Bureau of Mines
Report of Investigations 5145

DEVELOPMENT AND PRELIMINARY OPERATION OF THE GAS-COMBUSTION OIL-SHALE PILOT RETORT

BY A. MATZICK, J. R. RUARK, AND M. W. PUTMAN

United States Department of the Interior — November 1955

DEVELOPMENT AND PRELIMINARY OPERATION OF THE GAS-COMBUSTION OIL-SHALE PILOT RETORT

BY A. MATZICK, J. R. RUARK, AND M. W. PUTMAN

* * * * * * * * * **Report of Investigations 5145**

UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary
BUREAU OF MINES
J. J. Forbes, Director

November 1955

DEVELOPMENT AND PRELIMINARY OPERATION OF THE GAS-COMBUSTION OIL-SHALE PILOT RETORT

by

A. Matzick, 1/ J. R. Ruark, 1/ and M. W. Putman 2/

CONTENTS

TABLES

1/ Formerly chemical engineer, Bureau of Mines, Oil-Shale Experiment Station, Rifle, Colo.
2/ Chemical engineer, Bureau of Mines, Oil-Shale Experiment Station, Rifle, Colo.

Report of Investigations 5145.

TABLES (Con.)

ILLUSTRATIONS

SUMMARY

In its work under the Synthetic Liquid Fuels Program the Bureau of Mines has developed on a 6-ton-a-day-pilot-plant scale a continuous, gravity-feed retort for distilling oil from oil shale. The development work covered by this report was done from January 27, 1950, to January 26, 1952, at the Oil-Shale Experiment Station near Rifle, Colo. Over 300 pilot-plant tests were made during the investigation. The basic retort developed has been named the Gas-Combustion retort.

In this process, part of the heat for retorting of the shale is generated by burning recycled product gas in a combustion zone within the descending shale bed in the retort. Additional heat is supplied by combustion of the carbonaceous residue remaining in the spent shale after the oil has been distilled. Air for combustion is admitted through an air distributor in the center of the bed at about the midpoint of the retort. Hot gas rising from the combustion zone heats countercurrently the descending raw shale and liberated shale oil by pyrolysis of the shale. After passing through and exchanging heat with the incoming raw shale, the oil is condensed as a fog or mist in the gas, which is withdrawn at the top of the retort. The cool gas is then piped to an oil-recovery system where the oil is separated from the gas in centrifugal separators or other types of mechanical or electrostatic separators. The hot, spent shale below the combustion zone is cooled by heat exchange with recycle gas, which is a portion of the effluent gas from the oil-recovery system.

Important desirable features of the process are:

1. The spent shale leaves the retort at a low temperature of less than 200° F.; heat is conserved, and handling and disposal of the spent shale is simplified.

2. The temperature of the exit gas and entrained oil is not over 175° F. At this temperature the oil is in the form of a mist that can be separated almost completely by mechanical means without further cooling.

3. Owing to the high overall efficiency of the retort, energy in excess of that required for the process is available. This excess energy, in the form of low heating value gas, is suitable for steam or power generation or other purposes.

4. No cooling water is needed either at the retort or in the oil-recovery system. This is a highly important point since most of the richer beds of shale in the United States lie in semiarid or desert regions where water is scarce.

5. The yield of oil from the Gas-Combustion retort, under properly controlled conditions, is high, approximately 95 percent of the Fischer assay of the shale.

Operating problems of the process are:

1. The temperature of the combustion zone must be controlled within fairly narrow limits. If the temperature is too low the fire may go out; if too high the mineral constituents of the shale fuse, forming clinkers.

2. Refluxing usually occurs unless conditions are controlled properly. This results in excessive cracking of the oil and a consequent lower oil yield. It also may result in agglomeration of shale particles owing to the formation of pitch or coke in or somewhat above the retorting zone.

3. For the best operation the combustion zone must be uniform across the retort. An uneven combustion zone invariably causes erratic operation and low oil yields. Such a condition may result from clinker formation or from refluxing.

4. Rich shales containing more than about 33 gallons of oil per ton tend to agglomerate and form coke in the retorting zone, which interferes with the uniformity of shale and gas flows.

Most of the troubles listed above can be surmounted by careful control of the shale-air ratio and the shale-recycle gas ratio. These ratios must be determined through experience for shales of different compositions. With average Colorado shale as mined, containing about 30 gallons of oil per ton, the pilot plant has been run continuously for weeks with only minor operating difficulties.

Preliminary tests indicate that addition of a small amount of sodium chloride to the raw shale causes the formation of a more stable oil mist in the retort gas, owing to nucleation effects of the sublimed salt. When salt is added operating conditions may be varied more widely without loss of oil by refluxing and cracking in the shale bed.

