binder	Compressive strength, p.s.i.		Comp. strength after slacking test, p.s.i.		Apparent specific gravity		Abrasion index	
1	2		3		4		5	
	Raw	St.-dried	Raw	St.-dried	Raw	St.-dried	Raw	St.-dried
4	252	135	135	68	1.097	1.024	100.0	98.6
5	390	180	342	155	1.118	1.026	85.0	96.0
6	474	199	448	138	1.106	1.044	75.4	87.0
7	552	267	526	250	1.113	1.036	50.3	77.2
8	810	225	544	182	1.133	1.061	34.8	68.9
9	949	448	711	336	1.130	1.066	27.0	63.4
10	1435	638	1025	578	1.151	1.098	23.3	39.8

Col. 1 - Commercial binder A.
Col. 2 - Hydraulic compression test, end-loaded specimens.
Col. 3 - Hydraulic compression test, after slacking test according to Report of Investigations 3457.
Col. 4 - Apparent specific gravity by buoyancy method (weighing in air and water), using paraffin film to seal briquet surface.
Col. 5 - Determined on 5 briquets, using equipment for A.S.T.M. tumbler test, D441-37T. Percentage of material passing 0.263-inch, square-hole screen opening, after tumbling for 1 hour (2,400 revolutions).

TABLE 7. - Influence of 77 days weathering on weight loss and compressive strength of raw and steam-dried subbituminous-coal briquets

	Raw-coal briquets3/									
Exposure .... days	0	3	7	14	21	24	28	35	49	77
Average weight ..grams	67.1	64.1	64.5	65.1	64.9	61.2	61.6	60.0	61.3	60.8
Change in weight .... percent 1/	.0	-4.5	-3.9	-3.0	-3.3	-8.8	-8.2	-10.6	-8.7	-9.4
Compressive strength p.s.i.2/	795	-	675	210	-	-	575	-	1010	790

See footnote on p. 21.

TABLE 7. - Influence of 77 days weathering on weight loss and compressive strength of raw and steam-dried subbituminous-coal briquets (Cont'd)

	Steam-dried coal briquets3/									
Average weight..grams	71.5	70.9	71.3	73.4	72.5	70.9	71.6	70.6	72.3	72.4
Change in weight percent1/	0.0	-.8	-.3	+2.7	+1.4	-.8	+.1	-1.3	+1.1	+1.3
Compressive strength p.s.i.2/	610	-	590	390	-	-	555	-	740	620

1/ Percent change in weight based on original weight at 0 day exposure. Expressed as cumulative percent increase (+) or decrease(-) from original weight.
2/ End-loaded cylindrical specimens.
3/ It was observed that the moisture content of the raw coal had decreased to 24.8 percent and that of the steam-dried coal had increased to 7.6 percent during storage and handling of sample.

4. Effects of Accelerated Weathering on Properties of Briquets and Benefits of Paraffin as a Protective Coating

The briquets prepared for this study were made from as-received raw and steam-dried coal with 8 percent of binder A. As in all previous work, they were 1-1/2 inches in diameter and about 2 inches in length, compacted at 6,000 p.s.i. and 200°F. One hundred briquets were made from each coal, and 25 of these were coated with a special paraffin wax having a high melting point. The object of coating with paraffin was to determine whether physical properties or resistance to weathering would be improved.

The briquets were placed on the shelves of the weathering apparatus (fig. 15) and subjected to the following daily cycle of accelerated weathering for 100 days:

1. 20-hour period, employing ultraviolet radiation and hot air circulated at 130°F.
2. 1-hour cooling period, bringing briquet samples down to about room temperature by circulating air through the apparatus.
3. 3-hour wetting period by a spray of water at room temperature.

It is estimated that the accelerated weathering procedure is approximately three times as severe as normal outside exposure. Furthermore, it can be controlled and is a valuable tool for study of properties of low-rank fuels.

At the end of the fourth, eleventh, twenty-fifth and fifty-third days, 15 plain and 5 paraffin-coated briquets were removed for testing. Fifteen plain and 5 paraffin-coated briquets of both coals remained after 53 days, and these were exposed for an additional 7 weeks before complete disintegration. The results of these observations are presented in table 8 and in figures 18, 19, 20, and 22. The tumbler test for this series was run for 1,200 revolutions in 1/2 hour in the A.S.T.M. apparatus instead of 2,400 revolutions in 1 hour as was done previously.

The protective effect of the paraffin and the severe degradation suffered by the untreated briquets are indicated in figure 22. Although paraffin coating protects a briquet from wetting, it was noted that paraffin dissolves the binder and weakens the surface. This is indicated by the compressive strength of samples weathered less than 25 days. Figure 23 shows the extent of breakdown suffered by the briquets after the tumbler test. The chemical analyses of samples-removed after each weathering period show the extent of degradation induced by accelerated weathering. These data are presented in table 9.

The data in table 8 and figure 18 indicate that paraffin coating on raw or steam-dried subbituminous-coal briquets does not improve their strength. The purpose of this coating was to reduce the effect of weathering, and it was effective to some extent during the latter part of the weathering period. It should be noted that the strength of the paraffin-coated specimens always is lower than that of a corresponding uncoated specimen. This is explained by the penetration of the paraffin into the briquet, where it exerts a solvent or softening action on the binding material. Inspection of the fractured area of a coated briquet revealed that paraffin penetrates about 1/4 inch from all outside surfaces, dilutes, and softens the binder, thus weakening the structure.

The compressive strength of raw-coal briquets, either plain or coated with paraffin, is higher than that of steam-dried coal briquets, but the raw-coal briquets appear to change more during accelerated weathering. In other words, the steam-dried coal briquets appear to be more stable, although they are weaker when subjected to compression. During 53 days of weathering, the average strength of the plain raw-coal briquets was 312 p.s.i., and the average strength of the plain steam-dried coal briquets was 218 p.s.i., while paraffin-coated raw-coal briquets had an average compressive strength of 278 p.s.i. compared with 183 p.s.i. for coated steam-dried coal briquets. These averages were obtained by integrating curve areas in figure 18.

