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THE BOWIE-GAVIN PROCESS

ITS APPLICATION TO THE CRACKING OF TARS AND HEAVY OILS, ALSO TO THE RECOVERY OF OIL FROM OIL-SOAKED SANDS OR SHALES, OR FROM OIL SHALES

BY

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THE BOWIE-GAVIN PROCESS: ITS APPLICATION TO THE CRACKING OF TARS AND HEAVY OILS, ALSO TO THE RECOVERY OF OIL FROM OIL-SOAKED SANDS OR SHALES OR FROM OIL SHALES

By C. P. Bowie

INTRODUCTION

Petroleum engineers estimate that, under present methods of production, when an oil field is at the point of abandonment the sands still hold 80 to 85 per cent of the oil they originally contained. The total production of the world from 1857 to 1925 was approximately 12,384,473,000 barrels of oil. On this basis, when the oil fields that have produced in the past and are now producing have reached the point of abandonment, the sands will retain nearly 50,000,000,000 barrels of oil.

As many of the best wells in the United States are producing from sands 4,000 to 5,000 feet beneath the surface, to mine these successfully will not be possible until the price of petroleum products has increased greatly and present methods of mining have been revolutionized. It is estimated, however, that the oil shales of Colorado, Wyoming, Utah, Nevada, and Montana alone contain more than 100,000,000,000 barrels of crude oil.

In Santa Barbara County, Calif., are accessible deposits of oil-soaked sands and shale more than 1,000 feet thick. The oil-sand and "tar-spring" deposits of Alberta, Canada, all of which may be considered accessible, are estimated to contain more than 250,000,000,000 barrels of oil. These are only three instances of numerous places in the world where accessible deposits exist.

In view of the rapidly increasing demand for petroleum and its products, the Bureau of Mines believes that at least a study should be undertaken of ways and means to recover the "last drop" of usable oil in the ground, no matter what the conditions of its occurrence and what the other substances are with which it may be associated.

This paper describes a process and an apparatus designed to recover oil from such deposits. It also gives the results of extensive experimental work done by the bureau with the apparatus in cracking tars and heavy oils which, being perhaps the most accessible, will first be utilized to eke out the waning production from wells. This process can be used to recover oil from oil shale and oil-soaked sands, and the authors believe that when the necessary economies in its operation are worked out the process can be applied to cracking asphalts, still bottoms, and similar heavy residuals at refineries.

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Acknowledgment is also made of the assistance of M. J. Gavin, of the Bureau of Mines, who collaborated in the early experimental work and during the greater part of the spring and summer of 1919. Especial thanks are due H. Foster Bain, former director of the bureau; A. W. Ambrose, former assistant director; F. B. Tough, former chief petroleum engineer; J. O. Lewis, former chief petroleum technologist; and J. H. Wiggins, former petroleum engineer. The assistance of E. C. Lane, assistant chemist; L. A. Penn, former chemical laboratorian; and J. S. Desmond, associate chemical engineer of the bureau, were invaluable. Lane and Penn did most of the experimental work with the laboratory apparatus, and Desmond had virtually entire charge of the construction and operation of the 8-foot machine.

The castings for the bottom plate of the 8-foot machine were made by the Pacific Foundry Co., of San Francisco. Thanks are due E. J. Fowler and Dudley Baird, of that company, for valuable suggestions regarding construction. D. E. De Velbiss, chief engineer of the custom house buildings at San Francisco, an expert mechanic, not only loaned the facilities of his machine shops and forges, but voluntarily made a large number of appliances from materials furnished by the bureau.

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Board, for the donation of a 200-barrel tank; and the Port Costa Brick Co., for inert material.

OCCURRENCE OF SURFACE BITUMENS, OIL-SOAKED SANDS, AND SHALES

DEPOSITS IN THE UNITED STATES

Asphalts and bituminous rocks are widely distributed in the United States.[1] Asphalts are found in West Virginia, Oklahoma, Colorado, and Utah; bituminous limestones in Oklahoma, Texas, and Utah; bituminous sandstones in Kentucky, Missouri, Oklahoma, Texas, Utah, and California; veins of earthy bitumens of great purity in California; and brea in Oklahoma, Wyoming, California, and some parts of Montana.

In some of the States these deposits are extensive. Springs of tars and heavy oils in places have formed large deposits on the surface. In the Coast Range Mountains in California are oil-producing rocks nearly 1 mile[2] thick. Near Santa Paula, Ventura County, within 3 miles between Seesaw Creek and the Ojai Valley, is a deposit that is estimated to contain not less than 1,000,000 tons of material. Some of the wells drilled in the Edna field, San Luis Obispo County, Calif., show nearly 1,000 feet of oil-soaked sands. These wells produce daily 12 to 15 barrels of oil having a gravity of 12° to 14° A. P. I. Figure 1 shows an outcrop about 40 feet thick of the sands near that field.

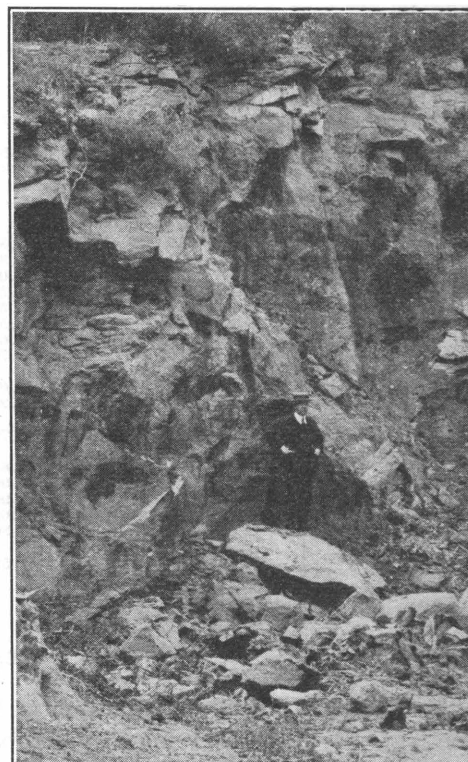

FIGURE 1.—Out crop of oil-soaked sand about 40 feet thick near the Edna oil field, San Luis Obispo County, Calif.

To the author's knowledge no estimate has ever been published of the quantity of oil that could be recovered from these deposits, but the total would unquestionably amount to billions of barrels.

[1] Eldridge, George H., The Asphalt and Bituminous Rock Deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., 1900–1901, pt. I, p. 219.

[2] Fairbanks, H. W., San Luis Obispo County—The Oil-Yielding Formations: Calif. State Mining Bureau Bull. 19, 1900, p. 146.

Retorting tests show that the oil-soaked sand and bituminous rocks contain 15 to 40 gallons of 20° to 24° A. P. I. oil per ton, and many of the asphalts and tars are so pure that when cracked they can be converted into an oil with a gravity of 20° to 24° A. P. I. through a loss in volume of not more than 12 to 15 per cent. The products "lost" are fixed gas and carbon, the former highly valuable as a fuel and the latter also having a fuel value that depends on the proportion of combined inert material and the method of treatment. These products will be discussed later.

Table 1[3] gives analyses of sand from oil wells and outcrops in various parts of California.

TABLE 1.—*Analyses of sands from wells and outcrops in the California oil fields*

Field	Location	Gravity of oil produced from well	Amount of sand used	Amount of oil obtained [1]	Gravity of cracked product	Cracked product per ton	Gasoline to 428° F.	Remarks
	Sec. T. R.	*°A. P. I.*	*Grams*	*C. c.*	*°A. P. I.*	*Gallons*	*Per cent*	
Coalinga	12 20 14	15.0	1,000	90	19.81	21.5	13.0	Old sand from sump.
Do	24 20 14	14.5	877.5	200	21.84	54.6	--------	Fresh sand from wells.
Do	27 19 15	22.0	1,247	90	26.00	17.0	--------	Old sand from sump.
Kern River	25 28 27	13.0	1,000	160	21.52	38.3	12.5	Do.
Do	36 28 27	13.0	1,000	89	21.52	21.3	15.0	Do.
Do	31 28 28	14.0	1,000	70	21.52	16.7	--------	Do.
Do	28 28 28	14.0	1,000	102	23.68	24.4	15.0	Do.
Do	3 29 28	----------	1,000	108	20.70	25.8	18.0	Outcropping near surface.
Midway	36 31 22	22.0	1,000	111	27.68	26.6	17.5	Old sand from sump.
Sunset	2 11 24	13.0	1,000	60	19.25	14.3	--------	Surface sand from sump.
Do	2 11 24	13.0	1,000	62	20.70	14.8	--------	Sand from sump, 5 feet under surface.
Do	12 11 24	13.0	1,000	110	24.61	26.3	18.0	Old sand from sump.
Do	12 11 24	12.8	1,000	64	25.90	15.3	19.0	Do.
Do	1 11 24	16.0	1,000	46	25.90	11.0	--------	Do.
Do	1 11 24	16.0	910	58	20.62	14.7	14.0	Do.
Do	13 11 24	14.0	----------	----------	22.80	16.0	--------	Outcropping near surface.
Salt Lake	(2)	15.0	872	226	24.52	62.1	20.5	Old sand from sump.

[1] Oil recovered from sands by retorting. [2] Niles lease.

HEAVY OILS

In California a large production of heavy oils ranging in gravity from 7½° to 14° A. P. I. might possibly be developed if a means can be found to convert them into lighter products that can be marketed. In 1924 the Associated Oil Co. was able to produce, at Casmalia, near Santa Maria, Calif., about 1,000 barrels a day of 10° A. P. I. oil because it could pump still bottoms with a gravity of approximately 32° A. P. I. from its Gaviota pump station, about 40 miles distant on the coast. Enough of these still bottoms is mixed with the heavy oil to reduce the viscosity so that the mixture can be pumped through pipe lines and marketed as fuel oil. The oil occurs

[3] Elliott, A. R., Recoverable Oil in By-Product Sands and Outcrops: Reports of Investigations, Serial No. 2182, Bureau of Mines, November, 1920.

with hot water (about 160° F.), and the limit of the production is the amount of still bottoms obtainable.

Such heavy oils could seemingly also be developed in large quantities in the vicinity of Santa Paula, in Ventura County, near Los Angeles, and in the Sunset-Midway and Kern River oil fields in Kern County.

OIL SHALES

As is well known, there are enormous quantities of oil shale in Colorado, Wyoming, Utah, Nevada, Montana, and parts of California; it is estimated that more than 100,000,000,000 barrels of crude oil can be produced from these shales if suitable process and apparatus can be devised.

DEPOSITS OUTSIDE THE UNITED STATES

Large quantities of heavy oils occur in Mexico and Canada; Trinidad, Colombia, and other parts of South America; in Central America; along the west coast of Africa; in Russia and in Galicia; in Persia; and in other districts of the Old World.

In virtually all fields where the heavy oils occur are also extensive deposits of oil-soaked sands, shales, and limestones. Dawson [4] describes the tar sand deposits along the Athabaska River, in the Province of Alberta, Canada, as follows:

> The occurrence of great quantities of bitumen or maltha along a portion of Athabaska River has long been known, having been noticed and commented upon by the very earliest travelers in the region. Beds of sand or very soft sandstone of Cretaceous age, varying from 140 to 225 feet in thickness, are there found to be more or less completely saturated with bitumen, for a distance of some 90 miles along the river. These beds are known as "tar sands." More recently a number of smaller occurrences of bitumen in the form of "tar springs" as well as sources of combustible gas, have been found in different places over a very extensive district. All these circumstances point to the probable existence of a great petroleum field, of which possibly some parts have already exhausted themselves in saturating the lowest Cretaceous sands, but of which probably the greater portion is still effectually sealed by the thick covering of overlying rocks. It is believed that the source of the petroleum which has given rise to the deposits of bitumen is in the Devonian strata, which here immediately underlie those of Cretaceous age.

CRACKING PROCESSES FOR HEAVY OILS AND TARS

Many so-called cracking processes have been patented for obtaining low-boiling hydrocarbons from heavier hydrocarbons by destructive distillation. The first patent of this kind seems to have been granted by the British Government in 1865 to a certain George Young. At present several cracking processes producing gasoline and

[4] Dawson, G. M., Summary Report on the Operations of the Geological Survey for the Year 1894: Canada Geol. Survey, 1895, p. 6A.

some of the lighter hydrocarbons are in commercial operation in the United States, but these use for their original oil relatively light products, which when subjected to destructive distillation yield only small amounts of free carbon. So far as the author is informed, none of these processes can be successfully applied to the destructive distillation of tars or very heavy oils, because so much free carbon is produced that deposits of it soon form on the inner shell of the still and cause local overheating, or clog the vapor lines, thus stopping operation.

THE BOWIE-GAVIN PROCESS

PRINCIPLE OF THE PROCESS

In 1916 and 1917 the Bureau of Mines spent much time and money attempting to perfect a process for cracking heavy oils and tars but was unable to overcome the difficulties caused by the large amount of free carbon produced. The inventors of the Bowie-Gavin process, while examining the results of an experiment in the retorting of oil-soaked shales, noticed that the oil produced had a distinctly "cracked" odor, and that in its production the free carbon liberated during the destructive distillation did not adhere to the sides of the retort or deposit in the vapor lines, but was entrained in the shale that contained the oil. These facts suggested the possibility of overcoming the carbon difficulties in cracking processes by mixing inert materials in proper proportion with the oil before it entered the cracking zone.

BENCH RETORT USED FOR TESTS

To make a series of preliminary experiments, a small bench retort (shown in fig. 2) was devised. It was made by welding disks cut from ⅝-inch boiler plate over the ends of a piece of 4-inch extra-heavy pipe about 14 inches long. In one of these covers a hole was drilled and a 2-inch plug containing a thermometer well was inserted. On the side near one end was welded an outlet to which a vapor line and condenser could be attached. Ordinary red brick was used for the temporary furnace, which was heated with Bunsen burners.

Using this small bench apparatus the author made a series of experiments with various types of inert material in varying proportions, ground to various meshes, and hydrocarbon compounds ranging from refined asphalt, such as would be chopped from a barrel, to oil of 16° A. P. I. Experimental runs were also made with oil-soaked sands and shales from different localities and with oil shales, such as occur in Utah, Colorado, and Nevada.

RESULTS

The process thus devised, termed the "Bowie-Gavin process," gave remarkable results. For instance, asphalts and tars of such heavy gravity as to remain virtually solid at ordinary temperatures could be converted into a cracked oil having a gravity of from 20° to 24°

A. P. I., with a loss in volume of 12 to 15 per cent. This loss, as stated before, consisted of fixed gases and carbon; the former is very valuable as fuel, as its heating value is about 1,300 B. t. u. per cubic foot against 550 B. t. u. per cubic foot for San Francisco city gas.