This report describes the step-by-step development of the Gas-Combustion retort and the various modifications and means of air admission used to obtain a workable unit. Work is continuing on the process to improve yields, simplify operation, increase the throughput of shale, and to learn more about the chemical and physical phenomena encountered in the pyrolysis of oil shale by this process.

INTRODUCTION

Under the Synthetic Liquid Fuels Program, work was begun by the Bureau of Mines in 1945 near Rifle, Colo., on the production of liquid fuels from Colorado oil shale. The NTU process 3/ tested initially included a batch-type retort heated by the internal combustion of retort gas and residual carbon in the shale bed. The development work showed the practicability of pyrolysis of Colorado shale and gave information regarding the properties of the oil produced. It also pointed to the need of further investigation which could be done most effectively in a small pilot plant of a few-tons-per-day capacity.

The first pilot plant, erected in 1947, 4/ was a retort in which a fixed bed of crushed shale was retorted by direct contact with a stream of hot gas heated by recirculation through pebble stoves. The principal reason for studying this batch-process was to obtain fundamental information on heat transfer, product yields and properties, and general operating techniques.

3/ Bureau of Mines, Synthetic Liquid Fuels, Annual Report of the Secretary of the Interior for 1949, Part II. - Oil from Oil Shale: Rept. of Investigations 4652, 70 pp.

4/ Cattell, R.A., Guthrie, Boyd, and Schramm, L.W., Retorting Colorado Oil Shale - A Review of the Work of the Bureau of Mines, U.S. Department of the Interior: Pres. before Second Oil-Shale and Cannel Coal Conference, Institute of Petroleum, Glasgow, Scotland, July 1950.

For economic reasons the use of a continuous process was indicated. Data from the batch process were used to design the first continuous gravity-feed retort used at Rifle.5/ A bed of shale moving downward through the retort between two parallel sets of louvers was retorted by a stream of hot retort gas flowing horizontally through the bed, entering at one set of louvers and leaving through the other. This was called the Gas-Flow process. A cost-evaluation study showed that investment costs would be high for this process and that the cost of producing liquid fuels from oil shale is influenced to a rather large degree by the magnitude of investment cost. Furthermore, the heat economy of the Gas-Flow process is poor. Accordingly, the efforts on retorting were diverted to development of a low-investment-cost, thermally efficient process.

From the experience gained, a retort was designed as a multipurpose unit capable of several operating arrangements. Continued operations and modifications of the new unit finally led to the development of the Gas-Combustion retort. This report describes the development of the Gas-Combustion process and operation of a 6-ton-a-day pilot plant from the time the unit was first operated in January 1950 to the completion of a 10-day demonstration run in January 1952. Included in the appendix are complete data for all operations during the same period. Subsequent work on the unit will be reported later.

ACKNOWLEDGMENTS

The work described in this report was done under the general supervision of Boyd Guthrie6/ and J. D. Lankford.7/ Along with the authors, J. B. Jones, Jr.,8/ A. A. Reeves,8/ and J. G. Tripp8/ were instrumental in the development of the Gas-Combustion process and participated in supervision of the pilot-plant operations. C. E. Shaffer9/ contributed many constructive suggestions.

PROCESS DEVELOPMENT

The Gas-Combustion process was the outgrowth of a series of experiments, the prime objective of which was to devise a thermally efficient, low-cost retorting process. In all these experiments the shale was heated with hot combustion gases generated in the retort vessel. The same basic vessel was used for all but a few of the experimental runs. It was a vertical, refractory-lined, cylindrical retort, 12 feet high and 20 inches inside diameter. For flexibility it was divided into three flanged sections, which could be interchanged or used for various modifications of the retort. In all the modifications the retorted shale was removed at the bottom of the retort by a turntable, which could be operated at varying speeds to control the rate of shale flow through the retort. Chains attached to the bottom of the turntable carried the spend shale to an opening above a sealed container. The principal dimensions of the retort are shown in figure 1.

5/ See work cited in footnote 3.
6/ Superintendent, Oil-Shale Experiment Station, Bureau of Mines, Rifle, Colo.
7/ Formerly chemical engineer, Bureau of Mines, Oil-Shale Experiment Station, Rifle, Colo. Present address: Office of Helium Activity, Bureau of Mines, Amarillo, Texas.
8/ Formerly chemical engineer, Bureau of Mines, Oil-Shale Experiment Station, Rifle, Colo.
9/ Chemical engineer, Koppers Co., Inc., Pittsburgh, Pa.