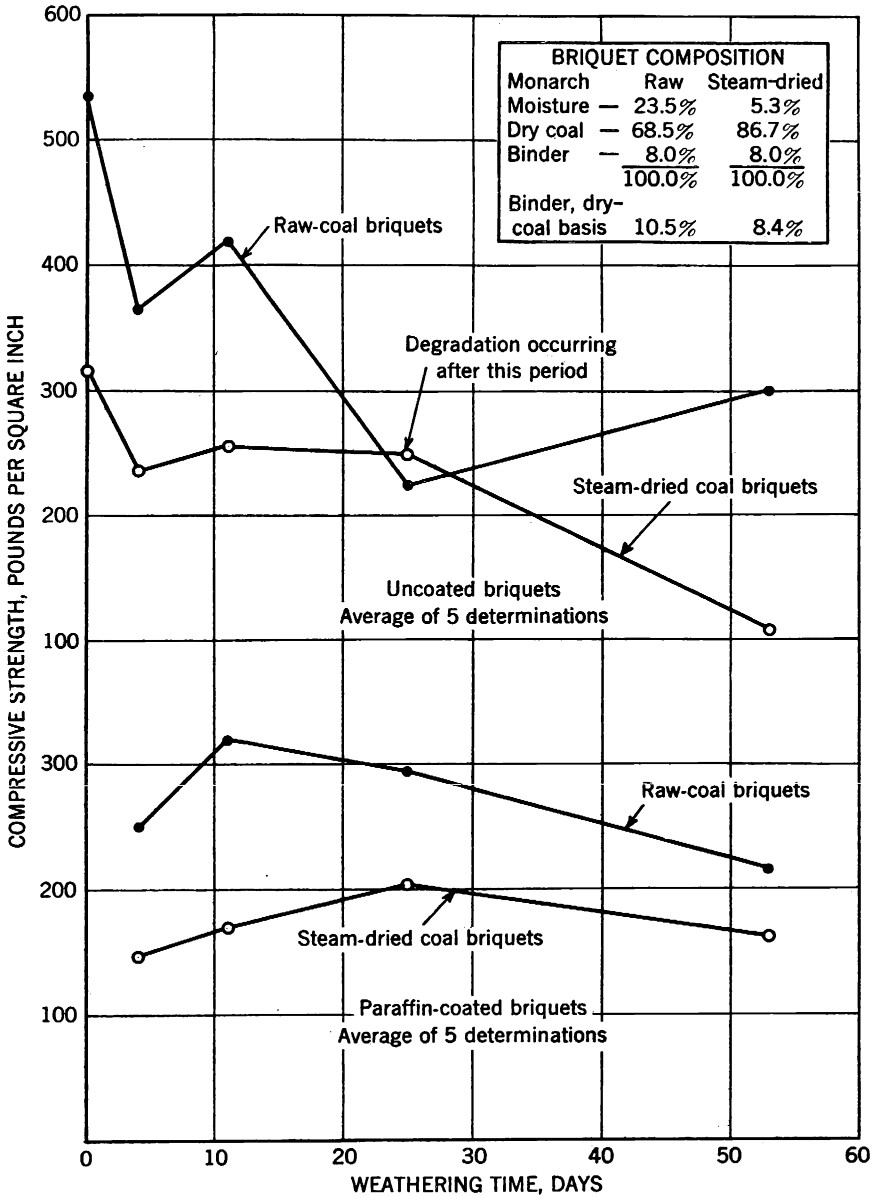


Figure 18.—Effect of accelerated weathering on compressive strength of raw and steam-dried subbituminous-coal briquets.

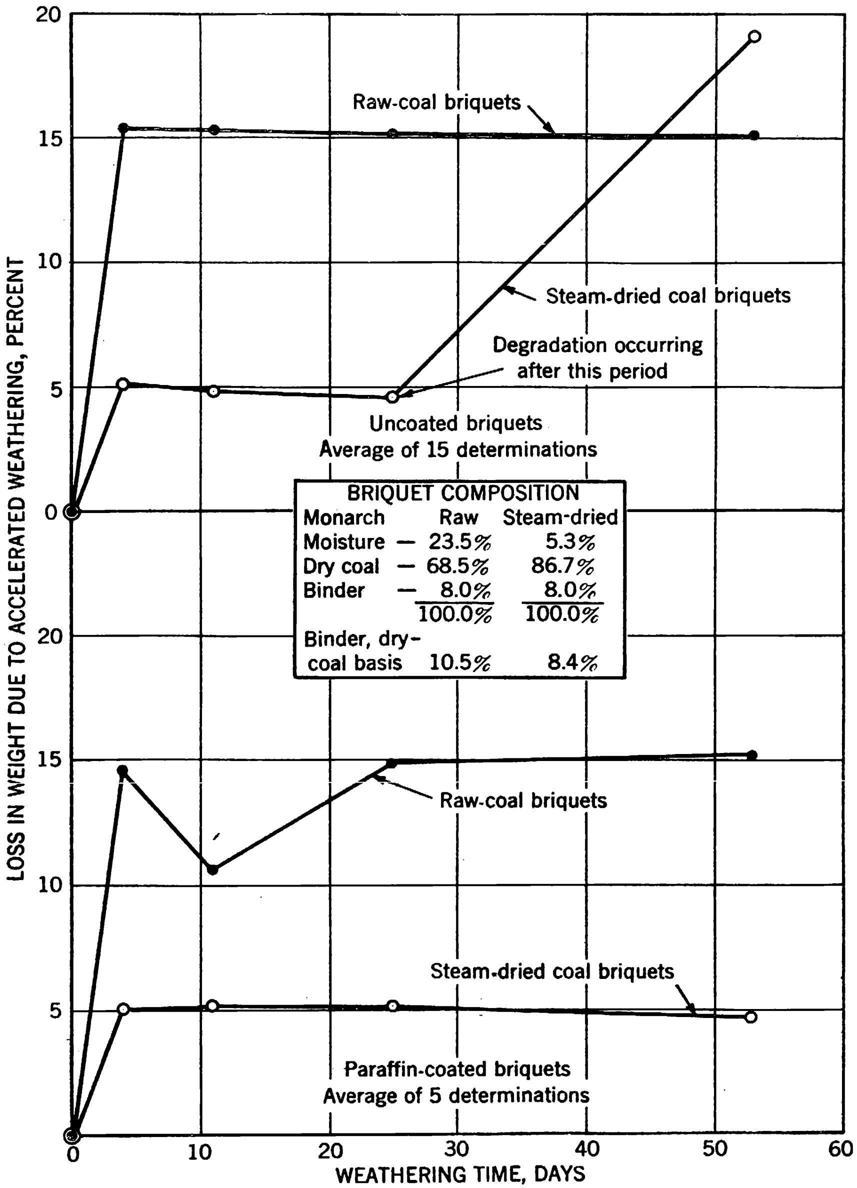


Figure 19.—Effect of accelerated weathering on weight loss of raw and steam-dried subbituminous-coal briquets.

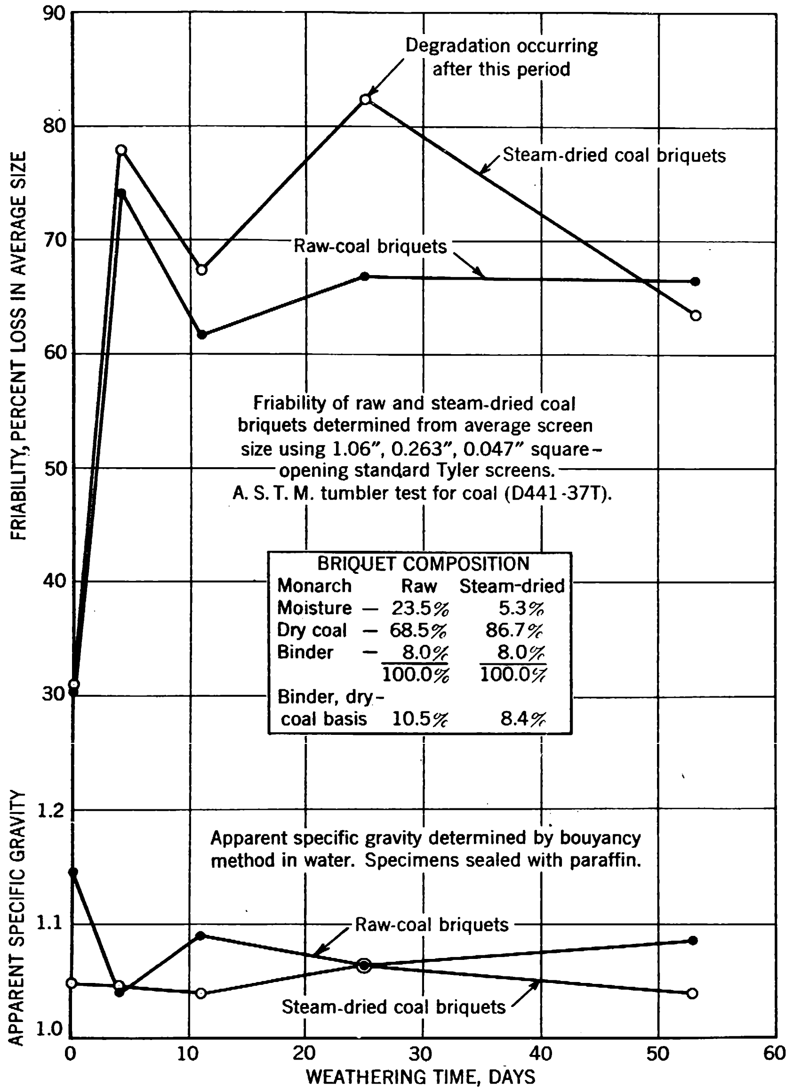


Figure 20.—Effect of accelerated weathering on friability and apparent sqecific gravity of raw and steam-dried subbituminous-coal briquets.

