characteristics of the Pittsburgh bed coal in Allegheny, Fayette, Washington, and Greene Counties, Pa., and Monongalia, Marion, Marshall, Ohio, Brooke, and Hancock Counties, W. Va.51/ Intensive study of the washability data shows the main washing problem concerns the release of sulfur. This problem is increased by the wide variations of sulfur content not only in the raw coal, but in the float product. No one method of cleaning will result in satisfactory upgrading of the high-sulfur coals to metallurgical standards. Selective mining, low-gravity separation, fine crushing and froth flotation, and combinations of the three must be employed before sulfur can be reduced significantly. Coals containing 1.80 percent sulfur in the raw product present no extraordinary technological problem, while coals containing sulfur in excess of 2.27 percent in the raw state cannot be considered as a metallurgical fuel. When the sulfur content of the raw coal is in the 1.81 to 2.27 percent range, the Pittsburgh-bed coal in the area studied may be upgraded to metallurgical standards by the development and application of intensive preparatory treatment.

Coal Preparation for Synthetic Fuels

A study was made of the effect of ash on oil losses during the elimination of nonliquefiable portions of the coal in the hydrogenation process.52/ The oil loss increases with ash content and results in increased consumption of coal, hydrogen, and power. To determine the economic limits for cleaning coal for hydrogenation due to this one factor, a comparison was made of the calculated economic advantages resulting from the use of a 2.3 percent ash coal from Rock Springs, Wyo., and a 6.0 percent ash coal from the same mining field in a 30,000-barrel-per-day hydrogenation plant.

Table 2 shows the maximum allowable cleaning costs in cents per ton of coal as received for each percent of ash reduction, using coals containing 10, 20, and 40 percent ash plus moisture and a washery recovery of 50 and 70 percent of the raw feed as clean coal. A large proportion of the remaining 50 and 30 percent, respectively, may be recovered as middlings and utilized as powerhouse coal. The calculations reflect the decreased fuel value of this middling product.

TABLE 2. - Maximum allowable washing costs for different coals for each unit of ash reduction, cents per ton of raw coal, as-received basis

Yield of washed coal ..... percent	50			70		
Ash plus moisture in raw coal as received ..... percent	10	20	40	10	20	40
Maximum allowable cost of washing for each unit of ash reduction, cents per ton:						
Based on moisture- and ash-free coal valued at $2.00 per ton (7 cents per million B.t.u.)	3.8	3.4	2.5	5.3	4.7	3.5
Based on moisture- and ash-free coal valued at $4.00 per ton (14 cents per million B.t.u.)	4.5	4.0	3.0	6.3	5.6	4.2
Based on moisture- and ash-free coal valued at $6.00 per ton (21 cents per million B.t.u.)	5.1	4.6	3.4	7.5	6.6	5.0

51/ Fraser, Thomas, Crentz, W. L., and Bailey, A. L., High-Sulfur Pittsburgh Coal: Upgrading in Southwestern Pennsylvania and Northern West Virginia: Bureau of Mines Bull. 483, 1950, 70 pp.

52/ Crentz, W. L., Doherty, J. D., and Donath, E. E., Coal Preparation for Synthetic Liquid Fuels: Am. Inst. Min. and Met. Eng. Tech. Pub. 2832F, Trans. Am. Inst. Min. and Met. Eng., vol. 187, 1950, pp. 507-510; Min. Eng., vol. 187, April 1950, pp. 507-510; discussion, Trans. Am. Inst. Min. and Met. Eng., vol. 187, 1950, p. 1158; Min. Eng., vol. 187, Sec. 1, November 1950, p. 1158.

Using a cost figure of 15 cents per ton of coal feed to the washery as the operating cost of the washing plant, it is possible to calculate the minimum reduction in ash content for different coals to justify washing the coal. These data appear in table 3.

TABLE 3. - Minimum reduction in ash content to justify a washing cost of 15 cents per ton of raw coal, percent

Yield of washed coal ..... percent	50			70		
Ash plus moisture in raw coal as received .... percent	10	20	40	10	20	40
Reduction in ash content necessary to justify a washery cost of 15 cents per ton of feed coal:						
Based on moisture- and ash-free coal valued at $2.00 per ton (7 cents per million B.t.u.)	4.0	4.4	6.0	2.8	3.2	4.3
Based on moisture- and ash-free coal valued at $4.00 per ton (14 cents per million B.t.u.)	3.4	3.8	5.0	2.4	2.7	3.6
Based on moisture- and ash-free coal valued at $6.00 per ton (21 cents per million B.t.u.)	2.9	3.2	4.3	2.0	2.3	3.0

Briquetting of Coal

The Bureau continued cooperative work with the Natural Resources Research Institute, University of Wyoming, on problems incident to briquetting of subbituminous coal. Fuels for briquetting were prepared and dried at the Bureau laboratories and then briquetted in the pilot plant at the University. A publication describing this investigation was issued by the University.53/

During the year, an integrated pilot plant for drying and briquetting coal was designed by the Bureau and erected at the University of Wyoming by the Natural Resources Research Institute. This pilot unit for processing coal at the rate of about 3 tons per hour is illustrated in figure 5. The fluidized drying process developed by the Bureau will dry and preheat the subbituminous coal fed to the briquetting press.