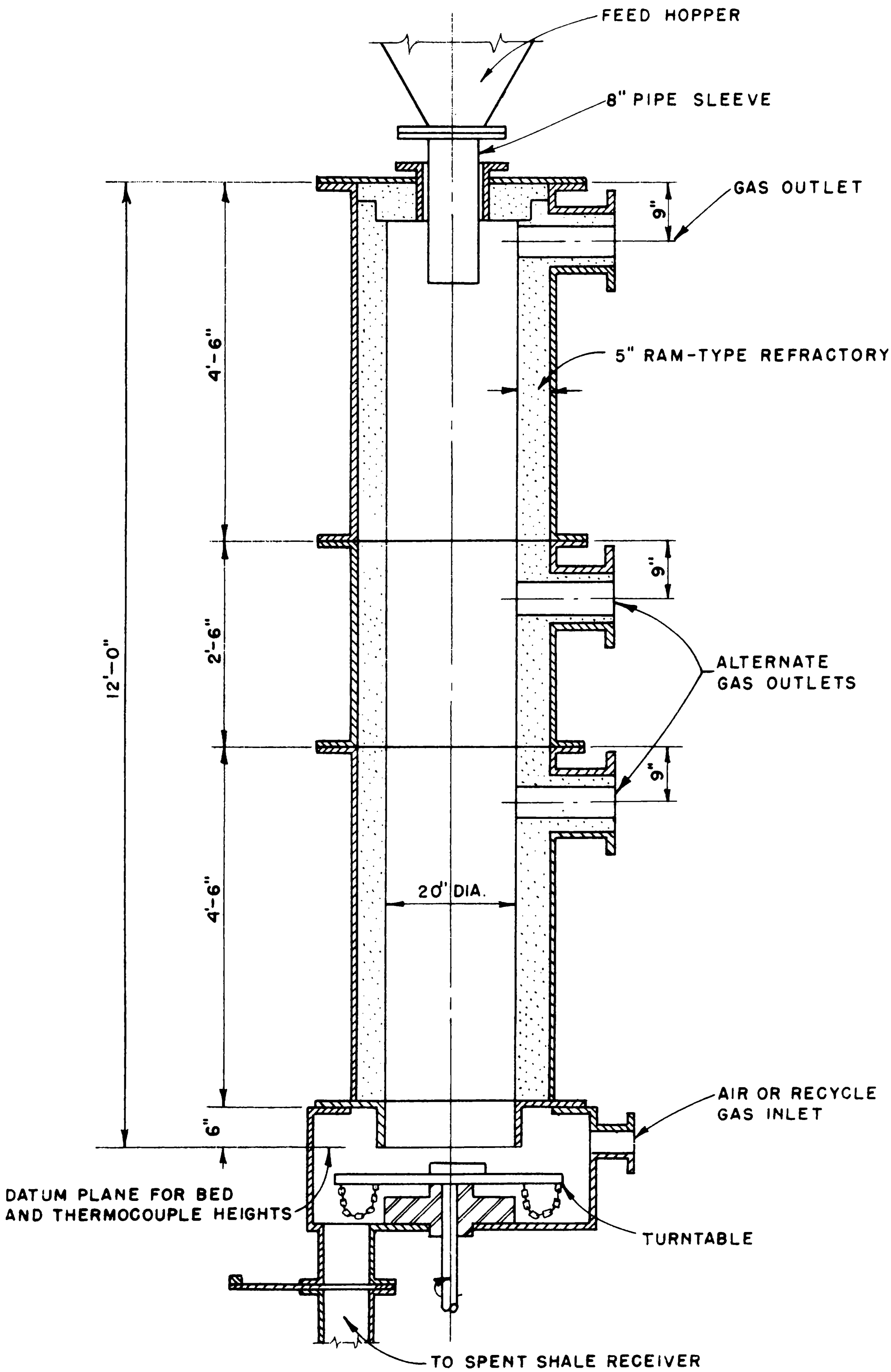


Figure 1. - Basic oil-shale retort.

Dual-Flow Retort

The first adaptation of the basic retort is shown in figure 2. Raw shale of 1/2 by 1-inch size range was charged at the top of the retort through a double-lock hopper arrangement designed to prevent loss of gas. Two funnel-like restrictions of stainless steel were supported between the flanged sections of the retort, forming three separate zones - a shale preheating zone in the upper section, a retorting zone in the center, and a combustion zone at the bottom.