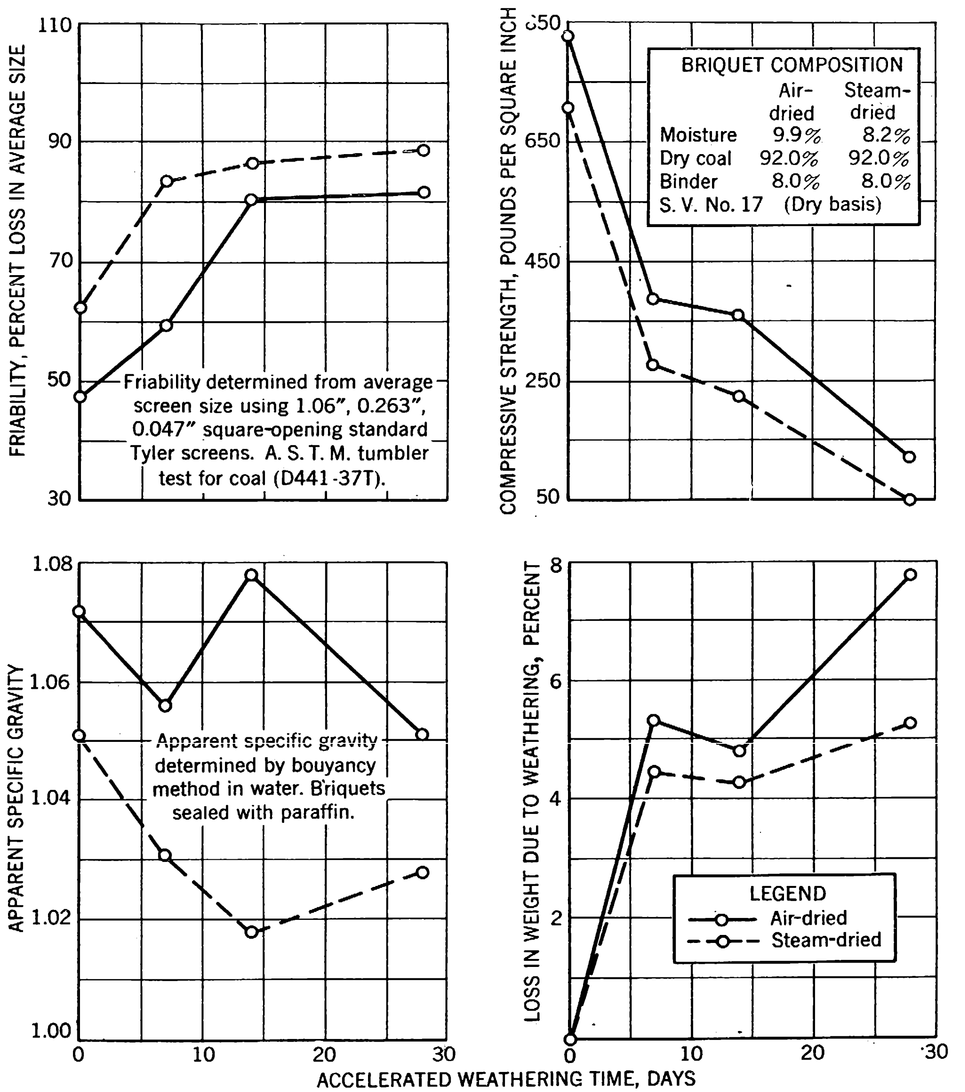


Figure 21.—Physical properties of air- and steam-dried Monarch (Wyo.) subbituminous-coal briquets made on equivalent dry-coal basis as influenced by 28 days accelerated weathering.

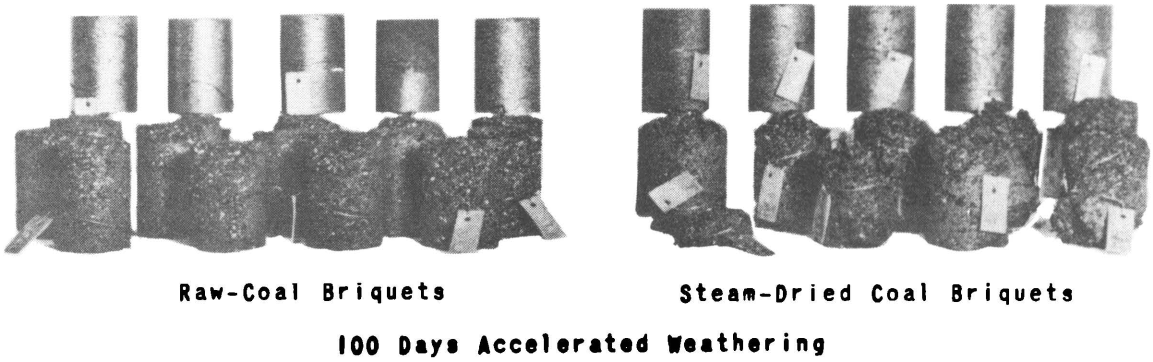


Figure 22.—Appearance of raw and steam-dried coal briquets after 100 days accelerated weathering.

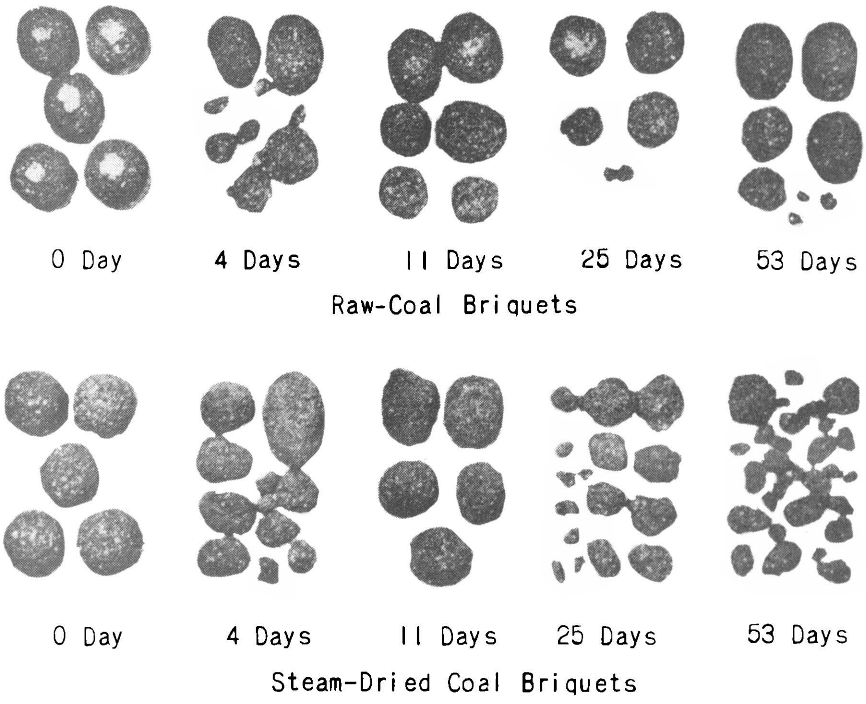


Figure 23.—Residues from standard tumbler test after 0 to 53 days accelerated weathering retained on 0.263-inch screen. Dry-coal : binder ratio, 92 : 8.