Table 2 gives the results of some of the more important experiments made with the bench still. The main points illustrated by

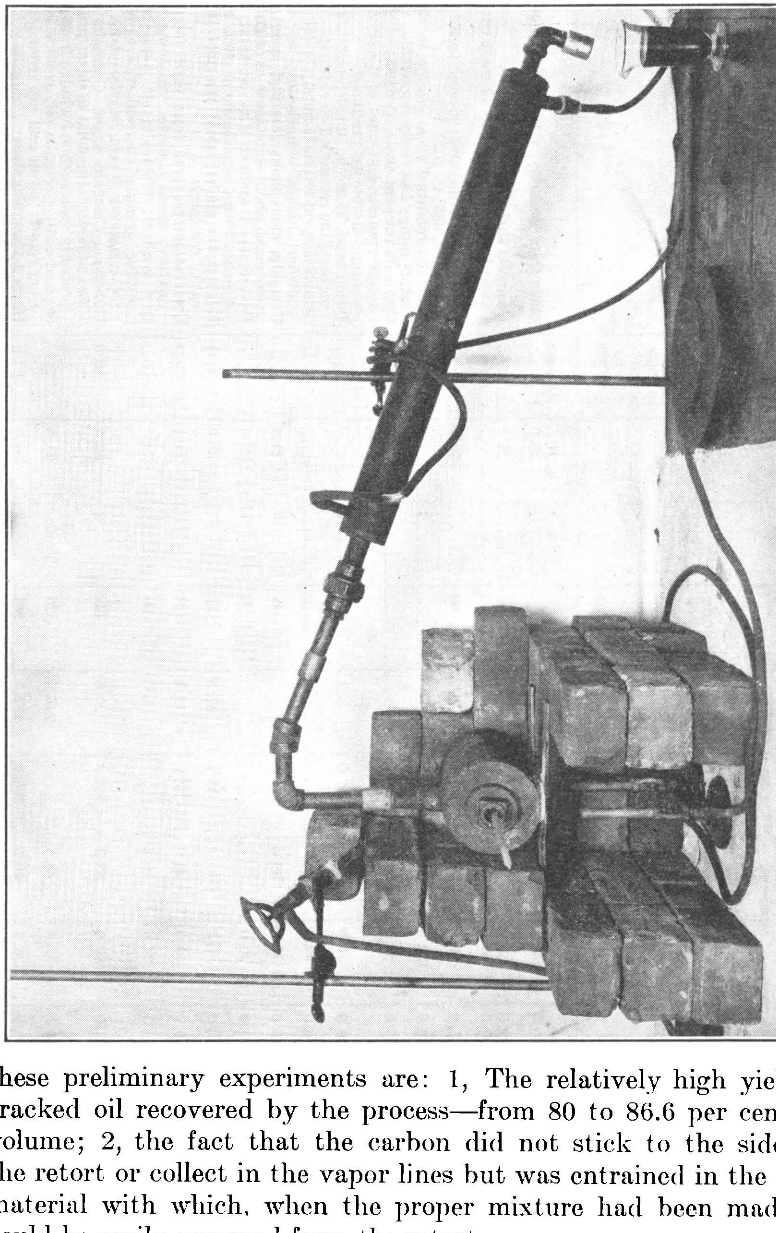

FIGURE 2.—Bench retort made from 4-inch extra-heavy pipe

these preliminary experiments are: 1, The relatively high yield of cracked oil recovered by the process—from 80 to 86.6 per cent by volume; 2, the fact that the carbon did not stick to the sides of the retort or collect in the vapor lines but was entrained in the inert material with which, when the proper mixture had been made, it could be easily removed from the retort.

TABLE 2.—*Results of experimental work with small bench retort (Bowie-Gavin process)*

Run number	Gravity of original oil	Weight of original oil and water	Weight of inert materia	Inert material, by weight	Weight inert material and carbon recovered	Approximate weight of oil recovered	Volume cracked oil recovered	Volume water recovered	Gravity cracked oil recovered	Cracked oil recovered approximate (oil and water in shale deducted), by volume	Remarks
	° A. P. I.	*Grams*	*Grams*	*Per cent*	*Grams*	*Grams*	*C. c.*	*C. c.*	*° A. P. I.*	*Per cent*	
10	13.4	200.0	200.0	50.0	----------	----------	----------	----------	29.0	----------	Shale from Berkeley, Calif.; still foamed; Casmalia, Calif., crude oil.
11	13.5	168.0	50.0	23.0	----------		----------	----------	24.5	----------	Casmalia shale, Casmalia oil.
12	13.4	160.0	160.0	50.0	181.0	----------	125	----------	----------	----------	Casmalia shale ground to 42 mesh contained about 22 gallons oil per ton.
13	7.5	235.0	150.0	39.0	----------	----------	90	----------	22.0	----------	Casmalia reburned shale ground to 100 mesh; highest temperature in retort, 385° C. (725° F.).
15	7.5	188.0	132.0	41.4	----------	----------	----------	----------	----------	----------	Casmalia reburned shale ground to 100 mesh; spent material in retort lumpy but easily removed.
16	7.5	150.0	50.0	25.0	----------	----------	----------	----------	----------	----------	Casmalia unspent shale, 35 mesh; still foamed; spent material in retort granular and most of it easily removed; large amount of noncondensable gas produced.
17	7.5	60.0	40.0	40.0	47.0	----------	37	10	----------	----------	Beach sand, 35 mesh; spent material in retort in soft cakes which on breaking resembled steel filings; very abrasive.
19	7.5	60.0	40.0	40.0	----------	----------	----------	----------	----------	----------	Casmalia spent shale, 35 mesh; spent material in retort in form of powder; highest temperature, 398° C. (748° F.).
20	7.5	70.0	30.0	30.0	36.0	----------	45	19	20.0	----------	Casmalia spent shale, granular; spent material in retort in granuular mass, about same mesh as original material.
26	7.5	225.0	49.0	----------	----------	----------	172	4	21.0	----------	Diatomaceous earth in Rittman tube; filled bottom of tube about 6 inches with Casmalia spent shale before pouring in mixture.
27	10.0	67.2	67.2	50.0	68.7	47.8	52	3	22.2	80.4	Dehydrated shale; spent material in retort dry and granular, easily removed.
28	10.0	150.0	50.0	25.0	65.7	114.2	124	3	22.2	81.9	Used shale recovered from experiment 27; retorted 203.2 grams mixture; spent material remaining in retort easily recovered.
29	10.0	109.5	24.8	18.5	----------	86.3	94	----------	22.5	----------	Dry sawdust; Casmalia oil; odor of creosote very noticeable; residue, granular charcoal sticking somewhat to sides of retort; 8 c. c. aqueous liquid, largely acidic.
30	10.0	164.0	82.0	33.3	103.3	126.8	138	2	22.4	80.0	Unburned Casmalia shale; Casmalia oil; residue in retort cokelike, adhering somewhat to sides; probably too high temperature; probably some carbon included from previous run.[1]
31	10.0	134.7	67.3	33.3	----------	113.6	123	Trace.	21.6	----------	Ground coal; Casmalia oil; residue cokelike but easily removed from retort; oil in coal not determined.
32	10.0	200.0	133.3	40.0	155.0	152.5	164	2	20.5	82.8	Burned Casmalia shale; Casmalia oil; probably some carbon included from previous run.

33	10.0	156.8	104.5	40.0	105.7	134.5	144	2	19.8	82.8	Unburned Casmalia shale; Casmalia oil.[1]
34	10.0	188.3	80.7	30.0	90.8	159.2	170	2	19.5	84.7	Unburned Casmalia shale; Casmalia oil; residue in retort cokelike.[1]
35	10.0	206.0	68.6	25.0	81.5	173.0	186	2	20.5	85.8	Do.[1]
36	10.0	159.3	79.6	50.0	155.7	133.7	144	----------	20.8	----------	Equal parts by weight of Casmalia unburned shale and blacksmiths' coal used as inert material; residue cokelike, one solid piece; moisture in coal not taken.[1]
37	10.0	118.8	79.2	40.0	----------	99.8	104	----------	15.8	----------	Blacksmiths' coal; Casmalia oil; residue in retort coke hard to remove; still foamed slightly; moisture in coal not taken.
39	10.0	79.1	33.9	30.0	35.2	67.9	74	----------	22.6	86.6	Unburned Casmalia shale; Casmalia oil.[1]
40	10.0	114.7	28.6	20.0	35.9	92.1	98	----------	19.0	81.1	Do.[1]

[1] Contained approximately 20.8 gallons oil per ton and 13 gallons water per ton.

Aside from the high yield of cracked product, the gravity is to be noted. This ranged from 15.8° to 29°, averaging around 22° A. P. I. Inasmuch as the cracking took place at atmospheric pressure, these yields and gravities seem very remarkable.

OIL PRODUCED

When the cracked oil from these experiments was distilled it yielded 18 to 22 per cent of a gasoline cut boiling to 428° F. (220° C.), 30 to 35 per cent of a kerosene cut boiling between 428° F. (220° C.) and 572° F. (300° C.), and a residual oil having a gravity of 15° to 18° A. P. I. and a viscosity, even when the gravity was 15° A. P. I., virtually the same as that of California crude with a gravity of 20° A. P. I. This meant that no matter how heavy and viscous was the tar or asphalt used for the original charge the oil that remained after the gasoline and kerosene cuts had been removed from the cracked product would still be so fluid as to flow through a pipe line freely without heating; the residual, therefore, could at least be used for a fuel oil even if parts of it were not possibly more valuable for other uses. Typical analyses of these cracked oils appear in Tables 3, 4, and 5.

The analyses of the oils indicate that no great difference is due to the action of shale or coal. The gasoline yield, up to 437° F. (225° C.), from the oil made with the shale was slightly higher and the viscosity of the oil slightly lower than from the oil made with the coal. However, these differences may have been due to a slight difference in the temperature carried.

The gasoline and kerosene produced from the "cracked" oil contains a relatively large proportion of unsaturated hydrocarbons, but it is believed that, especially for the gasoline, this will be no serious detriment where the oils can be carefully refined and blended with the required proportions of uncracked products before being marketed.

CARBON

When the proper proportion of inert material ground to the proper mesh was mixed with the heavy oil, no carbon settled on the sides of the retort or in the vapor lines, but all was deposited in the inert material.

TABLE 3.—*Distillation analysis of crude oil obtained by cracking Casmalia 10° A. P. I. crude in Bowie-Gavin furnace in presence of dry shale*

[Sample No. 00635; specific gravity of oil, 0.942; A. P. I. gravity, 18.7°; percentage of sulphur, 2.7; percentage of water, nil; Saybolt Universal viscosity at 50° C. (122° F.), 55 sec.; amount distilled, 300 c.c. Distillation, Bureau of Mines Hempel method]

AIR DISTILLATION: FIRST DROP, 39° C. (102° F.)

Temperature, ° C.	Per cent cut	Sum, per cent	Specific gravity of cut	° A. P. I. of cut	Viscosity	Temperature, ° F.
Up to 50						Up to 122
50–75	0.6	0.6				122–167
75–100	1.2	1.8	0.767	53.0		167–212
100–125	2.1	3.9				212–257
125–150	3.3	7.2	.825	40.0		257–302
150–175	2.5	9.7	.842	36.6		302–347
175–200	3.7	13.4	.850	35.0		347–392
200–225	4.6	18.0	.860	33.0		392–437
225–250	6.0	24.0	.873	30.6		437–482
250–275	8.7	32.7	.893	27.0		482–527
275–300						527–572

VACUUM DISTILLATION AT 40 MM.

Temperature, ° C.	Per cent cut	Sum, per cent	Specific gravity of cut	° A. P. I. of cut	Viscosity	Temperature, ° F.
Up to 175	1.3	1.3	0.917	22.8	45	Up to 347
175–200	3.4	4.7				347–392
200–225	7.4	12.1	.933	20.2	56	392–437
225–250	7.7	19.8	.950	17.5	112	437–482
250–275	7.3	27.1	.966	15.0	258	482–527
275–300	8.4	35.5	.975	13.6	493	527–572

TABLE 4.—*Distillation analysis of crude oil obtained by cracking 10° A. P. I. Casmalia crude in the Bowie-Gavin furnace in the presence of Castlegate, Utah, coal*

[Sample No. 00626; specific gravity of oil, 0.952; A. P. I. gravity, 17.1°; percentage of sulphur, 2.6; percentage of water, 0.1; Saybolt Universal viscosity at 50° C. (122° F.), 75 sec.; amount distilled, 300 c. c. Distillation, Bureau of Mines Hempel method]

AIR DISTILLATION: FIRST DROP, 62° C. (144° F.)

Temperature, ° C.	Per cent cut	Sum, per cent	Specific gravity of cut	° A. P. I. of cut	Viscosity	Temperature, ° F.
Up to 50						Up to 122
50–75	0.3	0.3				122–167
75–100	.8	1.1	0.757	56.2		167–212
100–125	1.2	2.3				212–257
125–150	2.2	4.5	.798	45.8		257–302
150–175	2.7	7.2	.830	39.0		302–347
175–200	3.4	10.6	.854	34.2		347–392
200–225	4.4	15.0	.865	32.1		392–437
225–250	5.7	20.7	.880	29.3		437–482
250–275	8.4	29.1	.900	25.7		482–527
275–300						527–572

VACUUM DISTILLATION AT 40 MM.

Temperature, ° C.	Per cent cut	Sum, per cent	Specific gravity of cut	° A. P. I. of cut	Viscosity	Temperature, ° F.
Up to 175	0.2	0.2	0.915	23.1	47	Up to 347
175–200	4.1	4.3				347–392
200–225	6.5	10.8	.933	20.2	63	392–437
225–250	9.2	20.0	.954	16.8	123	437–482
250–275	7.6	27.6	.970	14.4	257	482–527
275–300	10.5	38.1	.982	12.6	615	527–572

TABLE 5.—*Analysis of oil (Bowie-Gavin distillate) obtained by cracking 12.5° A. P. I. Panuco (Mexican) crude oil*

[Sample No. F-001; specific gravity of oil, 0.919; A. P. I. gravity, 22.5°; Saybolt Universal viscosity at 100° F., 65 sec.; amount distilled, 300 c. c. Distillation, Bureau of Mines Hempel method]

AIR DISTILLATION: FIRST DROP, 54° C. (129.2° F.)

Temperature, ° C.	Per cent cut	Sum, per cent	Specific gravity of cut	° A. P. I. of cut	Viscosity	Cloud test, ° F.	Temperature, ° F.
Up to 50							Up to 122
50–75	0.5	0.5	0.728	62.9			122–167
75–100	1.6	2.1					167–212
100–125	2.6	4.7	.760	54.7			212–257
125–150	3.8	8.5	.783	49.2			257–302
150–175	4.5	13.0	.803	44.7			302–347
175–200	4.8	17.8	.823	40.4			347–392
200–225	5.7	23.5	.843	36.4			392–437
225–250	6.2	29.7	.867	31.7			437–482
250–275	7.5	37.2	.890	27.5			482–527
275–300							527–572
VACUUM DISTILLATION AT 40 MM.							
Up to 200	2.0	2.0					Up to 392
200–225	4.6	6.6	0.912	23.7	41	<0	392–437
225–250	9.0	15.6	.932	20.3	51	<0	437–482
250–275	7.9	23.5	.948	17.8	73	<0	482–527
275–300	11.7	35.2	.962	15.6	120	44	527–572

NOTE.—Unsaturation crude naphtha 25.3 per cent, crude kerosene 33.2 per cent. Refined and doctored with about 17 per cent loss, not including steam still bottoms.

INERT MATERIAL

The proper amount of inert material to be used depended, of course, on the gravity and nature of the oil to be cracked, also on the nature of the inert material. When asphalt-base California crude oil (gravity, 10° A. P. I.) and ground shale or clay were used, best results were obtained from a mixture by volume of approximately 60 per cent of oil with 40 per cent of inert material.

Oil-soaked shale, such as occurs in the vicinity of Santa Maria, Calif., and in its natural state contains approximately 23 gallons of oil per ton, was found to be an excellent inert material. The best results were obtained when it was ground to pass about ¼-inch mesh. The greater part of the inert material used in the experimental work was obtained from the Port Costa Brick Co., at Port Costa, Calif. It was taken after passing the pan mills, where it had been ground to the proper mesh for brickmaking. Sand of oil-soaked sands and sandstones, beach sand, coal, coke, and sawdust also served as inert materials, and the retort gave very satisfactory results when used to distill oil shales such as occur in Colorado, Utah, and Nevada.