The combustion zone was formed by burning a mixture of recycled retort gas and air entering the bottom of the retort and preheated by the descending bed of hot spent shale. Additional heat was supplied by combustion of organic residue in the spent shale. Part of the hot products of combustion were withdrawn at the disengaging space below the lower funnel and bypassed to the top of the retort. From here the gases flowed down through the retort to a side outlet, preheating the unretorted shale in transit. The remainder of the gas from the combustion zone flowed up to the center section where the preheated shale was retorted. This gas, carrying the distilled oil, was then withdrawn from the retort through the side outlet under the upper funnel, together with the preheating gas from the upper zone. Owing to splitting of the combustion gas and its two-directional flow, the retort was called the Dual-Flow retort. Provision was made to vent part of the gas at the top of the retort if so desired.

Figure 2 also shows a flow diagram of the oil-recovery system used with the Dual-Flow retort. It consisted of a water-cooled tubular condenser, two low-velocity centrifugal separators, and a gas blower. The condenser tended to plug with deposited carbon and soon was eliminated from the system.

Instrumentation and controls for this pilot plant were designed as simply as possible. Gas quantities were measured by conventional orifice meters and were controlled by hand-operated valves. The shale rate was controlled by varying the speed of the spent-shale extractor, using the temperature of the combustion zone as an index of control. This temperature was quite sensitive to rate of shale flow. Thermocouple locations in the shale bed of the retort are shown in figure 9 in the appendix to this report.

In this exploratory phase of the investigation the flows of shale, air, and recycle gas were varied widely to secure fundamental information. Shale feed was varied from less than 100 pounds to over 200 pounds per hour per square foot of bed area; air, from about 6,000 to 16,000 cubic feet per ton of shale; recycle gas, from about 10,000 to over 30,000 cubic feet per ton. In a few tests no recycle gas was used. In general, higher oil yields were obtained at the lower air and recycle gas rates; high air rates caused excessive clinker formation in the combustion zone.

The Dual-Flow retort was operated as originally designed for only seven runs. Subsequently, the bypass line from the combustion zone to the top of the retort was closed, which eliminated the preheating of the shale and caused all of the combustion gas to pass through the retorting zone to the side outlet.

Oil yields obtained while operating the Dual-Flow system as originally designed were low, averaging about 65 percent of the Fischer oil-shale assay.[10] As shown by the data of runs 1 to 7 in table 11 of the appendix, the gas outlet temperatures were high.

10/ Stanfield, K. E., and Frost, I. C., Method of Assaying Oil Shale by a Modified Fischer Retort: Bureau of Mines Rept. of Investigations 3977, 1946, 11 pp.