Drying Low-Rank Coals

Rocky Mountain Coals

Investigations on the drying of low-rank coals in the entrained and fluidized state were continued54/ in the small pilot plant illustrated in figure 6. Various grades and sizes of coal up to three-fourths inch were studied in this unit. It was found that, when drying any surface-dry low-rank coal having natural bed moisture ranging from 15 to 65 percent, the major operating factor was to strike a heat balance to accomplish the required drying. It was proved that theoretical and practical operation of the drying process coincided and the performance of the dryer could be estimated in advance. This important confirmation allows correct appraisal of the drying of surface-dry coals without the formality of testing. It was further

53/ Boley, Charles C., and Rice, Neal, Briquetting of Dried Low-Rank Western Coals: Univ. Wyoming Bull. 3, 1949, 76 pp.

54/ Parry, V. F., and Wagner, E. O., Upgrading Missouri Basin Coals by Flash Drying: Colorado School of Mines Quarterly, vol. 45, No. 2B, April 1950, pp. 57-66.

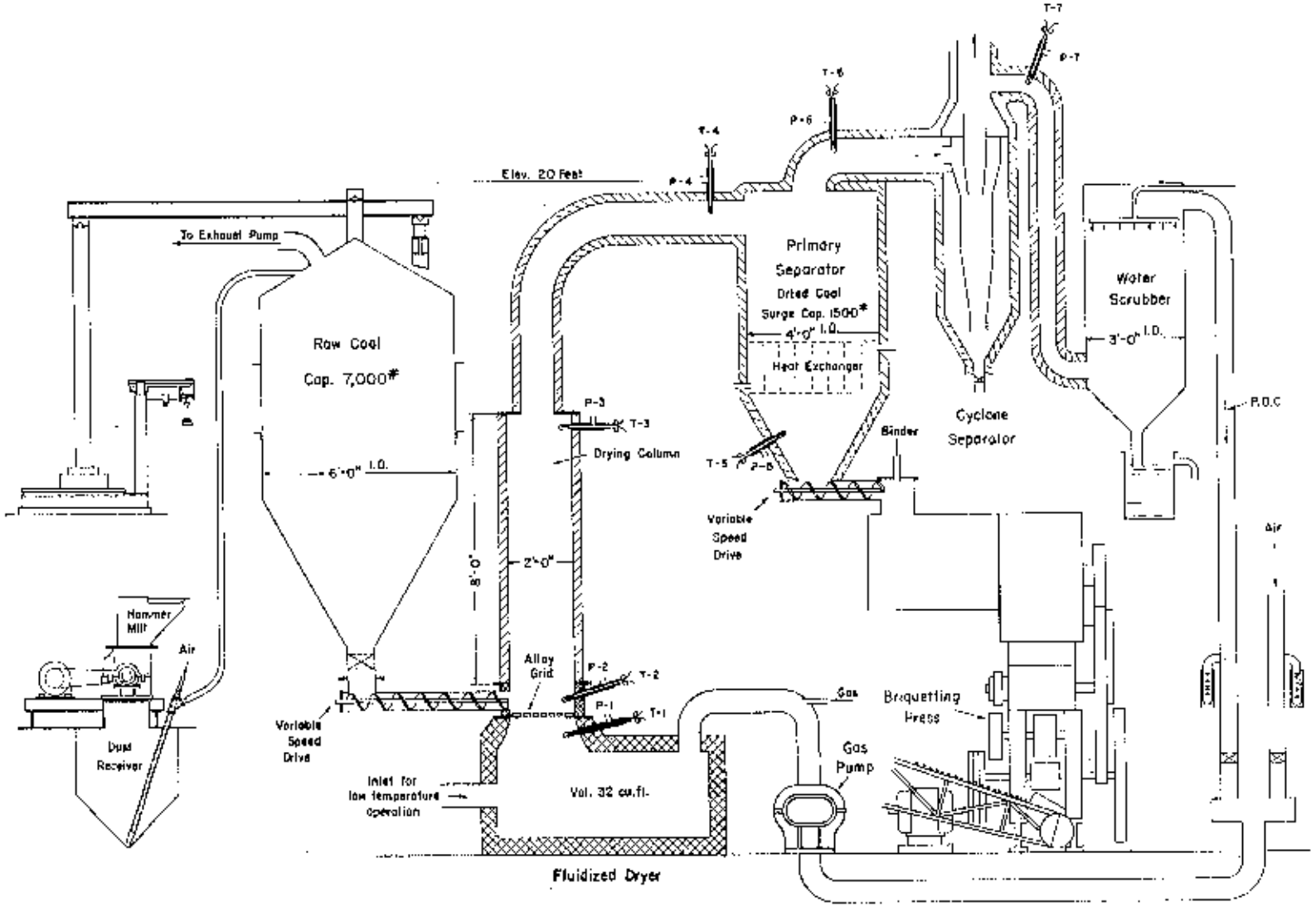

Figure 5. - Integrated pilot plant for fluidized drying and briquetting of coal; capacity 3½ tons raw coal/hr.