TABLE 8. - Properties of untreated and paraffin-treated subbituminous-coal briquets, as influenced by 53 days of accelerated weathering[1/]

Property and type of briquet	Weathering time, days				
	0	4	11	25	53
Compressive strength, p.s.i.					
Raw, uncoated	535	366	418	225	301
Raw, paraffin-coated	-	250	320	295	217
Steam-dried, uncoated	315	235	255	248	109
Steam-dried, paraffin-coated	-	148	170	204	163
Weight loss on weathering, percent[2/]					
Raw, uncoated	0	15.7	15.6	15.3	15.3
Raw, paraffin-coated	0	14.3	11.2	14.7	15.4
Steam-dried, uncoated	0	5.3	4.8	4.3	[3/]18.2
Steam-dried, paraffin-coated	0	5.1	5.3	5.2	4.4
Tumbler test[4/]					
Reduction in average size, percent[5/]					
Raw, uncoated	30.3	74.3	61.7	66.9	66.3
Steam-dried, uncoated	31.0	77.8	67.4	82.4	63.5
Passing 0.263-inch screen, percent					
Raw, uncoated	18.8	69.9	55.0	64.3	61.0
Steam-dried, uncoated	41.7	70.2	63.8	74.1	82.1
Apparent specific gravity[6/]					
Raw, uncoated	1.146	1.041	1.089	1.064	1.085
Steam-dried, uncoated	1.050	1.044	1.040	1.063	1.040
Devolatilization test					
Loss on heating, percent					
Raw, uncoated	49.9	42.3	42.7	41.6	40.9
Steam-dried, uncoated	46.1	40.5	40.9	41.3	41.1
Time required to devolatilize, minutes					
Raw, uncoated	22	20	19	19	18
Steam-dried, uncoated	21	22	21	19	15

1/ Batches prepared on as-received basis using 8 percent of binder A. Briquets made from raw and steam-dried subbituminous coal. Total weathering time, 100 days. Properties not measured at 100 days because of severe disintegration of sample.

2/ Cumulative percentage, based on original weight at 0 day weathering.

3/ High value due to spalling, disintegration becoming pronounced at 53 days.

4/ A.S.T.M. tumbler test for coal (D441-37T). 5 briquets tumbled 1,200 revolutions in one-half hour.

5/ Original size considered as 1-1/2 inches. Average size after tumbling determined by screening on 1.05-, 0.263- and 0.047-inch, square screens.

6/ By buoyancy method (weighing in air and in water). Specimens sealed with paraffin before weighing.

TABLE 9. - Chemical analyses of raw and steam-dried subbituminous-coal briquets as affected by accelerated weathering 1/ 2/

	Raw-coal briquets														
	As-received					Moisture-free					Moisture- and ash-free				
Weathering time ....days	0	4	11	25	53	0	4	11	25	53	0	4	11	25	53
Proximate analysis, percent															
Moisture	16.2	6.3	5.8	4.9	4.3	-	-	-	-	-	-	-	-	-	-
Volatile matter	39.3	43.0	42.4	42.6	44.2	46.9	45.9	45.0	44.7	46.2	49.0	48.2	47.1	46.9	48.3
Fixed carbon	40.8	46.7	47.5	48.2	47.3	48.7	49.8	50.5	50.7	49.4	51.0	52.0	52.9	53.1	51.7
Ash	3.7	4.0	4.3	4.3	4.2	4.4	4.3	4.5	4.6	4.4	-	-	-	-	-
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate analysis, percent															
Hydrogen	6.0	-	-	-	5.1	5.1	-	-	-	4.9	5.3	-	-	-	5.1
Carbon	61.0	-	-	-	67.9	72.8	-	-	-	70.9	76.1	-	-	-	74.2
Nitrogen	1.1	-	-	-	1.4	1.4	-	-	-	1.4	1.4	-	-	-	1.5
Oxygen	27.7	-	-	-	20.9	15.8	-	-	-	17.9	16.6	-	-	-	18.7
Sulfur	.5	0.5	0.5	0.5	.5	.5	0.5	0.5	0.5	.5	.6	0.5	0.5	0.6	.5
Ash	3.7	-	-	-	4.2	4.4	-	-	-	4.4	-	-	-	-	-
	100.0	-	-	-	100.0	100.0	-	-	-	100.0	100.0	-	-	-	100.0
B.t.u.	10510	11660	11630	11690	11530	12540	12440	12350	12280	12040	13120	13000	12940	12870	12600

See footnote p. 25

TABLE 9. - Chemical analyses of raw and steam-dried subbituminous-coal briquets as affected by accelerated weathering 1/ 2/ (Cont'd.)

	Steam-dried coal briquets														
Proximate analysis, percent															
Moisture	7.3	5.4	5.0	4.3	3.9	-	-	-	-	-	-	-	-	-	-
Volatile matter	42.6	43.3	43.2	42.4	43.6	45.9	45.8	45.5	44.3	45.3	48.8	48.6	48.3	47.1	48.1
Fixed carbon	44.6	45.9	46.4	47.7	47.0	48.2	48.5	48.8	49.9	49.0	51.2	51.4	51.7	52.9	51.9
Ash	5.5	5.4	5.4	5.6	5.5	5.9	5.7	5.7	5.8	5.7	-	-	-	-	-
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ultimate analysis, percent															
Hydrogen	5.5	-	-	-	5.1	5.0	-	-	-	4.8	5.4	-	-	-	5.1
Carbon	66.1	-	-	-	67.0	71.3	-	-	-	69.8	75.8	-	-	-	74.0
Nitrogen	1.3	-	-	-	1.4	1.4	-	-	-	1.4	1.5	-	-	-	1.5
Oxygen	21.1	-	-	-	20.5	15.8	-	-	-	17.7	16.7	-	-	-	18.8
Sulfur	.5	0.5	0.5	0.4	.5	6	0.5	0.5	0.4	.6	.6	0.6	0.6	0.4	.6
Ash	5.5	-	-	-	5.5	5.9	-	-	-	5.7	-	-	-	-	-
	100.0	-	-	-	100.0	100.0	-	-	-	100.0	100.0	-	-	-	100.0
B.t.u.	11500	11560	11650	11590	11520	12410	12220	12270	12110	11990	13180	12970	13020	12860	12710

1/ See table 2 for analysis of raw and steam-dried coal.
2/ Briquets made from 92 percent raw or steam-dried coal on as-received basis with 8 percent of binder A. See table 1 for properties of binders.

A study of figure 19 and the data in table 8 reveals interesting trends regarding the loss of weight on weathering. The weight loss includes the moisture removed from the briquets, which is usually the greater part, and any dedusting or spalling. After 25 days, spalling was responsible for a large part of the loss of weight of the uncoated steam-dried briquets. The change in weight of all the briquets is negligible after the first 4 days, except for the paraffin-coated raw briquets, which showed less after 11 days than after 4 days. The uncoated, steam-dried briquets began to spall around the twenty-fifth day, but the raw-coal briquets did not spall. Water probably was absorbed by the paraffin-coated raw-coal briquets at the 11-day period. Otherwise the coated raw-coal briquets did not change in weight after the initial loss.