TUBULAR STILL

DESCRIPTION

Although a process was devised that gave promise of treating tars and heavy oils, oil-soaked sands and shales, combinations of tars and heavy oils with oil-soaked sands and shales, and oil shales satisfactorily, no apparatus had been made that would successfully treat these materials on a commercial scale. The first apparatus designed was a tubular still (fig. 3).

The oil and inert material separately entered one end of a horizontal tube, made from 8-inch standard black pipe; the oil entered through

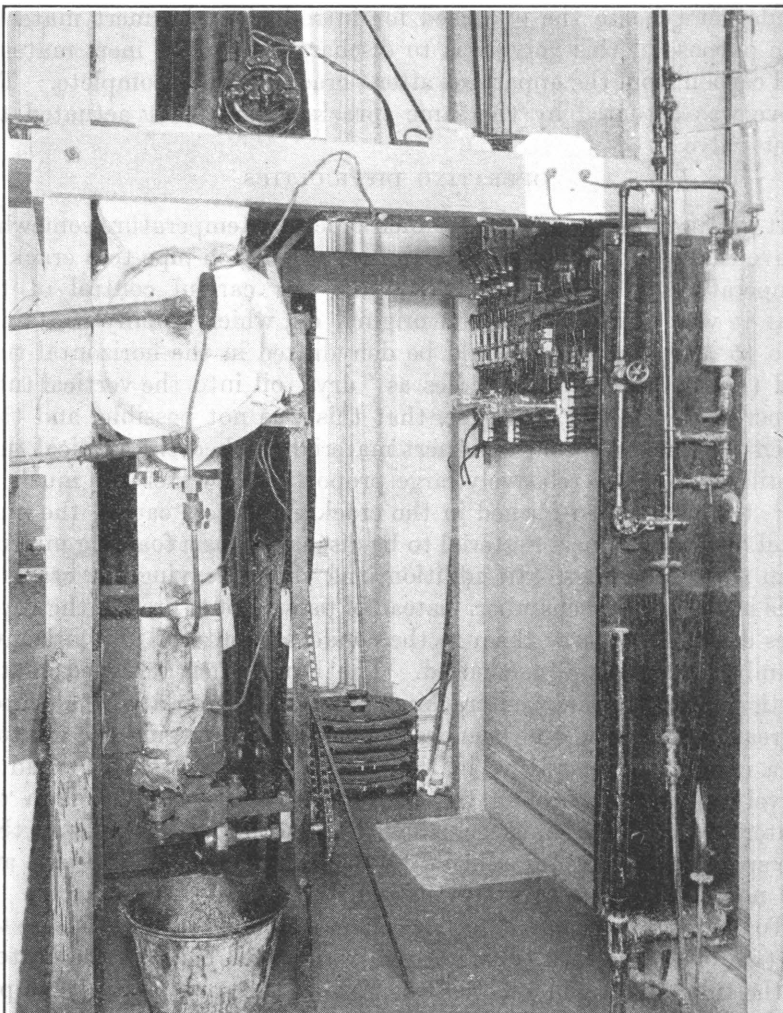

FIGURE 3.—Tubular cracking still and apparatus for electrical control

a cup in the bottom of which was a valve, and the inert material through a hopper beneath which was a pocket type of valve rotated by a sprocket and chain. Within the tube was a stirring rod fitted with paddles so inclined that their rotation mixed the oil and shale and conveyed them to a 3-inch vertical pipe welded to the 8-inch pipe near the opposite end. A relief valve was provided immediately above the 3-inch pipe, and the 3-inch pipe and the 8-inch pipe were fitted with openings in which thermometers or the terminals of pyrometers could be inserted. Both the horizontal and vertical pipes were incased in electric heaters and both were provided with vapor lines. In the bottom of the vertical pipe was a pocket valve similar in type to the one used for introducing the inert material. The purpose of this valve was to discharge the spent inert material and carbon from the apparatus after "cracking" was complete. The valve was actuated by the same sprocket chain that actuated the inlet valve.

OPERATING DIFFICULTIES

It was proposed to heat the 8-inch pipe to a temperature somewhat above that of boiling water and to heat the 3-inch pipe to a cracking temperature of approximately 800° F. By careful control of the heat it was believed that the original oil, which usually contained 2 to 15 per cent water, would be dehydrated in the horizontal tube and then forced by the paddles as "dry" oil into the vertical tube. Experiments proved, however, that this was not possible, and that when the mixture of oil and inert material reached the vertical tube it still contained a relatively large proportion of water—so much, in fact, that the steam formed in the cracking process caused the mass of oil, water, and inert material to be discharged as a foaming mixture from the vapor lines. In addition, the vapors leaving the cracking zone in the vertical chamber, instead of passing out through the vapor lines designed to carry them to the condenser, entered the horizontal chamber where they condensed. The liquid then returned to the vertical chamber and the cracking process was repeated. Further, a great deal of time and heat was consumed in bringing the mixture to a cracking temperature in the vertical pipe, as the heat had to travel 1½ inches through the inert material before the oil in the center of the pipe could be cracked. Another difficulty was that the spent inert material adhered to the sides of the vertical pipe and did not discharge by gravity through the valve in the bottom.

To overcome this last defect, scrapers were devised to fit inside the bottom of the vertical tube. A pan was placed beneath the bottom of the tube and a seal effected by allowing the spent material to pile up in the pan. A small piece of angle iron, bent to a curve of about 1½-inch radius, was fastened to the shaft that carried the scrapers, just above the inside bottom of the pan. It acted in much the same way as the vein in the runner of a centrifugal pump, discharging the surplus inert material, without breaking the seal, over the lip of the pan into an ordinary 4-gallon galvanized-iron bucket. After repeated changes and adjustments had been made in the length, size,

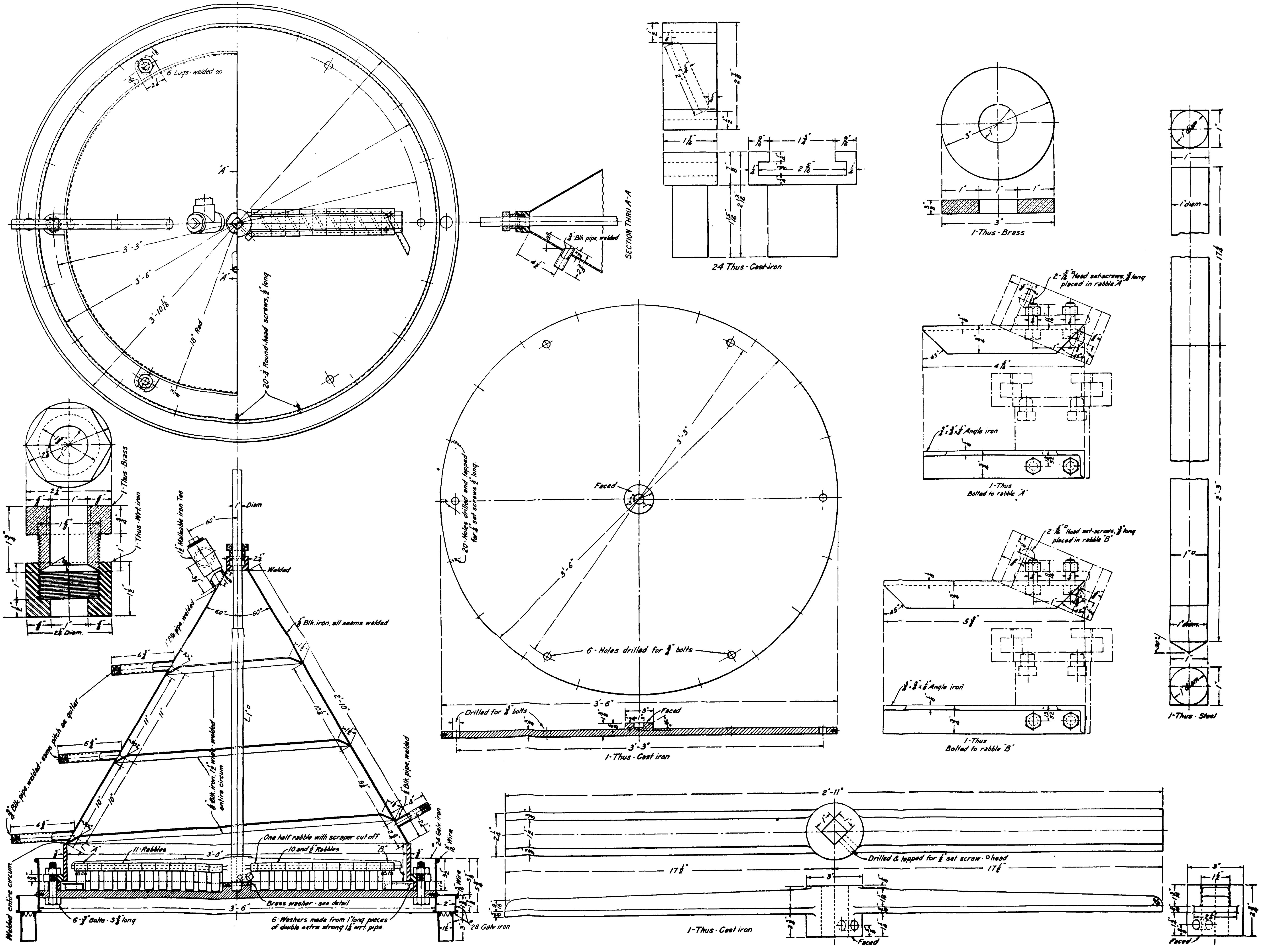

FIGURE 4.—Plan and elevation of the Bowie-Gavin cracking retort, laboratory size

and construction of this angle-iron vein or "gopher," the discharge mechanism gave satisfactory results, and the principle was used repeatedly in subsequent apparatus.

Virtually the entire summer and fall of 1919 were spent in experimental work with this apparatus, and many runs were made with it, but for all practical purposes it was a failure; hence details of those experiments are not recorded.

CONCLUSIONS

Although the results obtained were negative, they nevertheless had an important bearing on the design of a succeeding apparatus, as they brought out clearly the following points that would be essential to success on a commercial scale:

1. A successful machine must be so constructed that no matter how much water the oil contains the mixture can not foam into the vapor lines.
2. The vapors when once formed must immediately be removed from the cracking chamber, or else any condensate that forms within the retort must be removed and not allowed to return to the cracking zone.
3. Arrangements must be such that the mixture can be heated in thin layers; otherwise much time will be consumed in bringing all of the mixture to a cracking temperature, for the inert material is a very poor conductor of heat.
4. The inert material and entrained carbon must be discharged under seal when all the vapors have been removed.
5. The process must be continuous.

THE BOWIE-GAVIN APPARATUS

In an effort to fulfill these requirements the apparatus known as the Bowie-Gavin retort (shown in figs. 4 and 5) was designed and has since been developed. It consisted essentially of a bottom plate made of cast iron to which heat might be applied. Above this plate was a wrought-iron cone, to the inner walls of which were welded three troughs arranged to discharge any entering liquids into ¾-inch outlet pipes that also served as vapor lines. Resting on the center of the plate was a vertical shaft to which was attached rabble arms with rabbles so spaced that the rotation of the arms would carry material from the center of the plate toward its periphery. To the bottom of the cone was attached a circular angle iron which did not come in contact with the plate, but was supported at intervals by washers.

The outside of the bottom plate was surrounded by a ring of sheet iron that formed a lip. On the ends of the rabble arms were plows, also called gophers, that discharged the spent inert material beneath the angle iron and over the top of the lip. Figure 5 gives a good idea of the action of these plows. In this way the spent inert material

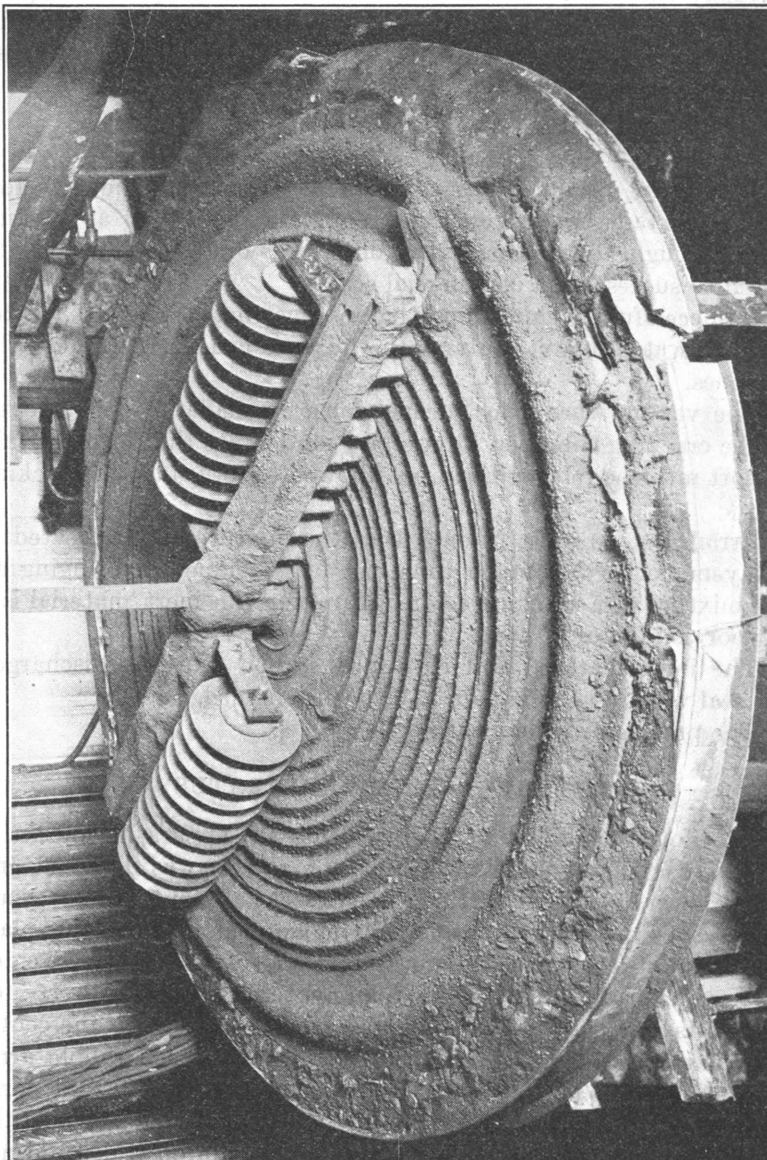

FIGURE 5.—Rolling type of rabbles, discharge plow, and movement of inert material

around the bottom of the cone formed a seal which was continually being replaced by added inert material forced outward by the plows; the surplus fell over the lip outside the apparatus without breaking the seal.

RABBLES

The original design of rabble was soon discarded for the rolling disk harrow type shown in Figure 5, which gives a view of the apparatus with the cone-shaped cover removed. The disks have the advantage that when set at the proper angle their motion as the arm revolves becomes partly slip and partly roll, and their weight is enough to force them continuously to scrape through the mass of inert material and oil. This action prevents carbon from building up on the plate and is decidedly important. The formation of carbon on the plate greatly decreases the efficiency of the process, as the heat must pass through the plate to the cracking zone.

The disk type of rabbles also is superior to a rigid type when the bottom must be made in more than one section, as is done in a retort of commercial size. Moreover, should one of the sections warp enough so that the edge projects above the normal surface of the plate and forms an obstruction, disks will roll up over it, whereas the rigid type of rabble will tear up the plate or break the harrow teeth or rabble arm.