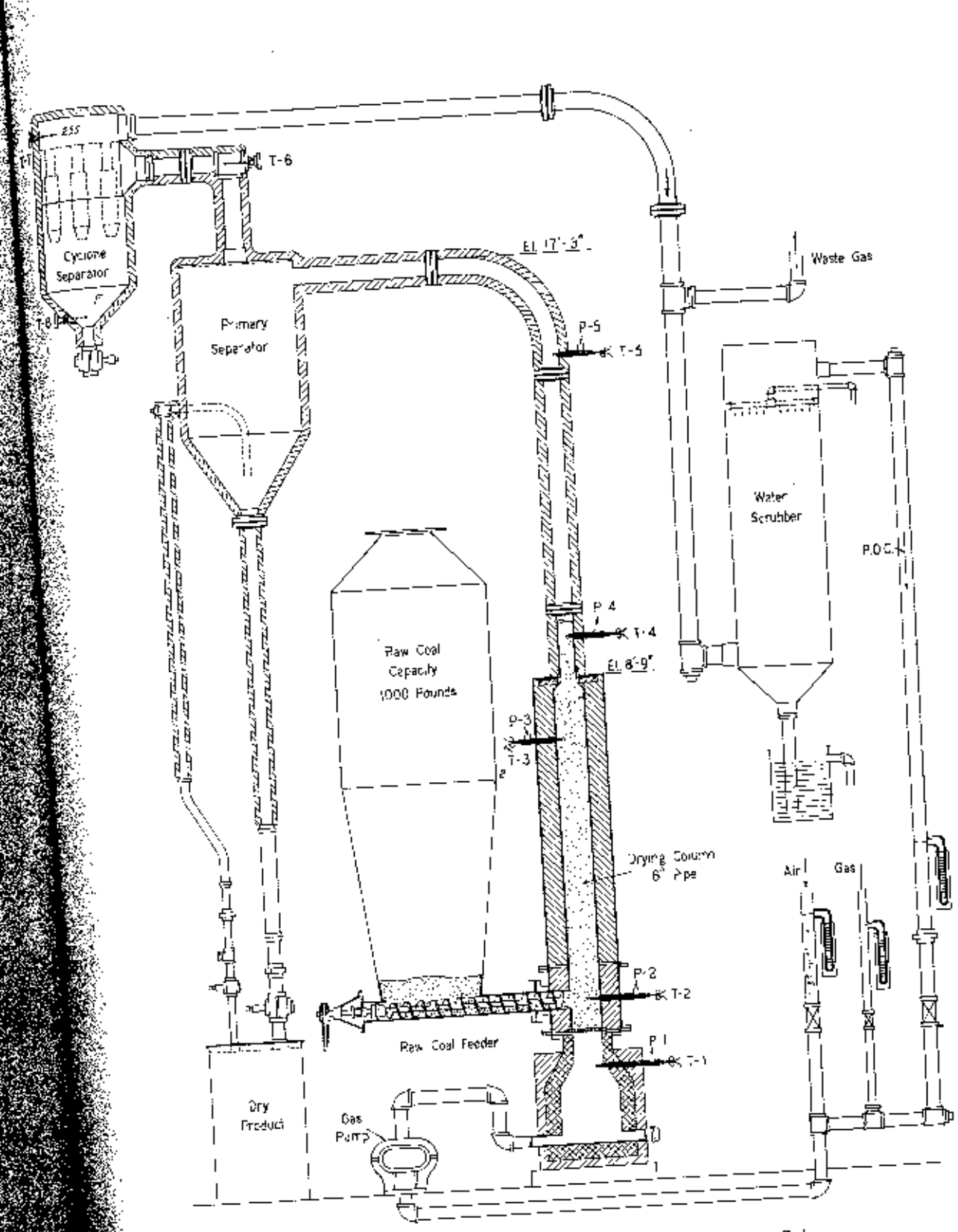

Figure 6. - No. 5 pilot plant for drying coal, Golden, Colo.

observed that the most practical size of raw coal for drying in the entrained state is 1/4 by 0 inch, but larger sizes can be handled as the natural bed moisture increases.

Lignite

American lignites are differentiated from solid fuels of higher rank by their higher natural bed-moisture content of 35 to 40 percent. To gain efficiency in utilization and economy in transportation, it is highly desirable to reduce this moisture content to 15 percent or less. During the year, the Lignite Pilot Plant at Grand Forks, N. Dak., dried 250 tons of lignite for the quadruple purpose of improving the drying operation, continuing storage observations, making combustion tests, and gasification. Table 4 gives the pertinent data and indicates the improvement obtained through drying.

TABLE 4. - Typical analysis of Dakota Star lignite

	Before drying	After drying
Moisture ..... percent	37.2	17.4
Improvement ratio	-	1.32
Heat value..... B.t.u./lb.	6,930	9,110

Operations were carried out in large autoclaves, using a modified Fleissner process with steam at a nominal pressure of 400 pounds per square inch. This was reduced from 1 hour to 30 minutes, thus doubling the capacity of the plant and cutting fixed charges in half. Approximately the same amount of water (65.0 and 67.5 percent of the total) was removed during the shorter cycle as during the longer one.

A summary of experiments on the drying of lignite in hot oil was published.55/

Storage of Coal

Low-Rank Rocky Mountain Coals

Field investigations on storage of low-rank coals were continued. Coal operators in the Denver, Colo., area are considering the advantages to be gained by storage of coal at industrial plants and mines and are adopting the improved methods of storage recommended by the Bureau. Another model 4,000-ton pile of subbituminous coal was placed at the Denver Federal Center during March 1950. It will be studied to determine conditions of storage during the hot summer months and will be consumed during the winter of 1950.

Two 5,000-ton piles of subbituminous A slack coal, placed in storage in 1948 according to Bureau recommendations, show no indications of heating or deterioration.