These results indicate that the paraffin coating does little good except to decrease undesirable spalling. Paraffin coating of the steam-dried briquets was of some value in cementing the surface particles and preventing their loss.

The results of the tumbler test on the weathered briquets follows the same trend as strength and weight loss. The major change occurs within the first 4 days of weathering, according to figure 20, and thereafter the trends follow the same pattern, including the degradation by spalling. The sharp increase in friability between the eleventh and twenty-fifth day indicates the beginning of the breakdown of the steam-dried coal briquets. This was not apparent on inspection until the samples were removed for testing on the twenty-fifth day of weathering. The extent of this breakdown is shown in figure 23.

The briquets take up oxygen during accelerated weathering. After 53 days of exposure, the oxygen content of both raw and steam-dried coal briquets increased about 2.1 percent, which is approximately eight times as much as would be absorbed by higher-rank coals, according to Schmidt, Elder, and Davis.[30]

It is evident from this study that any briquets made from subbituminous coal weaken rapidly during the first week or two after manufacture. The accelerated-weathering test indicates that the greatest changes occur during the first 5 days, and thereafter the physical properties do not change much.

30/ Schmidt, L. D., Elder, J. L., and Davis, J. D., Oxidation of Coal at Storage Temperatures: Ind. Eng. Chem., vol. 28, 1936, pp. 1346. Schmidt, L. D., and Elder, J. L., Atmospheric Oxidation of Coal at Moderate Temperatures: Ind. Eng. Chem., vol. 32, 1940, pp. 249-256.

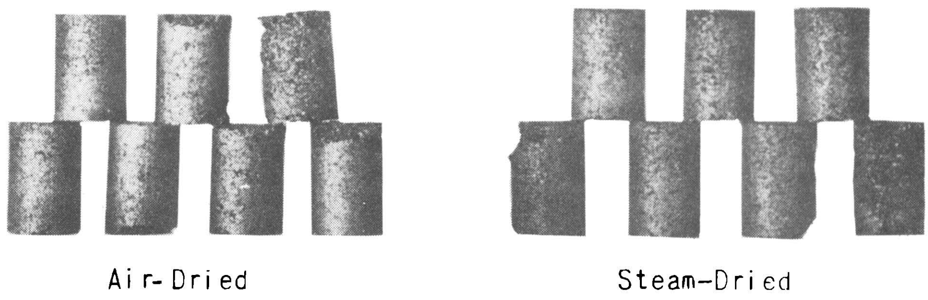


Figure 24.—Appearance of air- and steam-dried subbituminous-coal briquets compounded to same moisture-free coal : binder ratio after 28 days accelerated weathering.

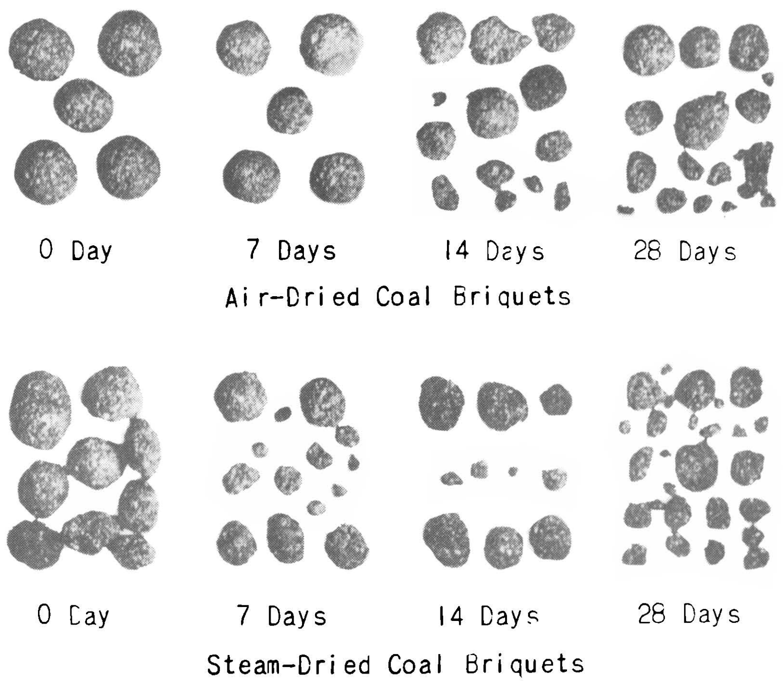


Figure 25.—Residues retained on 0.263-inch screen after tumbler tests of air-dried and steam-dried coal briquets.

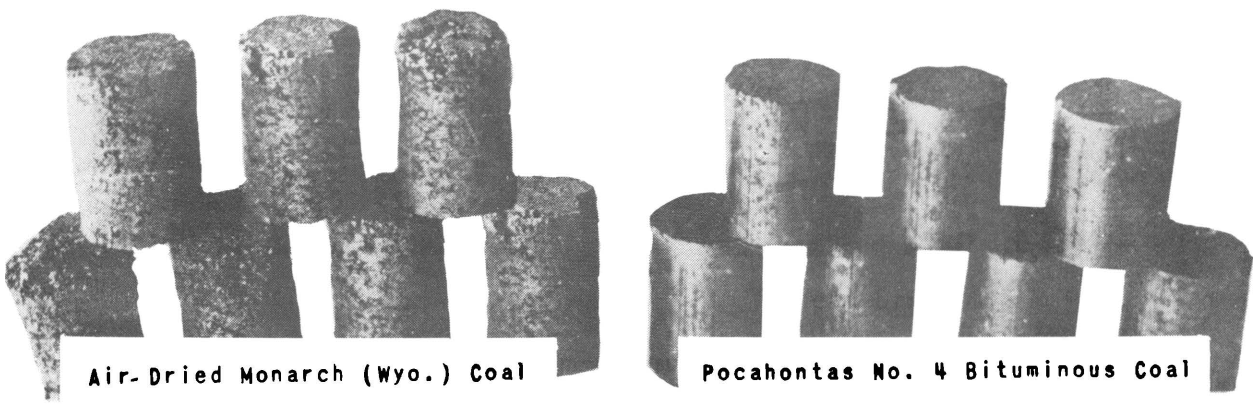


Figure 26.—Briquets after 28 days exposure to accelerated weathering.

The compressive strength can be expected to decrease about 25 percent; raw-coal briquets will lose about 15 percent of moisture, and the friability might increase 200 percent during the first week or two. Although raw-coal briquets are relatively dense when made, their specific gravity decreased about 9 percent after 5 days of accelerated weathering, owing to loss of moisture. In general, it was concluded that raw-coal briquets stood up slightly better under the conditions imposed by accelerated weathering, but the relative superiority over steam-dried coal briquets is not considered significant in view of the relatively poor qualities of both.

5. Properties of Briquets Made from Air- and Steam-Dried Subbituminous Coal, Using 8 Percent Binder

The briquet batches for the previous phase were prepared from the raw and steam-dried subbituminous coal on the as-received basis. Since the as-received moisture content of the coals was not equal, briquets prepared on that basis would not have an equivalent dry-coal: binder ratio, and raw-coal briquets would have a greater ratio of binder to dry coal than that of briquets from steam-dried coal. The object of this phase was to determine if the difference is significant.

Samples of raw and steam-dried coal were crushed to approximate size, and the moisture content was determined. The raw subbituminous coal contained 25.5 percent moisture, and that of steam-dried coal was 8.2 percent. The moisture in the raw coal was reduced to 9.9 percent by heating in an open, shallow tray which was stirred continually to expose fresh surfaces. The air- and steam-dried coal samples were then screened and graded as described in table 3. Briquetting batches were prepared on the basis of 92 parts of moisture-free coal and 8 parts of binder A to compensate for the remaining moisture in both the air- and steam-dried coals. Briquets were then made in the standardized manner.