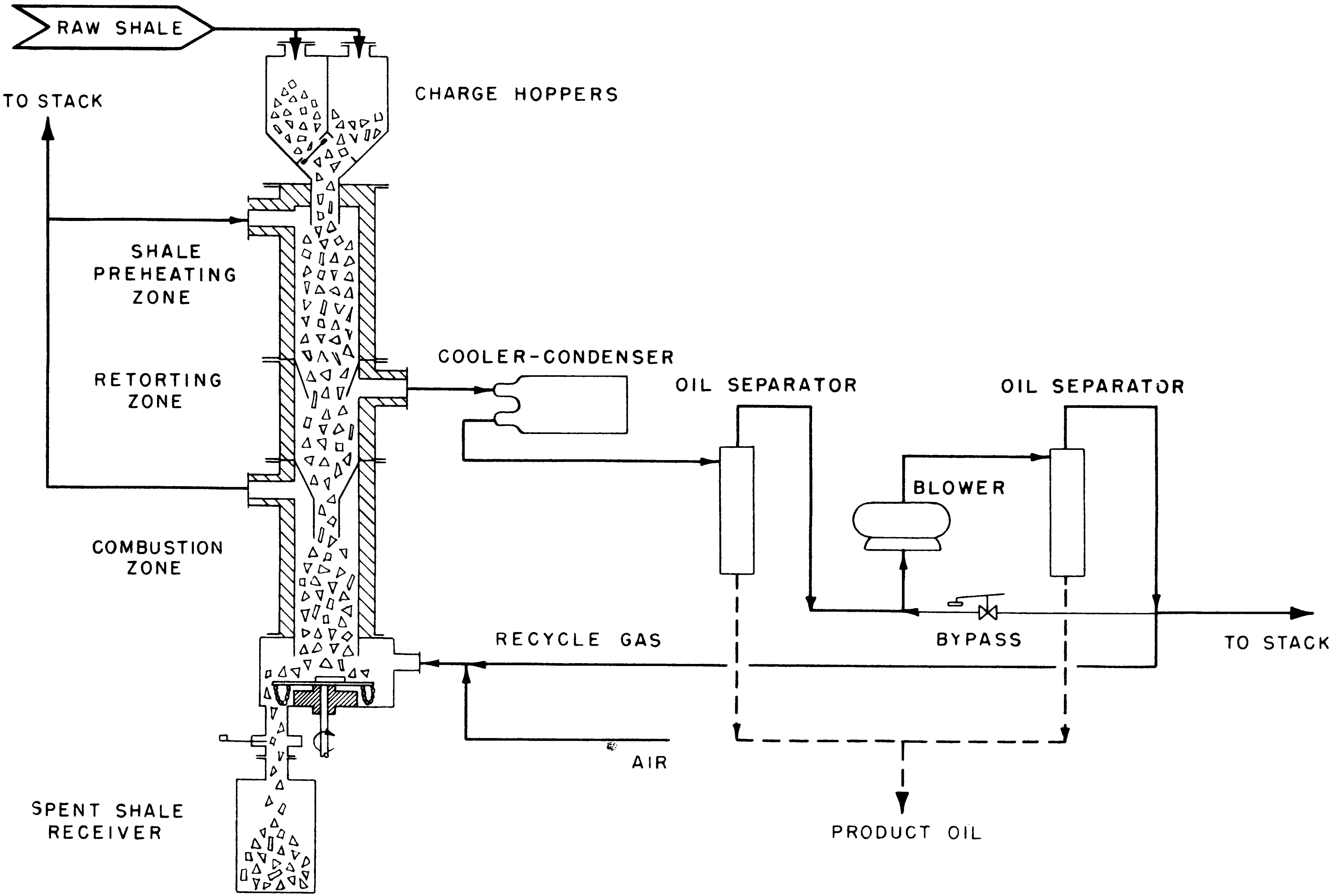


Figure 2. - Diagram of Dual-Flow pilot plant.

In the beginning it was thought that the shale must be preheated and the gas withdrawn at a high temperature to prevent condensation or refluxing of oil on the raw shale. However, after the preheating zone was eliminated, the yield and properties of the oil did not change. Moreover, decreasing the temperature of the outlet gas did not appear to affect the yield adversely even when the temperature was as low as 150° F. This discovery was of considerable consequence since it meant that the preheating of the raw shale could be dispensed with and that the gas and oil could be withdrawn from the retort at a low temperature. This would eliminate the need of water-cooled condensers, an important advantage in oil-shale regions where the water supply is limited.

From observations and results of the tests it was theorized that oil can be removed from the retort at a low temperature because a stable oil mist if formed within the retort shale bed. In the retorting zone the oil undoubtedly is liberated as a vapor. As the vapor moves upward through the descending cool shale, it is cooled to a temperature below the dew point of the oil. The gas then becomes supersaturated with oil, which condenses as minute droplets directly in the gas stream instead of depositing as a film on the shale. The oil mist is carried out of the retort by the cooled gas without any significant loss by impingement on the shale particles. The mist-formation theory seems to be confirmed in these tests in which the oil was successfully removed from the retort in the form of a mist at temperatures far below its normal condensation temperature.

Countercurrent Retort

The next step was to develop a simple countercurrent retorting system with the injection of air and recycle gas into the bottom of the retort. The Dual-Flow pilot was modified gradually over a period of 3 months until it was operating as shown in figure 3. The flow of shale was similar to that of the Dual-Flow process, except that there were no funnel restrictions between the preheating, retorting, and combustion zones.

As before, the mixture of air and recycle gas, preheated in the spent-shale bed, formed a combustion zone near the bottom of the retort. The resulting hot flue gas effected pyrolysis of the shale in a zone immediately above the combustion zone. In the upper section of the retort, heat exchange with the unretorted shale cooled the gas before its exit at the top of the retort.

The oil-recovery system also was modified gradually and is shown schematically in figure 3. The oil separators were a low-velocity centrifugal type; the blowers were a positive displacement type; the scrubber contained 5/8-inch Raschig rings. Both water and shale oil were used at different times in the scrubber, although in most runs the scrubbing medium was water. The blowers are an important part of the recovery system in that they agglomerate some oil through violent agitation of the gas-oil mixture. A detailed description of the evolution of the Dual-Flow retort to the Countercurrent retort and of the changes in the oil-recovery system is given in the appendix.