Lignite

To date, approximately 350,000 tons of lignite has been placed in storage in uncapped piles at the Garrison Dam in North Dakota. Heating was anticipated at one

55/ Burr, Alex. C., Oppelt, Walter E., and Kamps, Theodore W., The Rate of Drying of Lignite in Hot Oil at 315° F.: Proc. North Dakota Acad. Sci., vol. 2, 1949, pp. 32-36.

location because of improper pile-forming practices, and, as expected, a small fire developed at that point. As a result of this fire, the stockpiling contracts were changed to specify the rolling of each 1-foot increment of lignite with a sheep's-foot roller in order to achieve greater fragmentation and compaction. There have been no indications of heating since the introduction of the sheep's-foot rolling technique.

Figure 7 shows the occurrence of lignite beds AA and BB in the powerhouse excavation. The northern end of pile 3 appears at the right-hand edge of the picture. Figure 8 shows how the lignite is stripped from the beds by power shovel and loaded into carry-alls for transportation to the pile sites. (Note the size of the lignite lumps.) The lignite is dumped by the carry-all, leveled by bulldozer, rolled with a sheep's-foot roller, with slope of the sides of the pile maintained at about 17°. The lighter mass on the right is similarly piled lignite which has slacked for several days. The slacking aids fragmentation and compaction by the sheep's-foot roller.

Storage of Dried Lignite

The investigation of safe storage conditions was continued. The old storage pile of approximately 25 tons, which has been exposed to the weather for almost 2 years without firing, was repiled. This time, no attention whatever was paid to segregation, and pile fired at several places on the surface.

One hundred and ninety tons of freshly dried lignite was stored in several piles. Observation of these piles led to the conclusion that freshly steam-dried lignite of approximately 15 percent moisture may be safely stored for indefinite periods in piles of 100 tons or less, if the fines are removed and the dried lignite laid down in layers of approximately 18 inches.

UTILIZATION OF COAL FOR COMBUSTION

Fuel-Engineering Service

As in previous years, fuel-engineering service was rendered to Government establishments in the selection and use of fuel and fuel-burning equipment and in the economical use of steam. Total boiler-plant operating-cost comparisons were made for the use of oil, gas, and coal, and the type of fuel-burning equipment recommended for eight projects for the Veterans' Administration. Studies of boiler-plant equipment and operation at the Naval Research Laboratory, Bellevue, D. C., and the Naval Hospital, St. Albans, N. Y., indicated that plans for equipment for these plants could be changed to effect savings, respectively, of $52,000 and $30,000.

At the request of the Atomic Energy Commission, Oak Ridge, Tenn., tests and recommendations were made to eliminate fuel-burning difficulties in the heating plants of a housing development. Final acceptance tests were made of steam-generating equipment at the West Central Heating Plant, Washington, D. C.; changes shown necessary by previous tests improved the performance and reliability of the equipment so that the specification requirements were satisfactorily met. Assistance was given the Federal Works Agency in the design of a high-pressure overfire-air application for a large furnace fired by an underfeed stoker; tests were then made for boiler efficiency and stack-smoke emission, with various nozzle arrangements and amounts of overfire air, which resulted in the controlled elimination of smoke.

Specifications for a new power plant at Shiprock, N. Mex., of the Bureau of Indian Affairs, were studied, and final wordings recommended. A survey was made of