The accelerated weathering program as outlined in the previous section was employed for 28 days to determine the degradation of the briquets. Samples were removed for tests after 7, 14, and 28 days, and the results of these are shown in table 10 and figure 21. Figure 24 shows the appearance of the briquets after 28 days weathering, and figure 25 compares the extent of degradation induced by the tumbler test.

TABLE 10. - Properties of air- and steam-dried subbituminous-coal briquets as influenced by 28 days of accelerated weathering 1/

Property and type of briquet	Weathering time, days			
	0	7	14	28
Compressive strength, p.s.i.				
Air-dried	829	387	360	119
Steam-dried	709	278	222	2/ 42
Weight loss on weathering, percent 3/				
Air-dried	-	5.3	4.8	7.8
Steam-dried	-	4.5	4.3	5.3
Tumbler test 4/				
Reduction in average size, percent 5/				
Air-dried	47.2	59.2	80.4	81.7
Steam-dried	62.6	83.6	86.4	88.7
Passing 0.263-inch screen, percent				
Air-dried	39.0	57.8	72.6	71.9
Steam-dried	54.8	78.5	83.0	85.3
Apparent specific gravity 6/				
Air-dried	1.072	1.056	1.078	1.051
Steam-dried	1.051	1.031	1.018	1.028
Devolatilization test				
Percent volatile loss on heating				
Air-dried	42.0	39.1	37.5	36.1
Steam-dried	42.0	38.5	40.4	41.5
Time required to drive off volatile, minutes				
Air-dried	23	20	20	18
Steam-dried	20	20	18	16

1/ 92 parts of moisture-free coal used with 8 parts of binder A.
2/ Excessive spalling.
3/ Cumulative percentage, based on original weight at 0 day weathering.
4/ A.S.T.M. tumbler test for coal (D441-37T). 5 briquets tumbled for one-half hour (1,200 revolutions).
5/ Original size considered as 1-1/2 inches. Average size after tumbling determined by screening on 1.05-, 0.263-, and 0.047-inch, square-hole screens.
6/ By buoyancy method (weighing in air and in water). Specimens sealed with paraffin before weighing.

The steam-dried briquets are not quite as good as the air-dried or raw-coal briquets, but all have similar properties. The average compressive strength of the air-dried briquets for the 28-day period was 356 p.s.i. compared with 255 p.s.i. for those steam-dried; these values were obtained by integrating curves in figure 21. This 28.4-percent difference compares with 70.2-percent difference of strength found when 8 percent binder is compounded with raw coal on the as-received basis.

At the end of 28 days weathering, both show about equal spalling and weathering, but the steam-dried briquets have a better appearance. The results of the tumbler test, shown in figure 25, indicate that the air-dried briquets are a little tougher.

In general, it was concluded from this study that briquets made from either air-dried or steam-dried subbituminous coal are about equal in quality, despite the slightly higher strength of air-dried briquets.

6. Comparative Properties of Briquets Made from Air-Dried Subbituminous Coal and from Pocahontas Coal

In previous investigations, there has been no work that directly compared the properties of subbituminous coal and Pocahontas low-volatile coal briquets prepared and treated under similar experimental conditions. The purpose of this phase of the investigation was to fill the above need and to obtain data that could be used as a basis for comparison. In 1941, 13 of the 36 plants reporting operations made briquets from low-volatile bituminous coal, and Pocahontas coal appears to be a preferred fuel for briquetting purposes.

The coal samples were prepared as outlined in section 5, and the original moisture content was determined. The raw subbituminous coal contained 25.5 percent moisture, which was reduced to 3.0 percent by drying in a shallow, heated tray. The fresh bituminous coal contained 1.6 percent moisture, and this was not reduced before the briquet batches were made. Tables 2 and 11 give the analysis of subbituminous coal and that of Pocahontas No. 4. The graded sizes, described in table 3, were then prepared for briquetting. In preparing the briquetting mixture, 94 parts of Pocahontas was mixed with 6 parts of binder A, and 92 parts of subbituminous coal, moisture-free basis, was mixed with 8 parts of binder A. Cylindrical briquets 1-1/2 inches in diameter and weighing 70 grams were then made by the standardized method.

Accelerated weathering was imposed for 28 days, and samples were removed on the seventh, fourteenth, and twenty-eighth days. The changes in physical properties are shown in table 12 and in figure 17, and the appearance of the briquets after 28 days is shown in figure 26. The appearance of the specimens after the tumbler test is shown in figure 27. The increased strength of the Pocahontas briquets after weathering should be noted. The behavior of the two kinds of briquets when burned is shown in figure 28. Subbituminous-coal briquets do not stand up when burning, and in some instances they disintegrate into small granular particles. On the other hand, Pocahontas-coal briquets swell to some extent like popcorn and form solid lumps of coke that can be burned readily in a domestic hand-fired furnace.

This phase of the investigation shows the fundamental differences between briquets made from the two ranks of coal. The results indicate that it is impossible to make briquets from subbituminous coal equal to those made from low-volatile bituminous, even when more binder is employed. Any investigators attempting to make briquets from lignite or subbituminous coal should remember this. Briquets made from Pocahontas coal improve with age, whereas subbituminous-coal briquets deteriorate; furthermore, so-called good subbituminous-coal briquets do not hold up while burning.

TABLE 11. - Analyses of Pocahontas No. 4 coal 1/

	As-received	Moisture-free	Moisture- and ash-free
Proximate analysis, percent:			
Moisture	1.6		
Volatile matter	16.5	16.7	17.8
Fixed carbon	76.2	77.5	82.2
Ash	5.7	5.8	
	100.0	100.0	100.0
Ultimate analysis, percent:			
Hydrogen	4.6	4.4	4.7
Carbon	83.8	85.1	90.4
Nitrogen	1.3	1.4	1.4
Oxygen	3.7	2.4	2.5
Sulfur	.9	.9	1.0
Ash	5.7	5.8	-
	100.0	100.0	100.0
B. t. u.	14,520	14,750	15,660

1/ **Bureau of Mines, Pittsburgh analysis.** Coal sample 57. Bureau of Mines Tech. Paper 604, table 1, pp.4-5.