SOURCE OF HEAT

Electric heaters were so placed beneath the bottom plate as to supply zones of constantly increasing temperature for the material moving from the center of the apparatus to its periphery. The electric heaters, however, were not altogether satisfactory; some of them were constantly burning out, and the construction of the machine was such that their replacement was rather tedious and difficult. For this reason and because a commercial apparatus would probably be fired either with gas or oil, the electric heaters were soon discarded for a circular gas furnace that was fired at three points on its circumference and so arranged that the products of combustion would travel from the outer rim of the plate toward a stack near its center. San Francisco city gas was then used as a source of heat. A small air blower was used to facilitate firing.

MIXER

In the first experiments with the laboratory-size machine the inert material was fed separately into the apparatus by means of a spiral conveyor operating in a T and a short piece of horizontal pipe so arranged as to drop the material on the center of the plate from a point near the apex of the conical cover. The oil, after being heated enough to make it fluid, was fed into a cup at the left of the cone near its top. However, equally satisfactory results were obtained by mixing the inert material and oil in the desired proportions and to the proper consistence before feeding them into the apparatus.

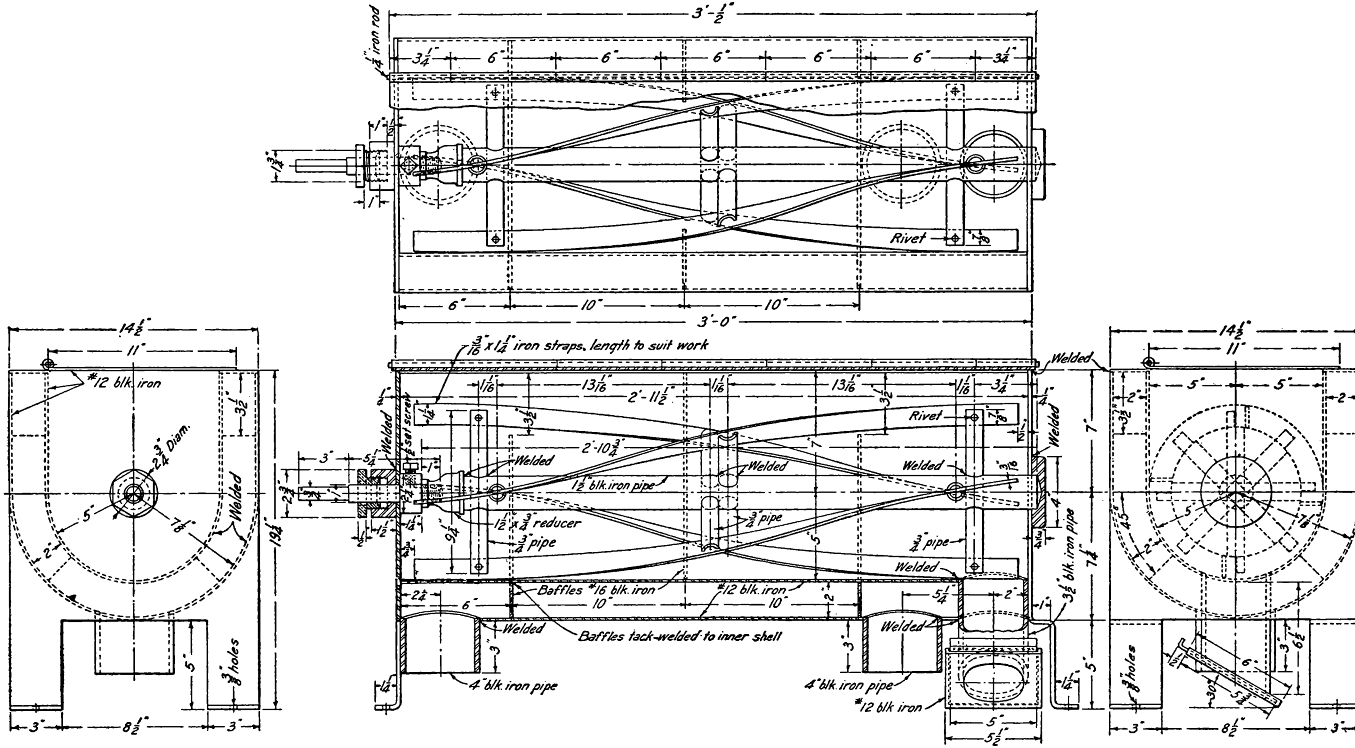

FIGURE 6.—Plan and elevation of mixer for oil and inert material

This mixing was done by means of a device (fig. 6) which consisted essentially of a double trough 3 feet long by 11 inches wide inside and 14½ inches wide outside. As Figure 6 shows, the bottom of the trough inside was rolled to conform to the circumference of a circle with a 5-inch radius. Within the trough and revolving on a central shaft were blades arranged in spirals in much the same manner as the blades of an ordinary lawn mower. The inert material and the oil to be mixed were placed within the trough and the blades slowly revolved. The blades mixed the material thoroughly and at the same time moved it gradually to one end of the apparatus, where it discharged through a 6-inch outlet pipe. The rate of discharge was controlled by a sliding door.

The mixer had a sheet-iron cover, and between the inner and outer walls was a space of approximately 2 inches divided by baffles into compartments. On the bottom of the outer wall near the ends were welded short pieces of 4-inch black pipe, from which sheet-iron pipe connections led to the furnace stack. By this arrangement part of the exhaust gases of combustion could be passed between the inner and outer walls of the mixer to preheat the oil and inert material during the mixing.

OPERATION OF APPARATUS

The mixture of oil and inert material was fed by means of a spiral conveyor (*5*, fig. 7) into the T attached to the top of the cone. The mixture fell on the plate near its center and the rabbles carried it in a relatively thin sheet to the periphery. As the material moved outward it passed through zones of increasing temperatures, and the oil it contained was cracked. Most of the vapors passed out through the vapor lines, but some condensed on the sides of the apparatus. This condensate ran down the inner surface of the cone and was prevented from returning to the cracking zone by the troughs, which carried it to the vapor lines and out of the apparatus. The condensate also served to wash down the light particles of carbon that settled on the sides of the apparatus and to carry them out through the condenser lines.

IMPROVEMENTS IN DESIGN

Noteworthy improvements in the design of this apparatus have been the construction of the bottom plate in two pieces to prevent cracking through expansion and contraction, the substitution of disk harrows for the rigid rabbles described, changes in the vapor lines, changes in the plows, and changes in the method of discharging the spent material which make the action more positive. These improvements will be discussed in the description of the semicommercial machine.

RESULTS OF EXPERIMENTS

By the end of 1923 the authors had made 72 runs with this apparatus; oils of various gravities and varying proportions of inert material were used in them. The longest continuous run, made with heavy Panuco (Mexican) crude, lasted 20 hours and 15 minutes, during which time 2 barrels of oil were fed into the apparatus. The results

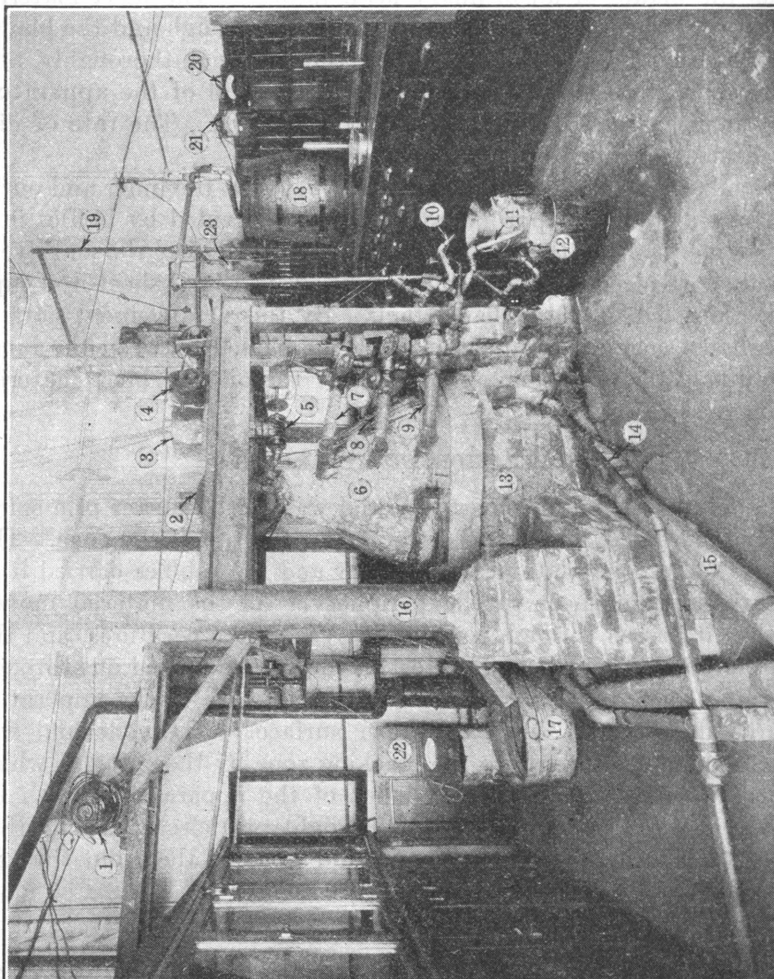

FIGURE 7.—Arrangement of apparatus and appurtenances in the San Francisco laboratory. (See text for explanation of figures)

obtained were highly satisfactory. Inspection showed that the apparatus at the end of the run was in virtually the same condition as at the beginning.

Figure 7 gives a good idea of the arrangement of the apparatus and its appurtenances in the laboratory at San Francisco at the time this run was made.

The numbering of the parts is as follows: *1*, Motor operating the main drive; *2*, main-drive pulley; *3*, oil and shale inlet; *4*, reduction gear driving the spiral conveyor in the T (*5*); *5*, T fitted with spiral conveyor; *6*, conical hood; *7*, *8*, and *9*, vapor condensate pipes leading to separate condensers; *10*, *11*, and *12*, outlets from the condensers; *13*, gas-fired furnace; *14*, gas pipe, supplying the furnace; *15*, air pipe supplying the furnace; *16*, furnace flue; *17*, receptacle for the inert material and carbon discharged from the apparatus; *18*, additional condenser through which the noncondensable gas passed; *19*, discharge pipe for the noncondensable gas; *20*, pyrometer indicator showing the temperature on the bottom plate of the apparatus; *21*, pyrometer indicator showing the temperature inside the apparatus, 6 inches above the bottom plate; *22*, pyrometer indicator giving stack temperatures; and *23*, gas meter for measuring the amount of noncondensable gas produced in the cracking process.

The mixer was being repaired at the time the photograph was taken and hence does not appear in Figure 7. It rested on the top of the platform and had its discharge end near *3*.

Tables 6 and 7 give the results of the 20-hour run. The gravity of the oil used in test 1 was 12.3° A. P. I.; the gravity of that used in test 2 was 13.2° A. P. I. The first run lasted from 11.30 a. m. to 10.05 p. m.; the second test began at 10.05 p. m. and lasted until 7.43 a. m. the next day. The fixed gas was measured as carefully as possible with a gas meter. Although it was wasted into the atmosphere, nevertheless an attempt was made to estimate the amount of fuel oil that would have been required to run the plant had oil been used as fuel and the fixed gas saved and burned with it. These figures, of course, can only be considered approximate.

TABLE 6.—*Test 1 made with Panuco crude oil of 12.3° A. P. I. gravity*

Time	Room temperature	Fuel gas, amount used	Temperature of vapors 6 inches above plate	Temperature outside of plate	Weight of shale and oil mixture	Weight of oil and water fed in	Weight of shale fed in	Loss by fixed gas	Weight of shale residue recovered	Weight of combined water and distillate recovered	Gravity of distillate corrected to 60° F	Stack temperature	Remarks
A. m.	*° F.*	*Cu. ft.*	*° F.*	*° F.*	*Lbs.*	*Lbs.*	*Lbs.*	*Cu. ft.*	*Lbs.*	*Lbs.*	*° A.P.I.*	*° F.*	
11.30	68	----	851	752	----	----	----	----	----	----	----	734	
12.30	73	200	716	824	73.55	29.40	44.15	80	33.87	28.75	23.8	761	
P. m.													
1.30	73	345	698	860	85.87	34.38	51.49	70	50.93	28.43	23.7	932	
2.30	77	305	743	914	85.50	34.20	51.30	80	53.06	28.56	21.0	944	Changed sprocket to increase feed; shut down 2 minutes.
3.30	75	250	698	878	91.72	36.69	55.03	70	51.37	30.37	23.7	960	Changed feed to original; 4 minutes lost.
4.30	75	355	770	914	82.88	33.15	49.73	90	50.00	30.18	21.0	937	More or less puffing out of vapor at shale discharge.
5.30	75	145	766	910	78.80	31.52	47.28	80	44.25	25.87	20.7	878	
6.30	75	370	756	950	85.90	34.36	51.54	85	47.12	28.68	20.8	971	
7.30	73	230	725	914	73.00	29.20	43.80	55	40.93	23.93	22.8	950	
8.30	75	300	743	932	83.60	33.44	50.16	65	50.75	30.00	23.1	910	
9.30	74	260	734	953	97.04	38.79	58.25	85	57.43	32.12	22.1	932	
10.05	75	140	743	968	53.34	21.35	31.99	40	32.56	19.00	22.3	919	Last of first drum of oil.
Total	----	2,900	----	----	891.20	356.48	534.72	800	512.27	305.89	----	----	

OIL USED AND RECOVERED

	Pounds
Weight of water and original oil (as above)	356.48
Weight of water in shale, 4.12 per cent of 534.72	22.03
Total weight of water and oil fed in	378.51
Weight of water recovered in distillate	85.95
Net weight of oil put in	292.56 = 35.68 gallons.
Weight of water and distillate recovered (as above)	305.89
Weight of water recovered	85.95
Net weight of oil recovered	219.94 = 28.70 gallons.

$\frac{28.70}{35.68}$ = 80.5 per cent, recovery by volume; $\frac{219.94}{292.56}$ = 75.1 per cent, recovery by weight.

Characteristics

	Oil used	Oil recovered
Gravity, ° A. P. I	12.3	23.2
First drop, ° F	82	113
Percentage over at 428° F	9.3	21.3
Gravity of naphtha, ° A. P. I	44.9	48.5

SHALE USED

Shale used, 534.72 pounds = 37 per cent by volume, approximately.
Specific gravity of shale = 2.575.
Moisture in shale (determined by U. S. Department of Agriculture) = 4.12 per cent.

FUEL REQUIREMENTS

Gas, San Francisco city (R. R. commission) = 550 B. t. u. per cubic foot.
Fixed gas recovered (U. S. Bureau of Mines, fixed gas made by Rittman process) = 1,300 B. t. u. per cubic foot.

Gas used, 2,900 × 550 = 1,595,000 B. t. u.
Fixed gas recovered, 800 × 1,300 = 1,040,000 B. t. u.

Heat to be supplied, 555,000 B. t. u.

$\frac{555,000}{19,000}$ = 29.20 pounds of oil required if oil were to be used to make up fuel requirements in excess of fixed gas.

$\frac{29.20}{292.56}$ = 9.98 per cent fuel oil required if fixed gas were saved and used for fuel.