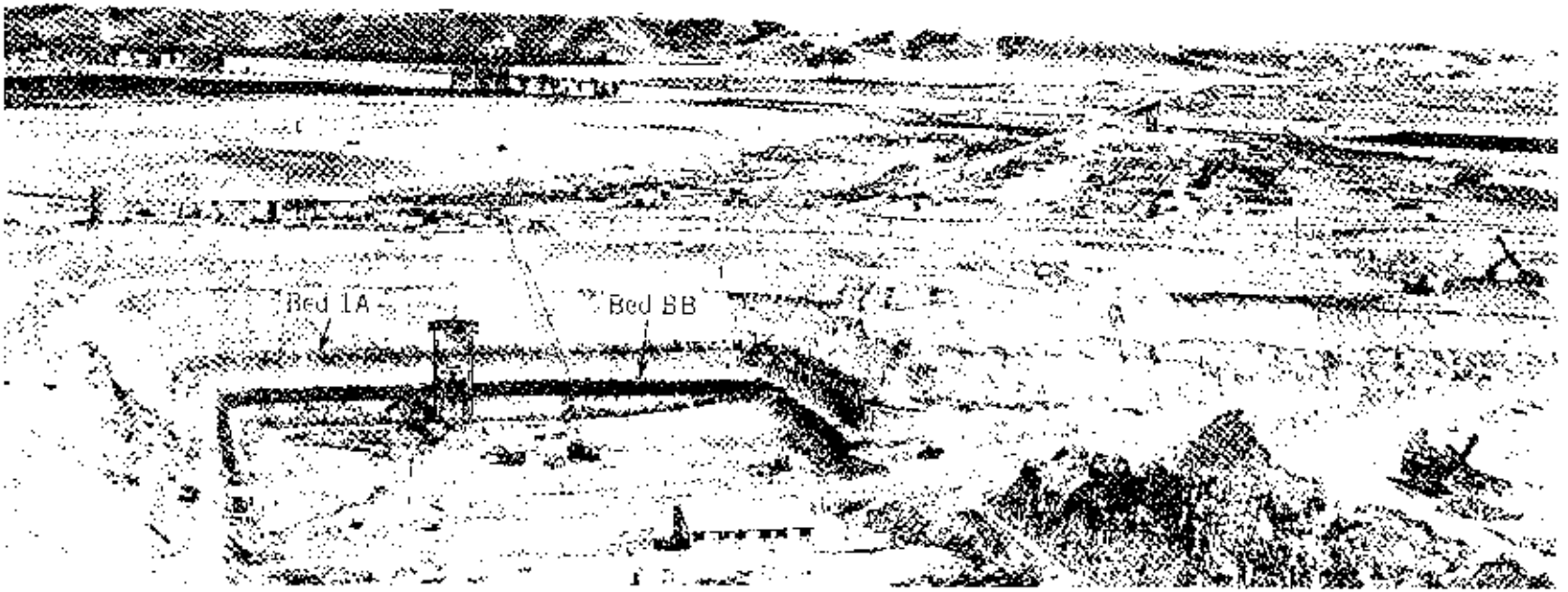

Figure 7. - Occurrence of lignite beds in the powerhouse excavation at Garrison Dam, N. Dak.

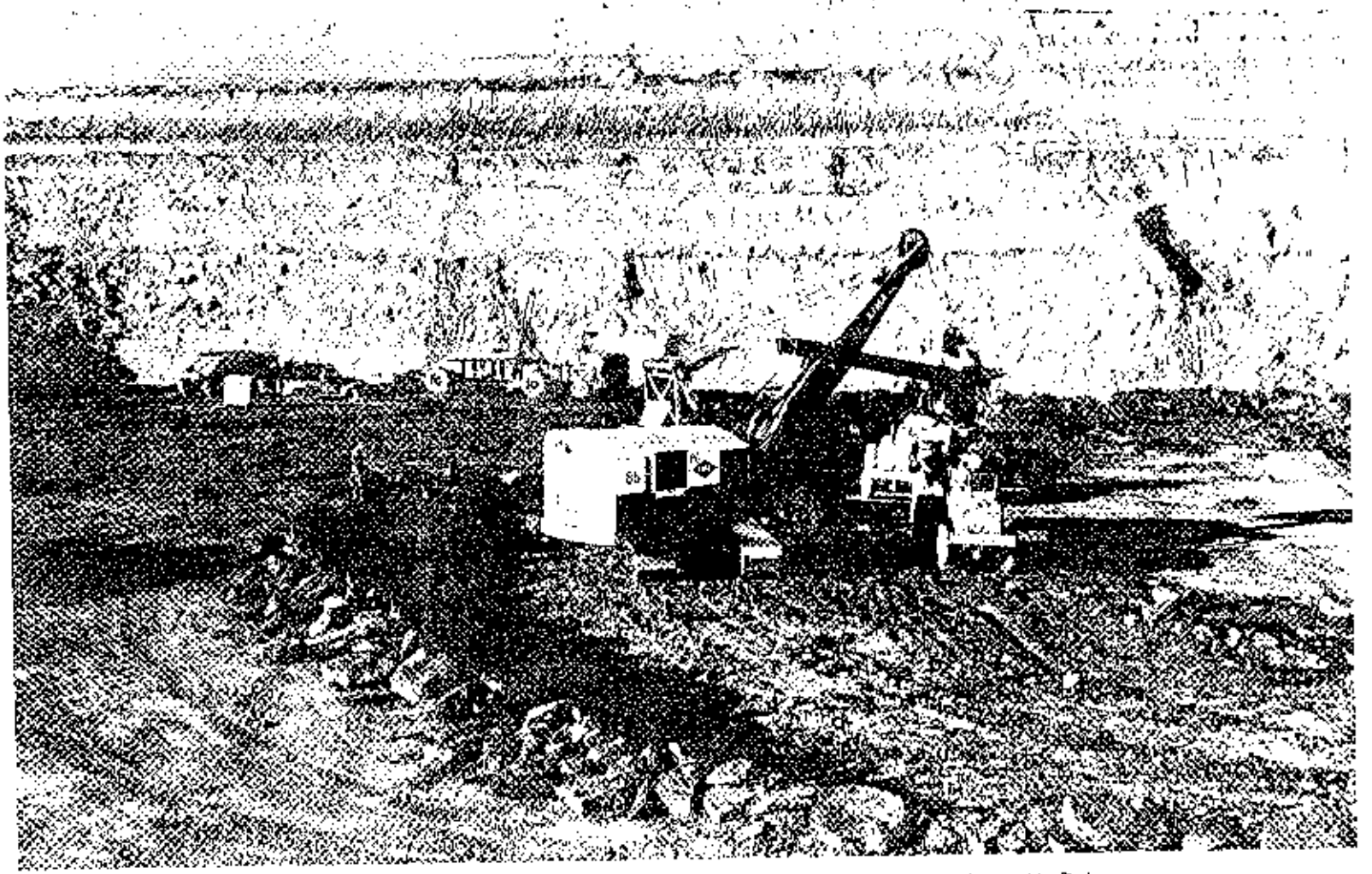

Figure 8. - View of the lignite-removal operations at the Garrison Dam, N. Dak.

a boiler plant of the Veterans' Hospital at Buffalo, N. Y., resulting in recommendations as to operation. Services on 139 special problems were given 32 different Government agencies.