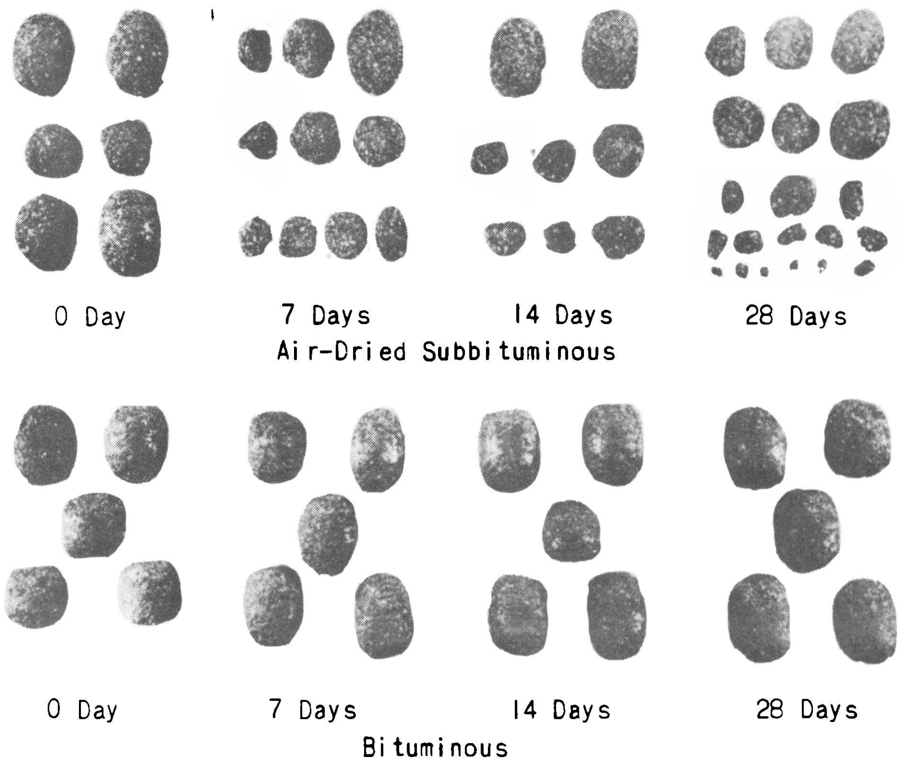


Figure 27.—Residues from tumbler tests of subbituminous- and Pocahontas-coal briquets retained on 0.263-inch screen.

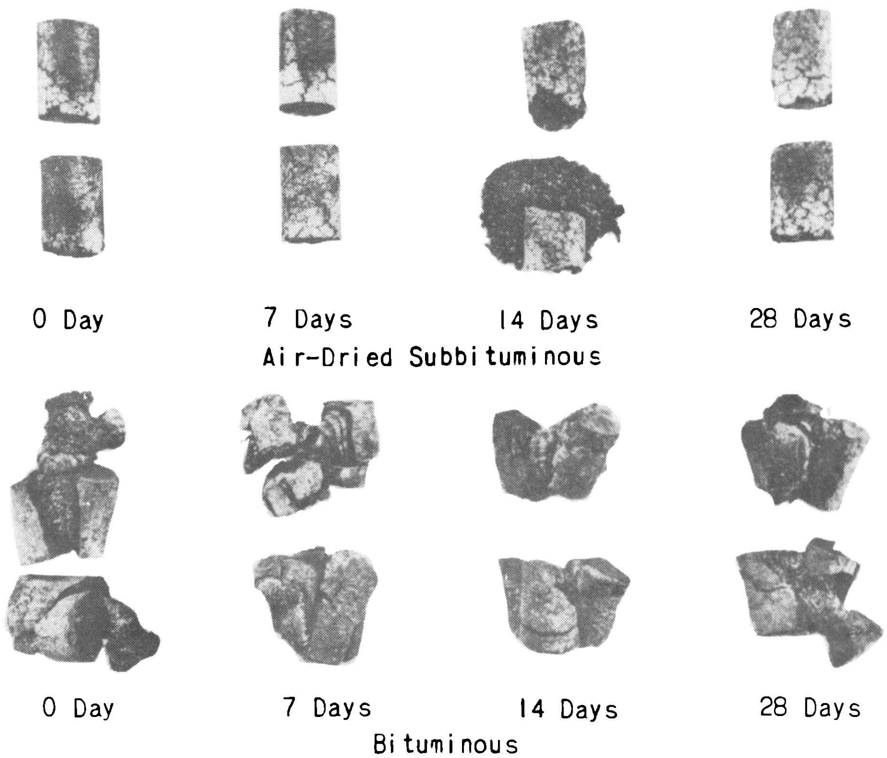


Figure 28.—Residues of subbituminous- and Pocahontas-coal briquets after residue is burned off.

TABLE 12. - Properties of air-dried subbituminous coal briquets and Pocahontas No. 4 briquets as influenced by 28 days accelerated weathering 1/

Property and type of briquet	Weathering time - days			
	0	7	14	28
Compressive strength, p.s.i.:				
Air-dried subbituminous	699	381	298	174
Pocahontas bituminous	1,070	958	1,030	952
Weight loss on weathering, percent 2/:				
Air-dried subbituminous	0.0	1.78	2.05	3/0.75
Pocahontas bituminous	.0	.54	1.19	.68
Tumbler test 4/				
Reduction in average size, percent 5/:				
Air-dried subbituminous	50.1	73.3	75.6	73.7
Pocahontas bituminous	42.0	37.2	36.3	35.0
Passing 0.263-inch screen, percent:				
Air-dried subbituminous	42.4	64.8	65.6	66.5
Pocahontas bituminous	32.7	27.1	26.6	24.3
Apparent specific gravity 6/:				
Air-dried subbituminous	1.078	1.075	1.063	1.060
Pocahontas bituminous	1.244	1.237	1.221	1.244
Devolatilization test; loss in weight, percent:				
Air-dried subbituminous	41.3	40.9	39.2	43.5
Pocahontas bituminous	18.9	19.9	19.1	20.2
Time required to drive off volatile, minutes:				
Air-dried subbituminous	19	16	18	17
Pocahontas bituminous	27	25	25	24

1/ Subbituminous-coal briquets composed of 8 parts of binder A and 92 parts of moisture-free coal. Moisture content of air-dried coal, 3.0 percent. See table 2 for as-received proximate analysis.
Bituminous-coal briquets prepared from 6 percent binder A and 94 percent Pocahontas No. 4 coal. Moisture content of Pocahontas coal, 1.6 percent.

2/ Cumulative percentage, based on original weight at 0 day exposure.

3/ Increase due to retention of free moisture in briquets.

4/ A.S.T.M. tumbler test for coal (D441-37T). 5 briquets tumbled for 1/2 hour (1,200 revolutions).

5/ Original size considered as 1-1/2 inches. Average size after tumbling determined by screening on 1.05-, 0.263-, and 0.047-inch, square-hole screens.

6/ By buoyancy method (weighing in air and water). Specimens sealed with paraffin before weighing.

7. Physical and Chemical Properties of Commercial Briquets

In 1941 the Bureau of Mines conducted a field study of several large briquet plants to observe methods and to obtain samples of briquets for comparative tests. Seven fuel-briquetting plants were visited, and small samples of about 20 pounds were collected for analysis and physical tests. Table 13 summarizes the measurements of these samples.

It is difficult to make true comparisons of commercial briquets owing to differences in shape and size. Specific gravity is a good measure, but it is affected by differences in weight of ingredients, coal grading, and the degree of compaction. Compressive strength tests of pillow-shaped briquets are important for plant control, but they cannot be applied accurately in comparing briquets made by different plants unless certain precautions are taken to reduce the effect of different shapes. One large asphalt-binder company cuts small cylinders from commercial briquets and makes stress-strain studies to compare properties of briquets made from different fuels and binders. It is a good method but requires special technique and equipment. The following technique was used at Golden to measure compressive strengths:

Parrallel surfaces were ground on the top and bottom surfaces of pillow-shaped briquets to make a flat area of about 1 square inch. The area of each surface was determined by measurement and covered with a 1/16-inch sheet of rubber. The briquet was then crushed, and the compressive strength (in pounds per square inch) was calculated on the basis of the average area of the flat surfaces. This is a practical method of estimating compressive strength and avoids some of the errors associated with crushing pillow-shaped briquets.

Briquets made in the laboratory are stronger and have greater density than commercial briquets. The laboratory briquets made from Pocahontas coal are 28 percent stronger than the average of four commercial briquets made with asphalt binder. This may be due partly to the difference in the shape of the test specimens. The density of laboratory briquets made in this investigation is about 4 percent greater than that of commercial briquets, and the abrasion resistance of a Pocahontas-coal laboratory briquet is about 6 percent greater than that of the average asphalt-bonded commercial briquet. Results of tumbler tests of several commercial briquets are shown in table 14.