As with the Dual-Flow system, conditions were varied widely to explore the operation of the Countercurrent process. Good correlations of data were not obtained, but certain trends were noted. The air-recycle gas ratio was found to be important. At high air-gas ratios the combustion and retorting temperatures were too high, resulting in excessive clinker formation and low oil yields. Best operation was obtained at an air-recycle gas ratio of about 1-2. A further increase of recycle gas resulted in low retort temperatures with a consequent loss of oil. In

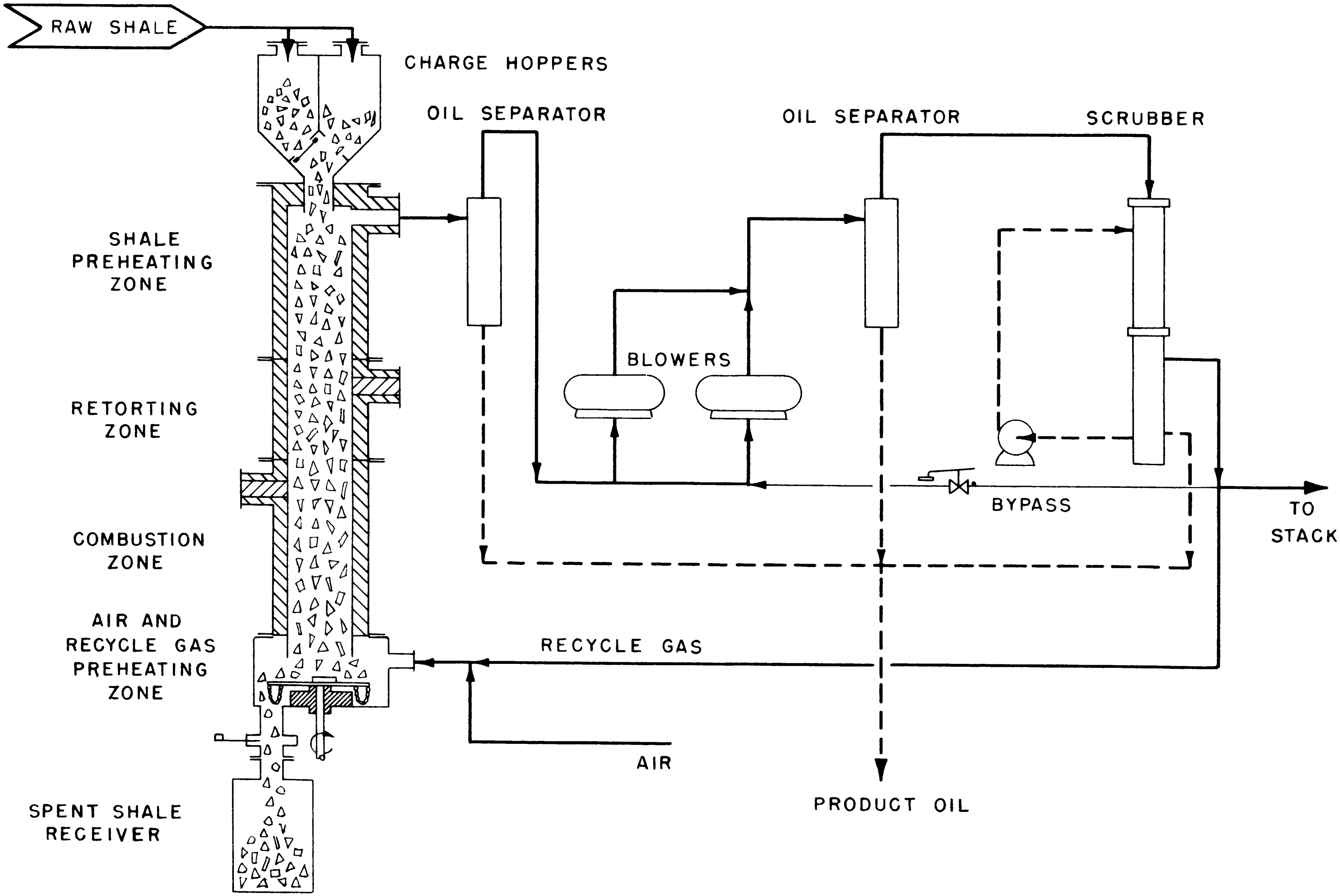


Figure 3. - Diagram of basic countercurrent pilot plant.

this event the shale was not completely retorted, and there were indications that some oil was lost owing to refluxing in the upper part of the bed.

A summary of the data of two extended runs, runs 42 and 45, is presented in tables 1 and 2. Only the data from those tests that were considered satisfactory have been averaged and included in the tables. Detailed data of the runs and an explanation of satisfactory and unsatisfactory results are given in the appendix. Tables 3 and 4 show material and heat balances on the two runs.