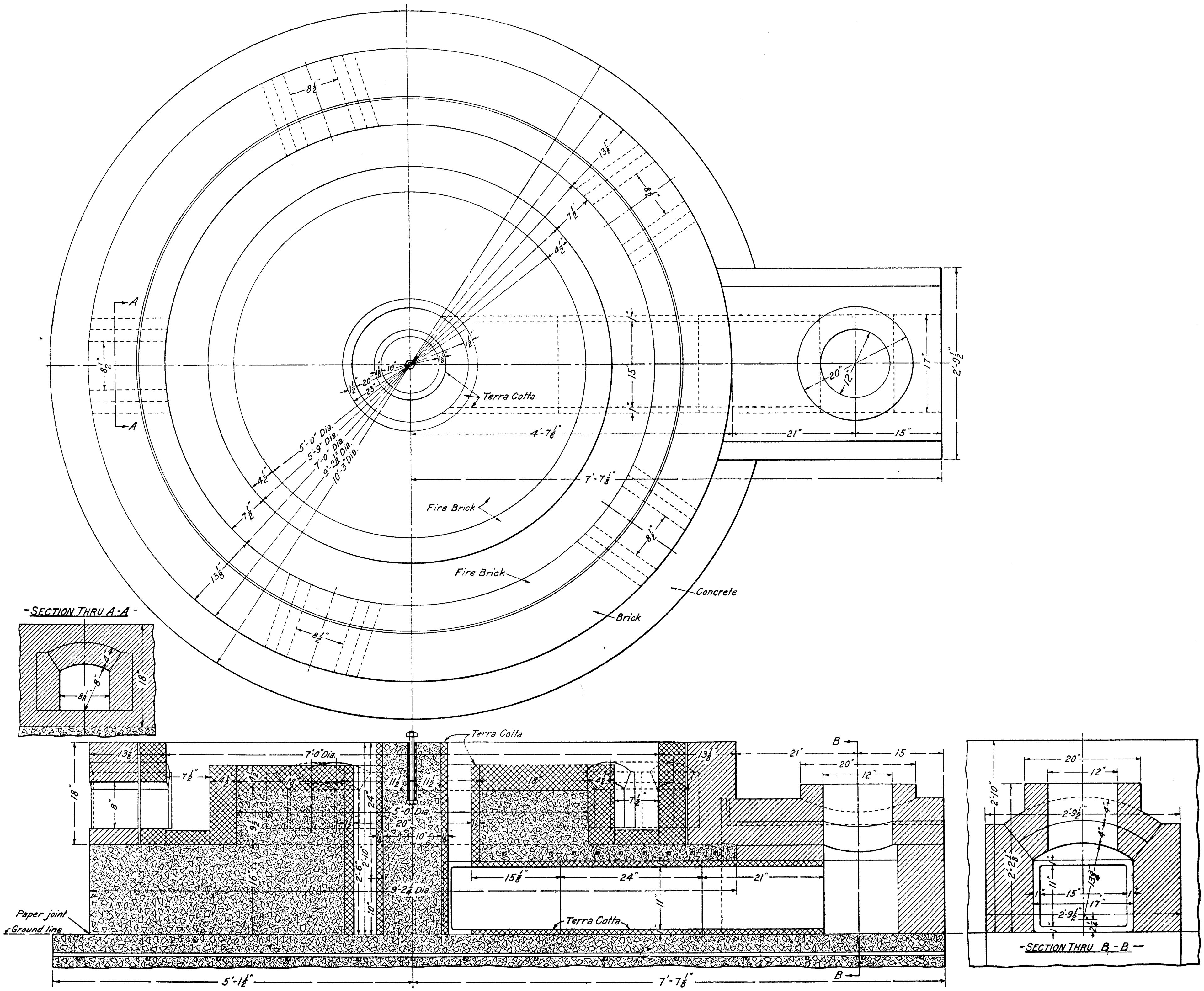

FIGURE 8.—Brickwork for Bowie-Gavin retort

102495°—26. (Face p. 22.)

TABLE 7.—*Test 2 made with Panuco crude oil of 13.2° A. P. I. gravity*

Time	Room temperature	Amount fuel gas used	Temperature of vapors 6 inches above plate	Temperature outside of plate	Weight of shale and oil mixture	Weight of oil and water fed in	Weight of shale fed in	Loss by fixed gas	Weight of shale residue recovered	Weight of combined water and distillate recovered	Gravity of distillate corrected to 60° F.	Redetermined gravity of distillate, next day	Stack temperature	Remarks
P. m.	°*F.*	*Cu. ft.*	°*F.*	°*F.*	*Lbs.*	*Lbs.*	*Lbs.*	*Cu. ft.*	*Lbs.*	*Lbs.*	°*A. P. I.*	°*A. P. I.*	°*F.*	
10.05	75	-------	743	968	-------	-------	-------	-------	-------	-------	-------	-------	919	
11.05	75	400	752	968	100.55	40.05	60.50	70	62.12	36.62	23.1	23.2	1,130	Heavy vapor leak at shale discharge, due to high temperature.
A. m.														
12.05	68	280	815	986	66.90	26.75	40.15	70	36.06	23.87	20.3	21.7	993	Feed cut off several times for 2 to 3 minutes; city gas-pressure changing.
1.05	77	190	689	910	98.00	39.25	58.75	50	50.00	32.06	24.8	25.3	986	
2.05	78	230	662	878	98.69	39.48	59.21	70	62.25	33.50	25.7	26.1	986	
3.05	68	300	626	860	99.83	39.91	59.92	50	60.18	34.37	26.4	26.3	977	Fixed gas sample No. 3 taken at 2.30 a. m.
4.05	68	310	653	869	102.94	41.14	61.80	65	55.81	36.25	25.6	25.1	950	
5.05	80	290	671	896	99.50	39.85	59.65	85	59.18	34.56	24.0	23.6	986	
6.05	77	280	680	914	92.35	36.95	55.40	60	53.12	34.00	24.8	24.3	977	
7.05	70	240	680	917	82.05	32.81	49.24	65	46.56	30.68	24.6	23.9	977	Fixed gas sample No. 4 taken.
7.43	74	185	698	932	57.63	23.00	34.63	45	41.37	22.93	22.4	23.3	977	
Total	-------	2,705	-------	-------	898.44	359.19	539.25	630	526.65	318.84	-------	-------	-------	

OIL USED AND RECOVERED

	Pounds
Weight of water and original oil (as above)	359.19
Weight of water in shale 6.42 per cent of 539.25	34.62
Total weight of water and oil fed in	393.81
Weight of water recovered	83.95
Net weight of oil put in	309.86=38.05 gallons.
Weight of water and distillate recovered (as above)	318.84
Weight of water recovered	83.95
Net weight of oil recovered	234.89=30.96 gallons.

$\frac{30.96}{38.05}$=83.7 per cent, recovery by volume; $\frac{234.89}{309.86}$=75.8 per cent, recovery by weight.

Characteristics of oil recovered

	Oil used	Oil recovered
Gravity, °A. P. I.	13.2	23.7
First drop, °F	86	79
Percentage over at 428° F	9.35	20.0
Gravity of naphtha, °A. P. I	461	466

EIGHT-FOOT SEMICOMMERCIAL APPARATUS

As has been stated, 72 runs were made with the 3-foot laboratory machine. It is not surprising, therefore, that toward the close of this part of the experimental work, fairly uniform results could be obtained.

As with the bench apparatus, in many experiments the yields of cracked products and the gasoline content of the cracked oil were remarkably high. In general, best results were obtained when the temperature was held at or near 400° C. (752° F.).

Apparently, however, some other type of bottom plate had to be developed if the process were to be used commercially. A machine of commercial size should be perhaps 25 feet in diameter. Obviously the type of bottom used with the laboratory machine would be out of the question for a machine of much larger diameter, because inequalities in heating and expansion and contraction of the metal would soon disrupt it or warp it so badly as to render it useless.

To build and experiment with a 25-foot machine would have required more money than the bureau could expend; so it was decided to construct a semicommercial machine 8 feet in diameter to solve as far as possible all the mechanical difficulties that might arise in the construction and operation of a larger commercial machine.

During the summer of 1921 an appropriation of $2,200 was made toward the construction of this 8-foot apparatus, which was enough to furnish labor and materials practically to complete the first machine and the necessary condensers. Through the personal efforts of Albert B. Fall, former Secretary of the Interior, an added appropriation of $3,400 was obtained later in the year as an operating fund. The machine was built on vacant property in the rear of 746 Sansome Street, San Francisco. Except for the bottom plate, its construction was much the same as that of the laboratory apparatus.

FOUNDATION

Figure 8 shows a plan and elevation of the furnace and part of the foundation. The foundation consisted of reinforced concrete, the lower part of which was a mat 18 inches thick by 10 feet 3 inches in diameter extending to the surface of the ground. Superimposed on this mat was a ring of concrete 9 feet 2½ inches in diameter and 16 inches thick, and superimposed on this was a second ring 5 feet in diameter by 9½ inches thick. A central pier of concrete 10 inches in diameter, incased in a terra-cotta flue lining, extended from the ground line to a point equal in elevation to the outer walls of the furnace. This pier formed a support for the central casting of the bottom plate, which in turn supported the central shaft to which

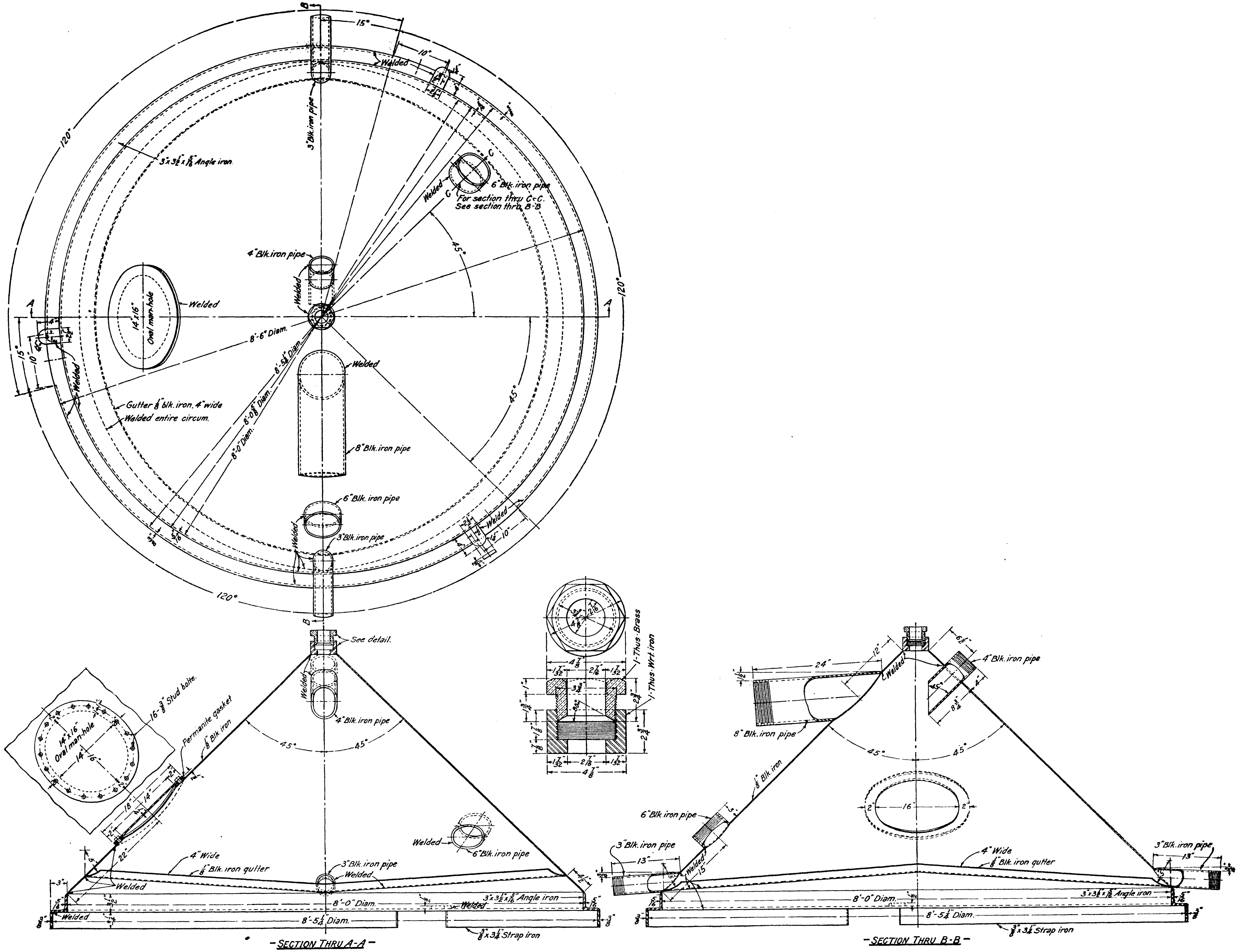

FIGURE 9.—Details of wrought-iron hood

the rabble arms were attached. Surrounding the central pier was an angular ring, approximately 3 inches wide, that served as a flue space. Connected with this angular ring and passing through the foundation, as shown in Figure 8, were terra-cotta flue linings 11 by 15 inches, inside measurement, placed end to end and leading to the stack base which was built of common red brick.

BOTTOM PLATE

The outer part of the bottom plate and hearth rested on the furnace walls, and the inner part was supported by short pieces of T rail made of cast iron spaced to form baffles to obstruct the free flow of the furnace gases in their passage from the fire boxes to the flue surrounding the central pier. This arrangement enabled the operators to distribute the heat evenly over the hearth.

The plates, with the exception of the center one, were wedge shaped with flanges or steps on their sides and ends designed to overlap when assembled, somewhat like the lid and surface of a stove. The plates that came in contact with the hot gases of combustion were approximately five-eighths inch thick; those that rested on the outer walls of the furnace were fifteen-sixteenths inch thick. The central casting was circular, with a hole in the center for a foundation bolt and above this a recess to carry the rabble shaft. Four wings on the bottom of the central casting were designed to engage in slots in the top of the concrete pier and prevent the casting from rotating with the movement of the shaft. There were three concentric rings of plates, and the plates in any one of these rings were interchangeable.

COVER

Figure 9 is a plan and elevation of the wrought-iron cover that rests on the hearth or bottom plate. The bottom part of this cover consists of a strap iron three-eighths inch thick, bent to conform to the circumference of a circle 8 feet 5¼ inches in diameter. To this strap iron was welded one leg of an angle iron 3 by 3 inches by $\frac{5}{16}$ inch, bent to conform to the circumference of a circle approximately 8 feet in diameter. Resting on this angle iron and welded to the other leg was a cone made of ⅛-inch sheet iron. To the inner walls of the cone, near the bottom, were welded strips of ⅛-inch sheet iron to form gutters draining to 3-inch outlet pipes, as shown.

The cone was also fitted with a manhole, three look boxes made by welding short nipples of 6-inch pipe to the cone, an inlet pipe for the mixture of oil and inert material, a vapor line, a pipe for a pyrometer terminal, and a 3⅝-inch stuffing box to admit the drive shaft which passed through the apex.

The strap iron on which the wrought-iron cover rested was not continuous but had three openings in it, approximately 8 inches long, discharging the spent inert material and carbon, as will be described later.

SPENT INERT MATERIAL AND CARBON DISCHARGE

Three openings through which the carbon and spent inert material were to be discharged were left in the strap iron upon which the cone rested. These openings were equally spaced about the circumference of the strap iron. They were about 10 inches long and 3⅞ inches wide, the height of the strap iron. Wrought-iron gates slightly smaller than the openings, hinged at one end and bent to the same radius as the strap iron, closed these openings. In operation, the free ends of these gates were made to extend about 1½ inches beneath the angle iron into the cone, and were held in this position by weights or springs.

To effect a seal between the bottom of the strap iron supporting the cone and the top of the plate, a piece of sheet iron approximately 1 foot wide was placed about the circumference of the brickwork near the top of the furnace, so that it projected about 10 inches above the top of the brickwork; the space between this sheet iron and the bottom of the cone was then filled with fine spent inert material and carbon.