To aid Federal designers of fuel-burning equipment to be installed in cities throughout the United States, a tabulation was made of the design requirements of smoke-abatement ordinances of 22 cities.56/ The tabulation showed that even after many years of fuel-burning practice and experience there is no common standard of design, the variations in the requirements for the same type of equipment under the same conditions of operation being very great.

During research work at the Naval Gun Factory, Washington, D. C., to evaluate the significance of sulfur dioxide and sulfur trioxide in causing corrosion and deposits, it was found that analytical determinations in the gaseous products of combustion for SO_2 and SO_3 as made by the A.S.M.E. code method did not give accurate results. Minute quantities of copper, for example, in the coal being used proved to be one source of the difficulty. Using certain basic procedures of the A.S.M.E. method, new procedures were developed that gave satisfactory results.57/

A representative of the Bureau of Mines served as chairman of the Bureau of Federal Supply Technical Committee on Solid Fuels which completed a new Federal specification covering the purchase of anthracite. Federal coal-purchasing agents were supplied needed information on mines for use in making awards of contract, the bis for supplying coal to a number of agencies being studied and recommendations made for award.

Cooperative work with the Air Preheater Corp., of Wellsville, N. Y., on the prevention of deposits and corrosion on air preheaters was continued, studies being included on the use of alkaline sprays, which appear to offer promising possibilities. A section entitled, "Typical Economic Study,"58/ was prepared for the chapter on "Combustion and Fuels" of the twelfth edition of Kent's Mechanical Engineers' Handbook. At the request of various Government agencies, operating and performance data were collected on a new type of automatic heating equipment using anthracite to provide information necessary for determining the economic application of such equipment to Government buildings.

Boiler Feed-Water Conditioning

Analyses and resulting recommendations were made on 9,335 samples of boiler water during the fiscal year, as follows: 3,597 from the Department of the Army; 1,973 from the Department of the Air Force; 1,692 from the Veterans Administration; 476 from the District of Columbia Government; 445 from the Department of the Navy; 276 from the Public Housing Authority; 273 from the Post Office Department; 225 from the Department of Justice; 189 from the Bureau of Indian Affairs; 83 from the Federal Security Agency; 52 from the Public Health Service; 33 from the General Services Administration; 12 from the Department of Agriculture; 10 from the Department of Commerce; and 3 from the Bureau of Mines. This is about 7-percent increase over the previous year.

56/ Barkley, J. F., and Morgan, R. E., Fuel-Burning Equipment Dimensions Required by Smoke-Abatement Ordinances: Bureau of Mines Inf. Circ. 7557, 1950, 19 pp.

57/ Berk, A. A., and Burdick, L. R., A Method of Test for SO_2 and SO_3 in Flue Gases: Bureau of Mines Rept. of Investigations 4618, 1950, 9 pp.

58/ Morgan, R. E., Comparison of Fuels. 5. Typical Economic Study: Kent's Mechanical Engineers' Handbook Power vol., 12th ed., 1950, pp. 2-16 and 2-17, John Wiley & Sons, Inc., New York, N. Y.

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Reports and recommendations covering 28 analyses of various scales, sludges, and deposits, 26 miscellaneous special analyses, and 5 analyses of boiler compounds were made.

Five hundred and eighty special Bureau of Mines field water-test kits, 10,259 bottles of chemical reagents, and 12,060 test-kit replacement items were distributed to various Government activities. Distributing these kits and reagents from a central source saved Government agencies about $15,000 this year as compared to open-market purchase.

Consulting service was given the Department of the Navy on the use of special boiler compounds in the Eleventh Naval District and on feed-water treatment of the effluent from hot process lime-soda softeners; the Department of the Air Force on condensate treatment with pressure-jet equipment at the Memphis, Tenn., airport; the Veterans' Administration on feeding phosphate to avoid feed-line deposition at Perry Point, Md., and on methods of dissolving tannin at Castle Point, Md.; the Bureau of Indian Affairs on the use of various boiler water test kits; St. Elizabeth's Hospital, Washington, D. C., on control of leakage at handhole gaskets; the Public Schools of the District of Columbia on replacing soda ash with caustic soda to minimize return-line corrosion; the Bureau of Federal Supply on use of tannin for boiler feed-water treatment; the Garnet Patterson Junior High School and the Banneker Junior High School on proper operating methods to prevent pitting; the U. S. Naval Observatory, Washington, D. C., on instructions on boiler-water sampling and testing; the U. S. Engineer Office, Philadelphia, Pa., on preparation of a manual on boiler-water treatment; and the Weather Bureau on the prevention of deposits in Alaskan plants.

At the request of the Bureau of Yards and Docks, Department of the Navy, a test of several months' duration was made on an electrolytic scheme of preventing scale in boilers at the Naval Air Station, Anacostia, D. C.; the method proved to be unsatisfactory. At the request of the Public Works Officer of the Naval Research Laboratory, Anacostia, D. C., a performance test was run on a deaerating heater.

Report was received from the Albuquerque Indian School, Albuquerque, N. Mex., that the cost of operating its boiler plant was reduced $13,700 annually by the application of Bureau of Mines boiler-water treatment practices. Based on the number of boilers used, this saving agreed closely with a previously reported saving of $139,000 annually by the Atomic Energy Commission, Los Alamos, N. Mex.; if similar savings are assumed for the thousands of Federal boilers now being served by the Bureau of Mines, some $20,000,000 per year savings are indicated.