TABLE 1. - Countercurrent pilot plant; operating conditions and yield data for two extended runs

Run history:		
Run number	42	45
Number of 24-hr. runs in average	4	4
Shale feed:		
Fischer assay ... gal./ton	28.3	20.4
Size range ... inch	1/2 - 1	1/2 - 1
Feed rate ... lb./hr. x sq. ft. bed area	207	215
Operating conditions:		
Air rate ... std. c. f./ton shale	8,980	7,920
Recycle gas rate ... do.	16,800	14,300
Gas outlet temperature ... °F.	152	144
Spent shale temperature ... do.	590	565
Yield:		
Oil collected (water-free) ... gal./ton shale	25.1	18.8
Oil ... vol.-pct.-Fischer assay	89	92
Gas ... std. c. f./ton shale	11,840	10,750

Both runs were made at about the same shale feed rates; however, the gas rate and shale assay both were higher for run 42. The higher gas rate used in run 42 may have caused some refluxing of oil in the retort, resulting in a slightly lower oil yield than for run 45. This is confirmed by the oil properties listed in table 2. The oil from run 42 was lighter and of lower viscosity than that of run 45 and therefore apparently had been subject to more cracking. Experience shows that oil mist separated by impingement on the raw shale is partly cracked during redistillation when the oil-coated shale approaches the retorting zone.

Retorting by this method was found to be more promising than by the processes previously investigated. A relatively high yield of oil could be obtained when retorting a commercial grade of shale at a throughput rate of about 200 pounds per hour per square foot of retort cross sectional area. This rate was considered to be a reasonably high throughput. The properties of the oil were similar to those obtained from other retorts. The product gas had too low a heating value to have much economic worth.

Study of the operation of the lower part of the retort showed that considerable heat available was not utilized since the temperature of the retorted shale discharge was over 600° F. in some runs. The quantity of gas injected in the bottom of the retort was enough to absorb the sensible heat of the retorted shale if it could be transferred. Unfortunately, this did not occur because the mixture of air and recycle gas ignited as soon as it reached combustion temperature, placing the combustion quite near the bottom of the retort, which caused the retorted shale to leave the vessel at a relatively high temperature. The high sensible-heat loss in spent shale is shown in the heat balances of table 4.

TABLE 2. - Countercurrent pilot plant; properties of retort products for two extended runs

Run number		42	45
Properties of crude oil:			
Gravity, °API	60° F.	21.5	19.3
Specific gravity	do.	0.9248	0.9383
Viscosity:			
Saybolt Universal @ 130° F.	seconds	118	129
Saybolt Universal @ 210° F.	do.	46	47
Ramsbottom carbon residue	wt.-pct.	2.2	3.9
Water	vol.-pct.	0.5	1.0
Nitrogen	wt.-pct.	2.0	2.1
Sulfur	do.	0.71	0.70
Vacuum distillation (40 mm. corrected to 760 mm.):			
Initial boiling point	°F.	410	404
2 percent	do.	444	434
5 percent	do.	494	510
10 percent	do.	538	554
20 percent	do.	615	624
30 percent	do.	702	692
40 percent	do.	764	773
50 percent	do.	844	845
60 percent	do.	896	892
Cut point	do.	900	900
Recovery	percent	60.3	61.7
Properties of product gas:			
Gross heating value	B.t.u./std. c. f.	58	57
Water vapor content at outlet temperature	vol.-pct.	9.2	10.3
Orsat analysis - (dry basis):			
CO_2	do.	22.4	23.6
Illuminants	do.	0.8	0.5
O_2	do.	0.0	0.0
CO	do.	4.1	2.4
H_2	do.	3.8	6.7
Hydrocarbons[1/]	do.	1.7	1.7
N_2	do.	67.2	65.1
Properties of retorted shale:			
Fischer assay	gal./ton	0.1	0.1
Mineral carbon dioxide	wt.-pct.	11.7	8.3

1/ Hydrocarbons consist of about 80 percent CH_4 and 20 percent C_2H_6 with traces of C_3 and C_4 compounds.

TABLE 3. - Countercurrent pilot plant; material balances for two extended runs

Basis: 1 ton of raw shale feed

Run number	42		45	
	Pounds	Wt.-pct.	Pounds	Wt.-pct.
Material input:				
Shale feed	2,000	74.4	2,000	76.7
Air	689	25.6	609	23.3
Total	2,689	100.0	2,609	100.0
Material output:				
Shale oil, water-free	193	7.2	147	5.6
Gas, saturated at vent-gas temp.	916	34.0	815	31.3
Water condensed	52	1.9	58	2.2
Spent shale	1,475	54.9	1,533	58.8
Unaccounted for	53	2.0	56	2.1
Total	2,689	100.0	2,609	100.0

TABLE 4. - Countercurrent pilot plant; heat balances for two extended runs

Basis: 1 ton raw shale feed Datum temperature: 60° F.