It was planned to adjust the plows on the ends of the rabble arms so that during their rotation they would gather the spent inert material and carbon in a pocket formed by the bottom plate, the strap iron supporting the cone, the leg of the angle iron resting on the strap iron, and the plow itself. As the greater part of the spent inert material and carbon pushed before the plow was dry and granular, it would be forced behind the gate and, when the plow reached the gate, it would be forced out of the apparatus into the seal of inert material outside, of which it would then become a part.

However, in order to maintain about the base of the cone a seal deep enough to prevent the escape of gas from the apparatus, so much power was needed to open the gates that the plows were either bent enough to become useless or were broken. Solenoids were then made which were timed to operate the gates at the exact instant the plows reached them. The timing mechanism proved unsatisfactory, and this entire method of discharge was discarded for a screw-conveyor system which was perfected in connection with the finally accepted type of bottom plate.

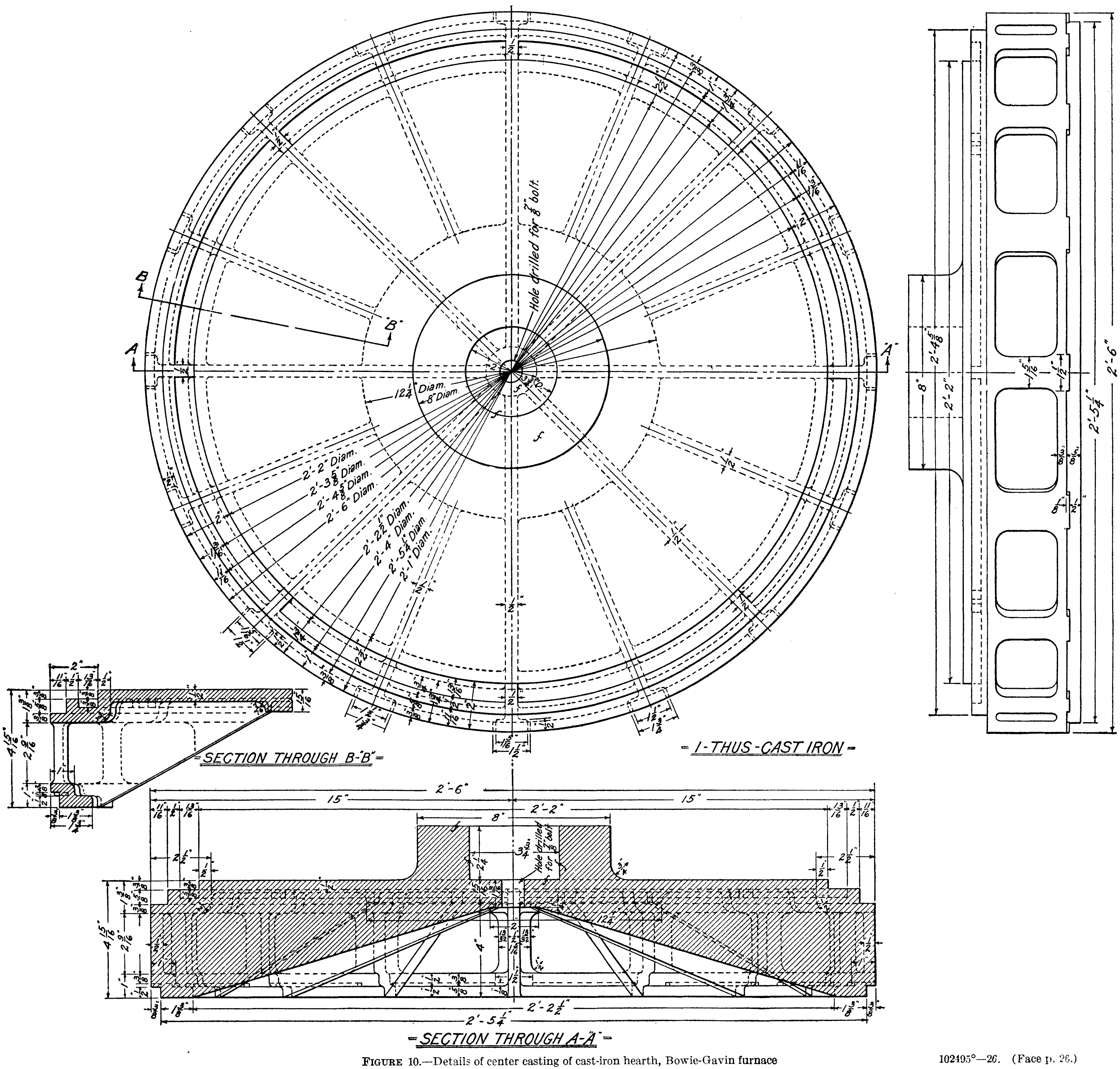

FIGURE 10.—Details of center casting of cast-iron hearth, Bowie-Gavin furnace

IMPROVED DESIGN OF HEARTH

A number of fairly successful runs were made with this machine. Table 9 gives the results obtained from them. It was soon found, however, that the plates subjected to the greatest heat warped so badly that the edges of many of them curled up enough to permit the fine particles of inert material and carbon, depended on to form the seal, to drop out of the flanges or steps and allow the escape of the petroleum vapors into the furnace. Some new plates for the "hot ring" were obtained, and various methods of supporting them were tried. As the trials proved unsuccessful, the plates were finally discarded entirely, and a new type of hearth was designed to overcome the difficulties mentioned.

TABLE 9.—*Result of the first series of runs made with the 8-foot still*

Run No.	Date, 1921	Original oil: Name	Original oil: Gallons	Shale by weight	Cracked oil and water	Fixed gas	Operating time	Fuel used, city gas	Rate capacity per day	Recovery	Distillation: Gravity of cracked oil	Distillation: Crude gasoline to 220° C. (428° F.)	Distillation: Crude kerosene to 275° C. (528° F.)	Remarks
				Pounds	*Gallons*	*Cubic feet*	*H. m.*	*Cubic feet*	*Barrels*	*Per cent*	*°A. P. I.*	*Per cent*	*Per cent*	
1	Sept. 26	Casmalia crude [1]	[2] 24	125	18	----	1 42	----	----	----	20.7	20.3	24.6	First sectional plate solenoid discharge; smoking; plate leaked.
2	Sept. 30	Kern River crude	40	[3] 700	36	----	2 25	3,300	8.0	82.5	21.1	16.0	13.6	Excess gas; smoking; plate leaked.
3	Oct. 4	Casmalia crude [1]	52.5	[3] 500	44	----	2 50	3,500	8.5	80	20.3	16.2	16.5	Smoking at plate and gates.
4	Nov. 7	do.[1]	[4] 210	----	20	----	----	----	----	----	----	----	----	Screw shale discharge and noncondensable gas meter installed; suction on gas; plates reset; plate leaked.
5	Nov. 9	do.[1]	[5] 115	----	10.5	892	1	----	----	----	----	----	----	Wet discharge; plate leaked; controlled slightly by suction on noncondensable gas line.
6	Nov. 29	do.[1]	23.6	350	23	540	1 54	2,230	7.1	[2] 90	21.0	14.7	16.5	Plates reset; 7 new plates; slight smoking and wet discharge.
7	Dec. 1	do.[1]	54.3	375	44.7	2,325	2 55	3,640	10.6	79.5	18.9	18.5	13.2	Wet discharge.
8	Dec. 2	do.[1]	44	300	30	1,550	2 20	2,720	10.8	65	19.0	15.6	13.0	Plates leaking badly.
9	Dec. 12	do.[1]	46	400	44.5	1,170	2 35	3,300	10.2	91	18.9	19.1	14.5	Plates reset; only slight smoking at discharge.
10	Dec. 13	do.[1]	45	350	35.5	1,020	3 5	2,400	----	77	19.2	14.7	17.9	Fairly reliable noncondensable gas measurements; discharge wet.
11	Dec. 22	do.[1]	36	275	28.5	795	2 7	2,580	9.75	75	19.0	18.7	14.4	Slight loss by smoking and wet discharge.
12	Dec. 23	do.[1]	12.8	100	10	----	55	1,100	----	73.5	18.5	22.5	14.7	Run without suction to observe conditions (slight pressure); plate and discharge leaking.

[1] Specific gravity of Casmalia crude, 0.9935. [2] Approximate. [3] 4 per cent water. [4] Pounds, approximate. [5] Pounds.

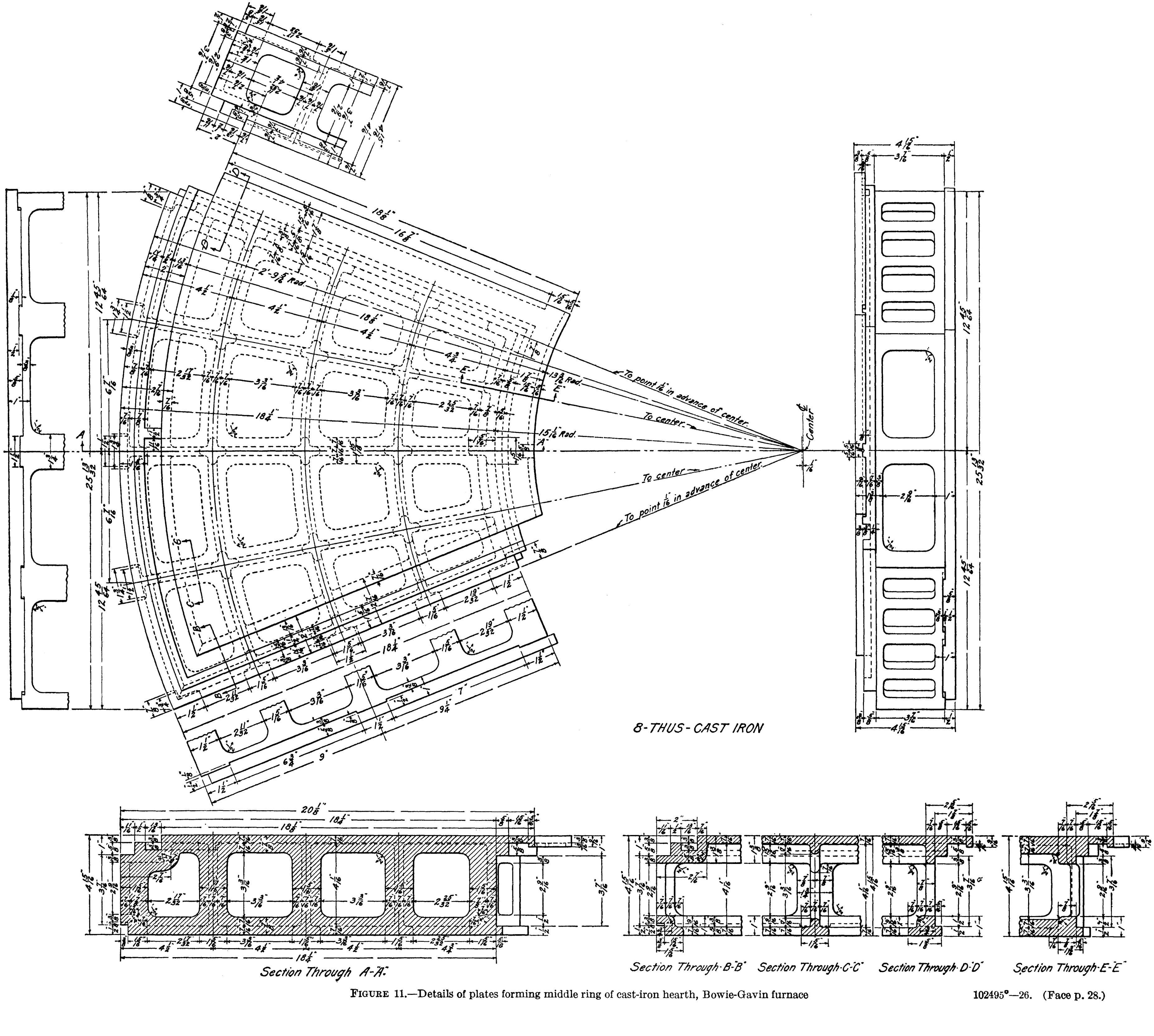

FIGURE 11.—Details of plates forming middle ring of cast-iron hearth, Bowie-Gavin furnace

This hearth consisted of a center casting surrounded by two concentric rings of castings. The castings in each ring in the first hearth were interchangeable.

The central casting (fig. 10) was 2 feet by 6 inches in diameter and $4\frac{15}{16}$ inches high. It had at its center a hub projecting up $2\frac{1}{4}$ inches to form a bearing for the vertical shaft that carried the rabble arms. The surface of this casting was one-half inch thick and was supported from beneath by ribs and webs. The outer rim of this casting was stepped and grooved so as to form a female joint for the reception of the next abutting castings.

Figure 11 shows a plan and various sections of one of these abutting castings. It was wedge shaped, and its greatest dimension was $25\frac{13}{32}$ inches. Two sides of it were fitted with male connections consisting of flanges, and two sides with female connections consisting of steps and grooves. The surface of the plate was approximately seven-sixteenths inch thick and was supported by a system of webs.

The castings (fig. 12) of the outer ring were constructed in much the same manner as those of the middle ring, except that the outer circumference was a plain face and its greatest dimension was $19\frac{15}{16}$ inches.

Figure 13 gives a good idea of the condition of the various castings before assembly and shows plainly the plan of the male and female joints. If a plate warped and one edge curled, it would have to carry up the neighboring plates with it. As the rabbles were designed to roll over rather than to tear up obstacles, it was believed that even though the plates warped enough to produce waves in the surface of the hearth they nevertheless could be used until the warping became so great as to obstruct the passage of the rabbles. Experience proved that this supposition was correct; at one time six of the plates were so badly overheated that they finally had to be replaced, but not, however, until the warping had become great enough to block the rolling disks in their passage. Even in this condition the joints between the plates were still tight and showed no signs of permitting the petroleum gases to leak into the furnace.

The outer ring of castings rested directly over the fire box of the furnace (fig. 13). The gases of combustion passed up through the web construction of the outer plates and thence along beneath the surface of each successive casting, through the webs toward the angular ring forming the stack at the center of the furnace. A very effective seal was maintained by the fine particles of inert material and carbon collecting in the cracks between the joints of the castings. Outside the outer castings a ring of strap iron $\frac{1}{2}$ inch by 5 inches was placed. It was made in two pieces bent to conform to a circle of the desired radius and was put together with four 1-inch bolts. With the previously described type of bottom, springs were used for taking up the expansion and contraction, but did not prove satisfactory.