Instruction booklets[29] for boiler-plant engineers were completed on the use of an improved tannin colorimeter for testing boiler water, on testing water for chloride content, on testing boiler water for phosphate, on testing boiler water for causticity, on the use of a hydrometer to control boiler blow-down, on testing of treated condensate for pH, on boiler-water treatment services furnished by the Boiler-Water Service Section, and on a new and improved method of testing the pH of boiler water by indicator paper.

Boiler-Water Research

Research work was continued on the use of chemicals to prevent corrosion in condensate lines in heating systems. This condensate, formed when steam condenses, is ordinarily acidic and attacks pipe vigorously; it also usually carries oxygen, which is active in corroding pipe. Satisfactory abatement of corrosion has been found by the use of several different volatile, alkaline organic chemicals called "amines." For any given plant, the cost of such treating chemicals must be balanced against the costs of maintenance and replacement of pipe. Proper choice of amines also has a bearing on over-all costs of treatment. Plants with low feed-water make-up may find it economical to use amines, and other plants, such as those having very high make-up, may find it uneconomical. For example, in three large housing developments containing more than 4,000 dwelling units, the cost of the amines ranged from 40 to 88 cents per million pounds of steam delivered, and the total cost for the entire heating season in all three plants was only $291.00. This low cost of treatment is very marked, when compared to replacement costs of more than $100,000 caused by corrosion in a few years in a similar housing development put into operation at approximately the same time but using no preventive methods. For plants where the feed-water make-up is so high that chemical treatment with amines is uneconomical, a cheaper chemical is needed; considerable progress has been made with tests to determine the conditions under which relatively inexpensive chemicals, such as ammonia, can be used successfully.

Many industrial processes require the heating or boiling of caustic soda (sodium hydroxide) solutions. All too frequently the vessels involved develop cracks in highly stressed parts, such as rivet heads, riveted seams, welds, and pipe connections. These cracks are for the most part intercrystalline and are identical to those produced in the seams of steam boilers. The results of a large number of laboratory

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29/ a/ Instructions for Use of Improved Comparator for Tannin by Boiler-Water Color: Bureau of Mines Form BWS 9A, 1949, 4 pp.
b/ Instructions for Determining Chloride Concentration in Water by Use of Bureau of Mines Chemical Reagents: Bureau of Mines Form BWS 14, 1950, 7 pp.
c/ Instructions for Bureau of Mines Boiler-Water Test Kit for Phosphate: Bureau of Mines Form BWS 15, 1949, 7 pp.
d/ Instructions for Bureau of Mines Boiler-Water Test Kit for Causticity: Bureau of Mines Form BWS 16, 1949, 12 pp.
e/ Instructions for Using a Boiler-Water Hydrometer to Test for Density as a Guide for Blowdown Control: Bureau of Mines Form BWS 17, 1949, 7 pp.
f/ Instructions for Bureau of Mines Test Kit for pH of Treated Condensate: Bureau of Mines Form BWS 18, 1949, 3 pp.
g/ Boiler-Water Treatment Services Furnished by the Boiler-Water Service Section: Bureau of Mines Form BWS 19, 1950, 23 pp.
h/ Instructions for Test Kit for pH of Boiler Water by Indicator Paper: Bureau of Mines Form BWS 20, 1950, 3 pp.

tests are given in figure 9, which shows temperature plotted against caustic concentration.60/ All the cracking occurred in a well-defined zone, roughly above 180° F. and between 15 and 40 percent sodium hydroxide. Within this zone the probability of crack development was about 40 percent. Avoidance of the severe-cracking zone outlined by this study should greatly reduce the probability of such cracking in industrial practice, but it cannot be said that conditions outside this zone will not produce cracking in highly stressed steel over long periods of time.

Smoke Abatement

Work on smoke-abatement problems continued quite active throughout the United States. Cities requesting Bureau of Mines publications and consulting service include the following: Providence, R. I.; Homewood, Ill.; Dearborn and Wyandotte, Mich.; East Syracuse, Great Neck, and Penn Yan, N. Y.; Cumberland, Md.; Indianapolis, Ind.; Bogota, N. J.; Springfield and Dayton, Ohio; Des Moines, Iowa; and Philadelphia, Pa. Upon request, an engineer of the Bureau of Mines met in conference with the smoke-regulation engineers of a number of cities in the Detroit-Windsor area to discuss proper handling of smoke-abatement problems. Work on smoke-abatement problems for the International Joint Commission was continued by its Technical Advisory Board on Air Pollution, which includes a Bureau of Mines engineer. Recommendations were made for abating the smoke from vessels on the Detroit River and its tributaries, including the establishment of a jurisdictional authority and the wording of a smoke-abatement ordinance.

Combustion

A chapter on combustion of solid fuels was published in the twelfth edition of Kent's Mechanical Engineers' Handbook.61/ This chapter discussed principles of combustion, stoichiometry and energetics of combustion, and combustion calculations of two types of material balances and an energy or heat-balance type.