TABLE 13. - Physical and chemical properties of commercial fuel briquets

Laboratory number	151	155	156	163	165	175	175A	Ave. 1/
Chemical properties (proximate analysis):								
Moisture .... percent (1)2/	1.2	0.5	0.7	6.0	1.1	1.0	0.8	-
Volatile matter.. Do (1)	12.3	21.3	22.5	32.7	20.8	19.2	21.4	-
Do . Do (2)	13.8	23.0	24.5	40.9	22.1	21.9	24.0	-
Fixed carbon ... Do (1)	77.2	71.4	69.2	47.3	73.4	68.4	67.8	-
Do .... Do (2)	86.2	77.0	75.5	59.1	77.9	78.1	76.0	-
Ash .... Do (1)	9.3	6.8	7.6	14.0	4.7	11.4	10.0	-
Sulfur .... Do (1)	.7	.9	.9	1.1	.6	1.6	.9	-
Do .... Do (2)	.8	1.0	1.0	1.4	.7	1.8	1.0	-
B.t.u. (1)	13,590	14,610	14,490	11,550	14,600	13,530	14,010	-
Do (2)	15,180	15,770	15,820	14,430	15,500	15,450	15,700	
Physical properties:								
Weight of briquet.......ounces	2.3	2.3	3.1	9.5	2.9	3.5	3.5	2.9
Compressive strength..p.s.i.3/	470	949	650	467	484	758	716	671
Apparent specific gravity.....	1.221	1.160	1.226	1.157	1.162	1.193	1.252	1.202
Abrasion index......percent 4/	10.0	15.4	38.6		34.3	26.3	37.0	26.9

1/ Average of 6 small briquets.
2/ (1) As-received basis; (2) moisture- and ash-free basis.
3/ Parallel surfaces were ground on top and bottom of Pillow-shaped briquets to make a flat area of about 1 square inch. The area was determined by measurement and covered with 1/16-inch sheet-rubber cushion. Briquet was then crushed and compressive strength calculated on basis of average area of flat surfaces.
4/ Tumbler modification of D441-37T. Tumbled for 1/2 hour (1,200 revolutions). Expressed as percentage of material passing 0.263-inch square-hole screen.

TABLE 13. - Physical and chemical properties of commercial fuel briquets (Cont'd.)

Laboratory number	151	155	156	163	165	175	174A	Ave. 1/
Binder:								
Temperature at rolls........°F.	180		150	150	Hot	150	150	-
Kind	St. & asph.	Asphalt	Asphalt	Asphalt 5/	Starch	Asphalt	Asphalt	-
Percent......................	4.7	6.5	6.0	7.0	1.5	6.5	6.5	-
Type of fuel	Anth.	Pocahontas	Pocahontas	Bituminous	Pocahontas	Semi-anth.	Low-vol. bit.	-
Press used	K & G 6/	Special	K & G Vulcan	K & G	Special	K & G	K & G	-

1/ See footnote on p. 33
5/ Plus starch and sodium silicate
6/ Komarek & Greaves.

TABLE 14. - Tumbler test on commercial briquets

Laboratory number	Binder	Weight of briquet, grams	Percentage of material passing 0.263-inch square-mesh screen after tumbling-1/ 200 revolutions	600 revolutions	1,200 revolutions
155	Asphalt	66	4.3	9.6	14.7
155	do	do	4.6	10.0	17.5
155	do	do	4.1	9.0	14.0
	Average		4.3	9.5	15.4
156	Asphalt	89	13.6	29.0	38.6
165	Starch	83	3.5	18.5	34.0
165	do	do	3.6	18.5	30.8
165	do	do	10.0	24.6	38.2
	Average		5.7	20.5	34.3
175	Asphalt	95	7.9	17.7	26.3

1/ A.S.T.M. apparatus for tumbler test for coal (D441-37T).

There is no clear definition of a satisfactory briquet because satisfactory briquets now being made have properties that vary widely. However, the average properties of briquets made in the larger plants can be considered a tentative standard for comparison purposes. A good briquet apparently should have the following physical properties:

1. Compressive strength made through parallel surfaces on pillow-shaped briquets sould be at least 650 to 700 pounds per square inch.
2. The apparent specific gravity, measured by weighing a paraffin-coated briquet in water, should be about 1.20.
3. The abrasion resistance, measured by material passing a 0.263-inch screen after five briquets are tumbled for 1,200 revolutions in the A.S.T.M. apparatus for tumbler test for coal, should be not more than 25 to 30 percent.

SUMMARY

This report describes laboratory investigations on the briquetting of subbituminous coal and the results of work to determine whether briquetting properties can be improved by steam drying just before briquetting. The investigation includes a study of the briquetting properties of raw subbituminous coal containing 25 percent moisture, of steam-dried coal containing about 6 percent moisture, and of air-dried coal containing about 10 percent moisture. The protective effects of paraffin coating were studied, and the

briquetting properties of Pocahontas coal are compared with those of subbituminous coal. The work includes a study of the effects of both normal and accelerated weathering, and equipment for conducting briquetting investigations on a laboratory scale is described by detailed drawings. The results of tests to determine physical and chemical properties of commercial briquets are summarized.

Generally speaking, it was found that briquets equal in quality to commercial briquets made from higher-rank coals, could not be made from raw or steam-dried subbituminous coal. The characteristic property of subbituminous coals-a tendency to slack and to disintegrate in the fuel bed-presents and shows up to some extent in the properties of asphalt-bonded briquets. Subbituminous coal requires about 2 percent more binder than higher-rank fuels to make a briquet that can be considered satisfactory. Completely satisfactory briquets could not be made from subbituminous coal, even when binder concentrations up to 10 percent were employed.

Steam drying stabilizes subbituminous-coal briquets to some extent but imparts no significant improvement in physical properties. The heating value of briquets made from steam-dried coal is about 12,200 B.t.u. per pound compared with 10,900 B.t.u. per pound for briquets made from raw coal. This difference in heating value has important significance when transportation costs are considered. The steam-dried coal briquets stood up better under normal weathering, but raw-coal briquets stood up slightly better during accelerated weathering.

All subbituminous-coal briquets disintegrate to some extent while burning because this fuel has no coking properties. High concentrations of binder do not overcome this undesirable property, and disintegration of subbituminous coal or lignite apparently cannot be eliminated by briquetting. It was found that paraffin coating affords no protection to subbituminous-coal briquets.

The following tentative standards describe the physical properties of satisfactory commercial pillow-shaped briquets, estimated from tests on briquets from eight plants:

1. Compressive strength made through parallel surfaces on pillow-shaped briquets should be at least 650 to 700 pounds per square inch.
2. The apparent specific gravity, measured by weighing a paraffin-coated briquet in water, should be about 1.20.
3. The abrasion resistance, measured by material passing a 0.263-inch square-hole screen after five briquets are tumbled for 1,200 revolutions in the A.S.T.M. apparatus for tumbler test for coal, should be not more than 25 to 30 percent.

For purposes of comparison, subbituminous-coal laboratory briquets with 8 percent asphalt binder had the following average properties:

Briquet made from:	Age, days weathering	Property		
		(1) Strength	(2) Specific gravity	(3) Abrasion resistance
Raw subbituminous coal	0	670	1.14	19
	25	225	1.06	64
Steam-dried subbituminous coal	0	416	1.05	48
	28	224	1.04	79
Air-dried subbituminous coal	0	764	1.07	41
	28	146	1.05	69