BURNER AND FIRE BOXES

San Francisco city gas was at first used for fuel, but as it was expensive the use of cracked oil and noncondensable gas, products of the process, was considered desirable. A type of burner that would

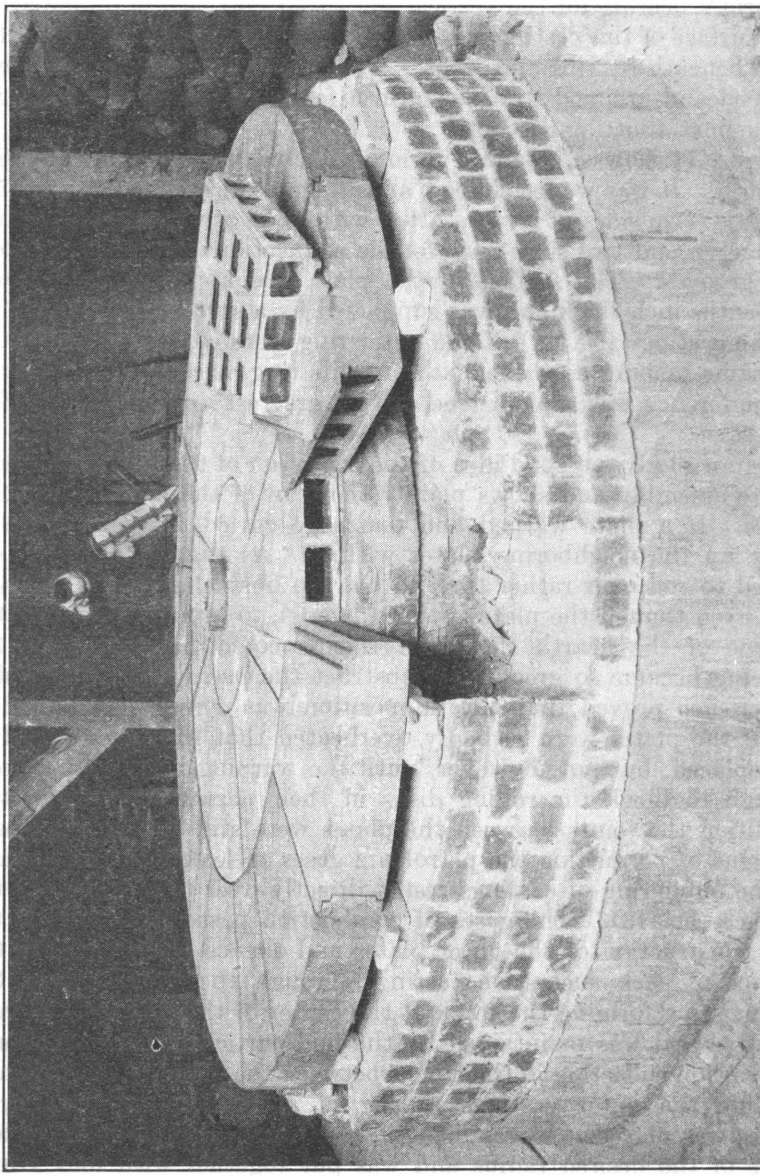

FIGURE 13.—Bottom plate of 8-foot retort, showing male and female joints and flue spaces

burn either gas or oil or both was designed and constructed. Dutch ovens were built adjacent to the five openings in the fire box. Four of these were approximately 18 inches square, inside, and the fifth

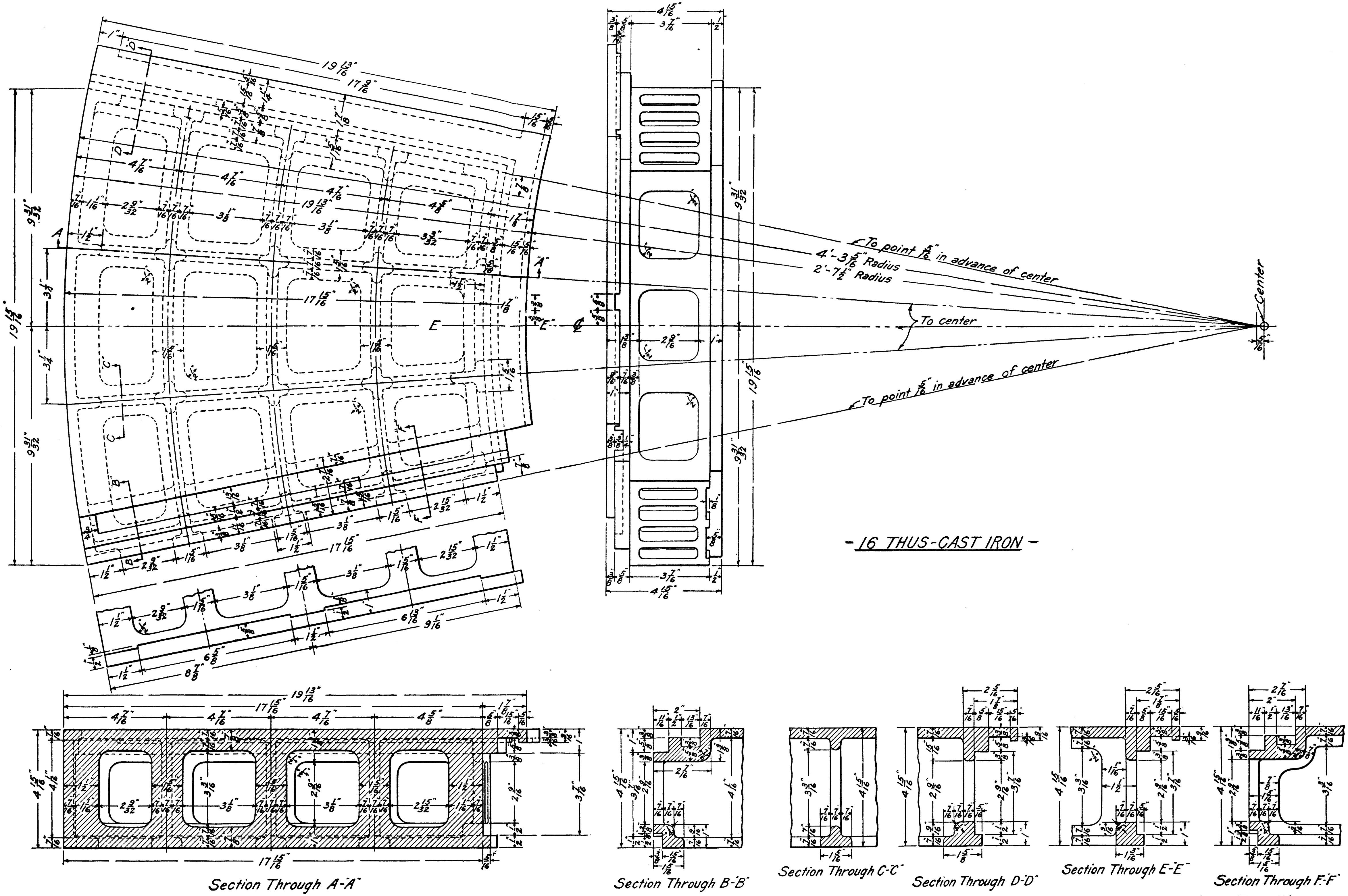

FIGURE 12.—Details of plates forming outer ring of cast-iron hearth, Bowie-Gavin furnace

approximately 5 by 3 by 2 feet, inside. Figure 14 shows the large fire box and part of two of the smaller ones, as well as the final arrangement of the plant.

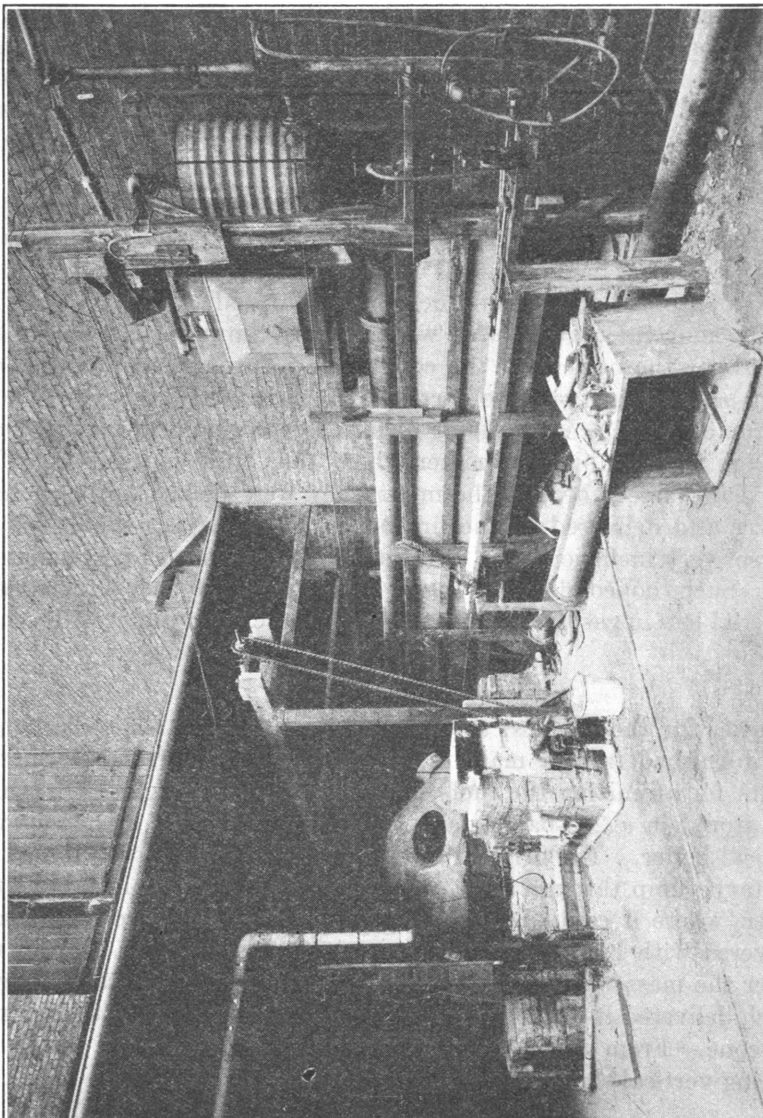

FIGURE 14.—Eight-foot retort complete with Dutch ovens and condensers

CONDENSERS

The condenser box was made from No. 20 galvanized iron and was 1 foot 8 inches wide by 3 feet high and 22 feet long. It was supported in a wooden frame (fig. 14). The condenser pipe leading from the apparatus was made from welded sheet iron. At the outlet of the apparatus this pipe was approximately 18 inches in diameter; it tapered from this point to a 12-inch elbow, made of the same material, which was bolted to a flange at the far end of the 12-inch pipe, as shown in Figure 14, just above the condenser box. The rest of the condenser consisted of one length of 6-inch pipe, one length of 4-inch pipe, three lengths of 3-inch pipe, and one length of 2-inch pipe, all of which were below the water line. The reducing nozzle from the 12-inch pipe to the 6-inch pipe was drilled and tapped for a 1½-inch pipe connection.

By this arrangement all the product of the air-cooled condensers was carried away separately and, by proper operation of the plant, water contained in the original oil could be collected with the lighter fractions from which it could be easily separated.

The noncondensable gases were trapped immediately above the U seals at the outlets of the condenser. Through an arrangement of by-passes they could be carried to a stack and discharged above the top of an adjacent building or into a receiving drum, and thence through a 600-cubic foot meter where they were measured. After they had passed through the meter they were picked up by a small blower and delivered to the fire boxes. This arrangement was, of course, very inefficient and can not be recommended for commercial use. Such noncondensable gases must be scrubbed, otherwise a material loss in gasoline content from the cracked product will result.

POWER

Power for the rabbles, the mixer, and the spent shale discharges was furnished from a main drive run by a 7½-horsepower motor. Steam for atomizing the fuel oil and heating the original oil, which was stored in a 200-barrel tank, was furnished by a 20-horsepower vertical boiler. The original oil when heated enough was forced by a rotary pump through a 1½-inch line to a definite point above the mixer, where it could be drawn off into a calibrated container and delivered with batches of inert material into the mixer. From the mixer the mass was fed into a hopper, thence into a spiral conveyor which delivered it under seal into a 4-inch inlet pipe near the apex of the cone. From this point it dropped or ran down the slowly revolving vertical shaft onto the center of the hearth.

DISCHARGE SYSTEM

After the carbon and spent inert material were moved over the hearth by the rotating rabbles, they were scraped by the plows on the ends of the rabble arms into a pocket cast in one of the hearth plates in the outer ring of castings, with the center hole in the back-ground of the casting inverted on the assembled part of the hearth shown in Figure 13. Three such pockets were originally used, but by properly operating the discharge mechanism one pocket was found adequate.

DISCHARGE MECHANISM

A 3-inch pipe, with one end blanked and otherwise shaped so that it could be welded on the casting in such a manner that the run of the pipe was perpendicular to the axle of the pocket, formed a bottom for the pocket and at the same time functioned as a conductor through which the material falling into it was moved, by means of a spiral conveyor, to a point outside the furnace wall and discharged into an ordinary 4-gallon bucket. A conveyor made of cast iron with the ordinary ribbon type of flight was originally used, but wear and tear became such an item that it was soon discarded for a flight made from ⅝-inch square iron bent into the form of a spiral spring.

OPERATION

A number of runs were made with this machine. Although the results of many of these were not very satisfactory because of necessary mechanical adjustments of the apparatus, some gave ample proof of the possibility of making the process continuous if proper control of feed and temperature were maintained. During the first runs difficulties arose from overheating some of the castings in the outer ring of hearth plates, but these were overcome by reconstructing the fire boxes and placing a pyrometer thermocouple in the back of each box so that the temperature could be controlled at that point.

TABLE 10.—*Result of the second series of runs made on the 8-foot still, improved design*

Run No.	Date, 1922	Original oil: Name	Original oil: gallons	Shale by weight	Cracked oil	Fixed gas	Operating time		Fuel used	Rate capacity per day	Recovery	Water in original oil	Actual oil feed, total —17 per cent water	Distillation: Crude gasoline to 220° C. (428° F.)	Distillation: Crude kerosene to 275° C. (528° F.)	Remarks
				Pounds	*Gallons*	*Cu. ft.*	*H.*	*m.*		*Barrels*	*Per cent*	*Gallons*	*Gallons*	*Per cent*	*Per cent*	
13	Apr. 25	Casmalia crude [1]	(2)	(3)			[4] 4	—	(5)							Fire boxes extended and combination gas and oil burners installed; sectional ribbed and honeycomb plate put in; run for adjustments.
14	Apr. 26	do.[1]	(2)				[4] 8	—	(6)							Run for operating conditions and training of men; operation of producer-gas tube with spiral conveyor unsuccessful mechanically.
15	Apr. 27	do.[1]	(2)				[4] 5	—	(6)							
16	Apr. 28	do.[1]	(2)				[4] 11	—	(6)							
17	Apr. 29	do.[1]	(2)				[4] 7	—	(6)							
18	Apr. 30	do.[1]	(2)				[4] 6	—	(6)							
19	May 1	do.[1]	(2)				[4] 7	—	(6)							
20	May 2	do.[1]	(2)				[4] 5	—	(6)							
21	May 6	do.[1]	(2)				[4] 12	—	(6)							
22	May 7	do.[1]	108			5, 640	7	30	(7)	8. 2						Recovery not measured.
23	May 8	do.[1]	(2)				[4] 7	—	(6)							Plates warped from local overheating.
24	May 31	do.[1]	(2)				[4] 3	—	(6)							Six new plates installed; thermocouples put in fire boxes for heat control.
25	June 1	do.[1]	(2)				[4] 5	—	(6)							Run for operating conditions.
26	June 2	do.[1]	(2)				[4] 4	—	(6)							
									Fuel oil, *gallons*							
27	June 3	do.[1]	54		[8] 45	1, 970	2	35	14	12	[4] 76	9. 2	44. 8			Controlled fire-box temperature.
28	June 5	do.[1]	112		[8] 105	2, 975	6	10	34		[4] 85	19	93			
29	June 6	do.[1]	75		[8] 65	3, 560	6	15	32	6. 8	[4] 80	12. 8	62. 2			
30	June 7	do.[1]	168		[8] 150	4, 600	11	45	60	8. 2	[4] 81	28. 5	139. 5			Discharge smoking.
31	June 8	do.[1]	94		[8] 84	2, 395	6	45	36		[4] 81	16	78			Producer pipe used to remove excess oil from shale.
32	June 12	Asphalt S. O. Co., light.	24	225	16. 5	517	1	25	10. 25	8	69	None.		17. 0	13. 0	Shale dried on furnace.
33	do	do	28	300	23	675	2	—	10. 5	8	82	None.		17. 0	13. 5	
34	June 20	Casmalia crude [1]	65	590	58	2, 130	4	40	15. 5	8	[4] 80	11	54	17. 0	15. 5	Most of shale discharge superheated in producer pipe.
35	June 21	do.[1]	65	660	42	1, 420	5	—	21	7. 5	78	11	54	22. 3	18. 0	Producer pipe plugged.