Corrosion of Wall Tubes in Steam Generators

Extended studies of the mechanism of external corrosion of furnace-wall tubes of high-capacity, slag-tap boiler furnaces were begun in 1942 by the Bureau of Mines in cooperation with the Combustion Engineering Co. These studies have shown that liquid alkali-metal pyrosulfates can be formed under operating conditions from deposits of alkali-metal sulfates on the tubes. The rate of attack will be considerably higher when the alkali-metal sulfates, or "enamel" deposits, form a liquid phase than when a liquid phase is not formed. The phase boundaries for three compositions of alkali-metal sulfates in the system M_2SO_4-SO_3 have been established. The conditions for the thermal decomposition of coal ash, leading to the formation of the SO_3 necessary for the corrosion process, have been determined. Alkali-metal sulfate deposits on furnace tubes are believed to result from volatilization of alkalies in the coal, which condense as corresponding oxides on the tubes and then convert to sulfates by reaction with SO_3 in the furnace atmosphere. Furnace-wall-tube attack, associated with deposits consisting mainly of FeS, is believed to be related to the deposition of pyrites on the tubes. The pyrites originate from coarse coal or coal that is poorly distributed in the burners with respect to size. It adheres to deposits previously formed, of alkali-metal sulfates, oxidizes relatively slowly to

60/ Berk, A. A., and Waldeck, W. F., Caustic Danger Zone: Chemical Eng., vol. 57, June 1950, pp. 235, 236, 238.

61/ Corey, Richard C., and Graf, Ernst G., Combustion: Kent's Mechanical Engineers' Handbook, Power vol., 12th ed., 1950, pp. 2-03 to 2-12, John Wiley & Sons, Inc., New York, N. Y.

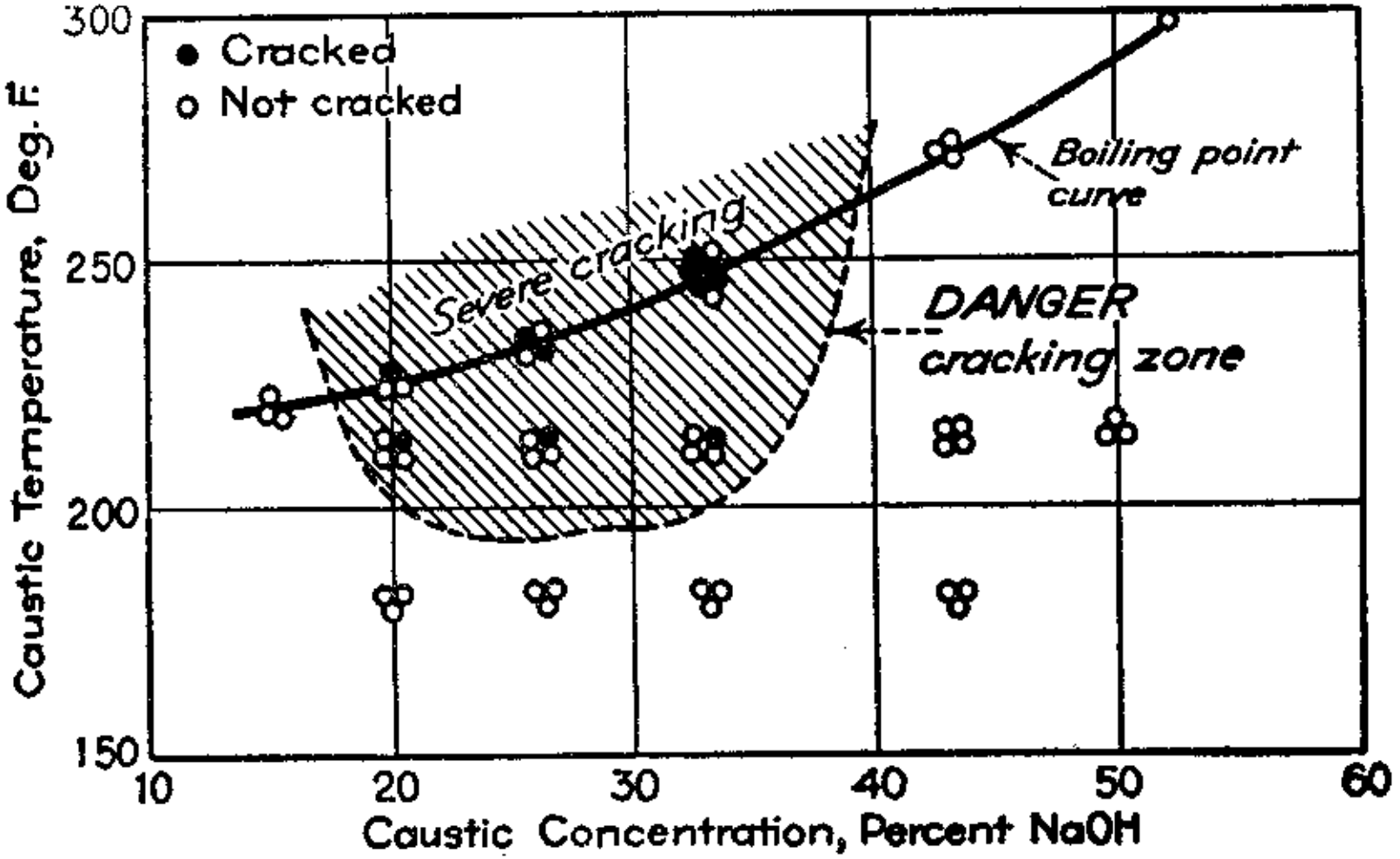

Figure 9. - Conditions of temperature and concentration of sodium hydroxide under which cracking of steel container may readily occur.