36	June 22	do.[1]	62		45.5	1,300	5	5	25.75	7	88.5	10.5	51.5	14.5	16.2	Gas calorimetric value taken by State Railroad Commission.
37	June 23	do.[1]	103	1,220	65	1,655	8	20	31.5	7.1	76	17.5	85.5	22.2	16.3	
38	June 27	do.[1]	47		36.5	2,500	4	25	26.5	6	94	8	39	20.9	16.0	
39	June 28	do.[1]	103		61	3,630	8	50	36	6.7	72	17.5	85.5	9.6	15.2	
40	June 29	do.[1]	84		50.5		6	40	26	7.2	72.5	14.3	69.7	19.9	17.5	
41	do	do.[1]	75		51	4,735	6	30	25.5	6.6	82	12.8	62.2			Run for observation of Mr. Pelzer and Mr. Cannon, of the Sinclair Refining Co.; all data obtained by them.
42	July 1	do.[1]	93.7		59.2		5	50	24.5	9.2	76.2	15.9	77.8			
43	July 17	do.[1]	140		80	4,760	7	45	33.5	10.3	69	23.8	116.2			
44	July 18	do.[1]	234			17,990	14	10	56	9.4		40	194			
45	July 19	do.[1]	234	2,600	145	10,220	14	5	57	9.25	75	40	194			
46	July 20	do.[1]	252	2,600	144		14	5	47	10	69	42.6	209.4			
47	July 21	do.[1]	384		212	20,315	22	20	60.5	9.8	67	65	319			
48	July 24 – July 27	do.[1]	670		410	[9] 14,178	67	—	180	5.7	[4] 74	114	[4] 556			
49	do – July 29	do.[1]	523		327	54,815	49	—	188	6.1	76	90	433			

[1] Specific gravity of Casmalia crude, 0.9935.
[2] Not measured.
[3] No weight.
[4] Approximate.
[5] Fuel oil and city gas.
[6] Fuel oil and fixed gas.
[7] Fuel oil, 30 gallons.
[8] Oil and water.
[9] For 14.5 hours.

This machine was operated intermittently from May 25, 1922, to July 29, 1922. During this period the castings forming the bottom plate were repeatedly heated and allowed to cool, which, it is believed, represents the most severe conditions of operation. At the end of this period, however, the plates were in virtually the same condition as when the series of runs began.

Table 10 gives the results of these runs. As the operating crew was untrained in this class of work and as many mechanical difficulties were still to be overcome, the plant often had to be shut down in the middle of a run without notice; in consequence accurate data could not always be gathered. The results, therefore, can be considered as approximate only.

Runs 41 and 42 were made for representatives of the Sinclair Refining Co. All data were carefully taken and recorded. A barrel of the cracked product recovered, with a gravity of 19.1° A. P. I., was shipped to the Sinclair Refining Co. at Whiting, Ind., and the following report of its analysis was submitted by H. L. Pelzer, experimental engineer of the process stills department.

Analysis of oil cracked by the Bowie-Gavin process

I. SYNTHETIC CRUDE

A. TESTS OF STOCK RECEIVED

Gravity, °A. P. I., 19.1.
Flash, °F., 125.
Pour, °F., 0.
B. S., per cent, 0.3.
Sulphur, per cent, 3.63.
Heat, 57.

500-C. C. DISTILLATION; INITIAL, 263° F.

Percentage over—	Temperature	Gravity	Percentage over—	Temperature
	°F.	*°A.P.I.*		*°F.*
10	442	39.6	0.7	284
20	506	32.2	3.2	374
30	558	27.4	5.7	400
40	604	23.9	12.4	450
50	646	21.1	19.0	500
60	681	18.8	39.7	600
70	715	17.1		
80	721	15.5		
90	751	14.8		

NOTE.—10 per cent bottoms—solid.

In order to get information on this material, a small amount was charged, run in 10 per cent cuts, and tested.

Percentage over—	Gravity	Flash	Fire	Viscosity at 100° F	Pour	Color
	°A. P. I.	*°F.*	*°F.*	*Saybolt seconds*	*°F.*	
10	38.0					Brown
20	30.8	145	170	36	0	Dark green.
30	26.3	205	240	40	0	Do.
40	22.2	260	290	49	0	Do.
50	19.1	290	330	67	0	Do.
60	16.3	325	375	137	0	Do.
70	13.9	355	415	310	20	Do.
80	13.6	385	445	821	25	Do.
90	12.0	400	465	89/210	30	Do.

NOTE.—10 per cent bottoms—asphalt.

From the above run the following running sheet was outlined:

B. YIELD DISTILLING FOR TOWER STOCK

[Charge, 100 per cent; gravity, 19.1° A. P. I.]

	Charge	Gravity
	Per cent	*° A. P. I.*
Tower stock	25.0	34.3
Lubricating distillate	63.3	19.6
Soft asphalt	11.2	9.0
Loss	0.5	

II. PRODUCTS FROM TOWER STOCK

The tower stock treated with 6 pounds of 66° acid, finished with doctor treatment, and rerun in tower still for 450 end-point gasoline; loss on treating, 3.0 per cent of charge, or 0.75 per cent synthetic crude.

YIELD—RERUNNING TOWER STOCK

[Charge 24.3 per cent synthetic crude; gravity, 34.3° A. P. I.]

	Charge	Synthetic crude	Gravity
	Per cent	*Per cent*	*° A. P. I.*
450 end-point gasoline	62.0	15.0	39.4
Bottoms—gas oil	36.7	3.9	26.0
Loss	1.3	0.4	

The 450 end-point gasoline was given doctor treatment.

TESTS OF FINISHED GASOLINE

Gravity, °A. P. I., 39.4.
Heat, °F, 44.
Iodine, number, 160.5.
Sulphur, per cent, 1.8.
Color, 0.
Doctor test, N. g.

100-C. C. DISTILLATIONS

Gasoline		Gas oil	
Percentage over (initial boiling point 212° F.)—	Temperature	Percentage over (initial boiling point 418° F.)—	Temperature
	° F.		*° F.*
10	276	10	461
20	297	20	478
30	320	30	484
40	336	40	496
50	349	50	507
60	363	60	516
70	380	70	540
80	397	80	568
90	415	90	598
End point	449	10 per cent bottoms	
1.0	221	4.0	450
18.0	284	31.5	500
66.5	374		

III. DISTILLATION OVER LYE OF LUBRICATING DISTILLATES

STRAIGHT CUTS

No.	Cut	Gravity	Flash	Fire	Viscosity at 100° F.	Pour
	Per cent	*° A. P. I.*	*° F.*	*° F.*	*Saybolt seconds*	*° F.*
1	5	31.9	135	165	36	0
2	10	28.9	170	205	38	0
3	15	26.5	205	240	40	0
4	20	25.3	210	245	42	0
5	25	24.3	220	250	44	0
6	30	23.1	235	275	47	0
7	35	22.0	255	295	50	0
8	40	21.3	270	310	54	0
9	45	20.4	290	330	60	0
10	50	19.5	295	335	70	0
11	55	18.2	300	355	83	0
12	60	17.0	315	360	99	0
13	65	16.1	330	390	121	0
14	70	15.9	340	410	164	15
15	75	15.5	340	420	226	15
16	80	15.0	350	430	308	20
17	85	14.6	360	445	426	25
18	90	14.0	370	470	608	30
19	95	13.7	375	465	396	35

MIXES

Cuts	Grade	Charge	Synthetic crude	Gravity	Flash	Fire	Viscosity at 100° F.	Pour
		Per cent	*Per cent*	*° A.P.I.*	*° F.*	*° F.*	*Seconds*	*° F.*
1 to 9 (inclusive)	Gas oil	45.0	28.5	24.5	215	250		0
10 to 14 (inclusive)	100-viscosity distillate	25.0	15.8	17.0	315	360	104	0
15 to 19 (inclusive)	500-viscosity distillate	25.0	15.8	15.0	370	445	450	25
Bottoms	Caustic fuel	3.5	2.2					

An attempt was made to treat the 500-viscosity distillate with 10 pounds of 98 acid, but the color of the resultant oil was very dark. Treating loss was 4.0 per cent of charge.

TESTS OF TREATED 500-VISCOSITY OIL

Gravity, °A. P. I., 15.7.
Flash, °F., 375.
Fire, °F., 445.
Viscosity at 100° F., 420
Pour, °F., 30.
Color, dark.
Emulsion, good.

IV. SUMMARY OF PRODUCTS

Grade	Synthetic crude	Gravity
	Per cent	*° A. P. I.*
450 end-point gasoline	15.0	39.4
Gas oil	37.4	25.1
100-viscosity distillate	15.8	17.0
500-viscosity distillate	15.8	15.0
Caustic fuel	2.2	
Soft asphalt	11.2	9.0
Losses	2.6	
	100.0	

Run 48, the longest continuous run, lasted 67 hours. It began on July 24 and ended July 27 at 4.30 a. m., when the fuel feed-pump broke down; in consequence the plant had to shut down until 12.20 p. m. of that day, when run 49 was started. The furnace, however, was not allowed to cool, and in effect runs 48 and 49 can be counted as one. Run 49 lasted 49 hours. Upon its completion operations were discontinued because of lack of funds. If these two runs are counted as one, the plant was in continuous operation from the morning of July 24 to the afternoon of July 29.

FIXED GAS

In runs 13 to 49, inclusive, the noncondensable gas was used to supply part of the fuel. Analysis of the calorific value of this gas was made by J. O. Wiley, assistant engineer of the California State Railroad Commission, using gas-testing apparatus loaned by the commission. It varied from 741 to 1,203 B. t. u. per cubic foot.

FUEL

The arrangement of using the fixed or noncondensable gas in combination with cracked oil for fuel worked out satisfactorily so far as furnishing an adequate supply of heat was concerned; but, as will be noted from Table 10, the fuel consumption was high. As the fire boxes were originally designed for gas, the change to oil made them inefficient, and the stack temperatures were at all times abnormally high. It is believed that the indicated amounts of fuel used should not be taken as a criterion of what is possible with a properly designed fire box.

VISCOSITY OF PRODUCTS

Table 11 compares the viscosity of the cracked product, also the residual oil after the gasoline and kerosene cuts had been removed, with various California crude oils.

TABLE 11.—*Viscosity of various crude oils, original oil, Casmalia crude, 10.9° A.P.I.*

	° A. P. I. (approximate)	Furol seconds
		At 77° F.
Bowie-Gavin cracked oil, run No. 1, 8-foot furnace	20	13⅖
Murvale, sec. 20, T. 32 S., R. 24 E	24	17⅕
Midway Pacific, sec. 24 T. 31 S., R. 32 E	22	33
Murvale, sec. 18, T. 32 S., R. 24 E	20	28
Pan American Co., sec. 6, T. 31 S., R. 25 E	18.8	77
Associated Oil, sec. 35, T. 31 S., R. 22 E	16.0	226
Bowie-Gavin residuum, run No. 1 (gasoline and kerosene cuts removed)	10.0	305
		At 122° F.
Bowie-Gavin residuum, run No. 1	10.0	45
E. & M. Oil Co., sec. 10, T. 31 S., R. 22 E	14.0	210
Associated Oil Co., sec. 35, T. 31 S., R. 22 E	16.0	44

The reader will note that the residual oil made from Casmalia 10.9° A. P. I. crude had virtually the same viscosity as 16° A. P. I. California crude produced in sec. 35 T. 21 S., R. 22 E., in the Midway field, which shows that so far as viscosity is concerned the residuum should make at least a good fuel oil.

REVIVIFYING SPENT INERT MATERIAL

The inert material gathered so much carbon after being used about three times that further attempts to reuse it were unsuccessful. This means that the volume of new inert material necessary for a plant would be about 13½ per cent of the volume of oil treated, or on the assumption that the inert material was of such specific gravity as to require a 50-50 mix by weight, the total weight of new inert material to be supplied would be approximately 16⅔ per cent of the weight of the oil.

Where cracking could be carried on at or near wells in the vicinity of a suitable supply of inert material, this item should not prove prohibitive. The cost of mining, tramming, and crushing the brick material (shale) produced during 1920 by the Port Costa California Brick Co. was approximately as follows:

Cost per ton of mining and crushing shale

Mining	$0.07
Powder	.025
Tramming	.0125
Crushing	.0125
Power	.0625
Total	.1825

This figure of 18¼ cents was based on the handling of 200 to 220 cubic yards of shale a day. The material was mined in an open pit with a small steam shovel and trammed in cars about one-third mile to the brick factory, where it was crushed in an 8-foot pan mill. These mills cost about $3,000 complete and have a capacity for this shale of about 10 tons per hour.

If, however, the process were to be applied to the reworking of residuals about a refinery, the problem of supplying new material and discarding the old might become serious. Probably the most desirable material to be used there would be discarded fuller's earth, which could be done if some means were provided for separating the carbon and fuller's earth. Experiments have shown that regenerated material of this class works quite as well as new material. In view of the importance of such regeneration, some preliminary experiments were made in burning out the carbon with an experimental electrically heated rotary kiln in the bureau's laboratory at Berkeley. Some preliminary experiments were also made in an attempt to regenerate the inert material by forming producer gas of the carbon through the medium of superheated steam applied immediately after the discharge of the inert material from the apparatus, thereby conserving as much heat as possible. Neither of these experiments, however, was carried far enough to give definite conclusions.

CAPACITY OF MACHINE

The capacity of the laboratory apparatus in an actual run of some 22 hours, based on crude fed in, was approximately 2.5 barrels daily. Although no attempt was made to run the semicommercial machine at what seemed the maximum capacity, a rate of 12 barrels a day was obtained. On the relation of areas, which seems to be a logical basis for computations, its capacity should be about 17.5 barrels a day. The author believes that a commercial apparatus should be 25 feet in diameter and, by this same reasoning, should have a daily capacity of about 170 barrels of crude.

COST OF COMMERCIAL PLANT

CONSTRUCTION COSTS

Construction of a 25-foot machine should involve no very great difficulties, as the materials used are largely concrete, brick, and sheet steel. Material for the concrete, exclusive of the cement, can usually be obtained near at hand, even though the point of erection is relatively remote, and the same is true in a general way of the brick. The castings could be made at the nearest suitable foundry; assembling them on the job, provided they had been properly assembled and marked before shipment, would be easy. The sheet-steel cover presents the only problem. Perhaps the best plan for handling it would be to cut and shape in the shop the plates of which it is composed, then to assemble and weld them on the job by means of a portable welding outfit after the hearth is in position.

A reasonable figure for the cost of a single machine or retort complete with furnace and steel stack should be about $7,500, exclusive of the condenser. A convenient arrangement for a unit would be four such retorts arranged in a square or rectangle with a common stack of brick at the center. The total cost of such an installation without a condenser should be approximately $30,000. An adequate condenser should be built for about $15,000.

OPERATING COSTS

One of the most important things to be determined from an experiment of this kind is the operating cost when the principles involved are applied to commercial practice. It was hoped that the operation of the 8-foot semicommercial machine could be carried on long enough to furnish data to determine such costs. However, as the bureau had only a small amount of money for furthering the work, and as at the outset of the problem the apparatus as well as the process was unproved, it soon became evident that if any results were to be obtained at all every effort must be concentrated on overcoming mechanical difficulties, regardless of the cost of operation.

The mechanical difficulties were overcome, and although insufficient data have been gathered to estimate even approximately the cost of commercial operation, it is believed that the bureau has solved the problem of a satisfactory bottom plate for the apparatus and has proved the possibility of making the process continuous.