Run number	42		45	
	B.t.u.	Percent	B.t.u.	Percent
Heat input:				
Heat of combustion1/	898,000	90.3	792,000	89.7
Sensible heat:				
Air	2,500	.3	2,200	.2
Recycle gas, wet	15,600	1.6	14,800	1.7
Raw shale	0	0	0	0
Vaporization of water in recycle gas ...	78,000	7.8	74,400	8.4
Total	994,100	100.0	883,400	100.0
Heat output:				
Sensible heat:				
Oil, water-free	9,100	.9	6,200	.7
Gas, wet	52,500	5.3	33,600	3.8
Spent shale	175,500	17.7	176,500	20.0
Vaporization of water in gas	190,100	19.1	167,700	19.0
Carbonate decomposition2/	276,300	27.8	319,000	36.1
Radiation and convection, calc.	75,000	7.5	75,000	8.5
Unaccounted for (by difference)3/	215,600	21.7	105,400	11.9
Total	994,100	100.0	883,400	100.0

1/ Basis: 100 B.t.u. liberated per std. c. f. air.
2/ Basis: Heat of decomposition: 57,000 B.t.u./mol. $MgCO_3$
77,900 B.t.u./mol. $CaCO_3$
3/ Includes heat of eduction of oil.

Air Into Combustion Zone

In order to reduce the temperature of the discharged spent shale and possibly reduce clinker formation, it was decided to admit air through the side of the retort, allowing the recycled retort gas to enter the bottom as before. In this manner the hot spent shale would be cooled by heat exchange with the recycle gas, and

and the latter would be preheated for more efficient combustion in a zone at the point of air admission higher up in the retort. As shown schematically by retort E in figure 11 (appendix), the air was admitted at two points on opposing sides of the retort about 2 feet from the bottom.

Only two runs were made with this arrangement (runs 31 and 32). The oil yields were low, and there was considerable clinker formation in the combustion zone, although the outlet temperature of the spent shale was lowered. It seemed apparent that the air distribution was not uniform in the fuel bed, and the method was abandoned.

Next, a perforated pipe was installed across the retort about 4 feet from the bottom, as shown in retort F of figure 11 (appendix). Thirteen runs were made with this arrangement, although not in chronological order. Again, clinker clusters were formed at the point of air admission, which tended to stop the flow of shale aggravated by the restriction of the perforated pipe extending across the retort. At air-recycle gas ratios high enough to achieve complete retorting, clinkering was severe.

It was reasoned that air entering the shale bed in this manner might still react preferentially with the carbon in the spent shale and cause excessive heating of the shale surfaces with resultant fusing of the minerals. With this in mind, the first air-gas mixer-distributor was installed. The distributor is shown schematically as installed in retort G in figure 12 (appendix). It consisted of a 4-inch, open-end cylinder about 2 feet long mounted vertically in the center of the retort and shielded with a conical cap a few inches above the cylinder to prevent shale from entering. Air was admitted to the cylinder from two pipes extending through the side walls of the retort, which also acted as supports for the distributor. Because of gas-flow restriction in the shale bed outside the cylinder it was reasoned that a portion of the preheated recycle gas would enter the bottom of the cylinder where it would mix with the air before flowing into the combustion zone above the distributor. In this manner the air would be diluted with considerable excess gas, and combustion would be spread out over a longer but less intense temperature zone.

Runs 60 to 87, the first series using the new air-gas mixer, gave much better results than had been obtained previously. These results will be described, together with those of later runs, in another section of this report entitled "Gas-Combustion Retort." Following run 87, mixers of different design were tried, but, in each case, the principle of combining air and recycle gas in a mixer within the shale bed was followed.

First, to eliminate the possibility of restriction to shale flow by the centrally located distributor, the device was cut in half longitudinally, and the halves were mounted on opposing side walls of the retort at the same elevation as before. The arrangement is shown by retort H of figure 12 in the appendix. The flow of shale was perhaps a little more uniform with this arrangement, but the shale oil produced was lighter and of lower viscosity than that obtained with the center distributor, indicating that cracking of the oil was more severe. Runs 88 to 105 were made with this wall-type of mixer-distributor.

The next step in the development was the installation of a peripheral-type distributor, as shown by retort I in figure 13 (appendix) and more in detail in figure 4. The distributor consisted of a cylinder mounted in the lower section of the retort from which the refractory lining had been removed. The projecting walls

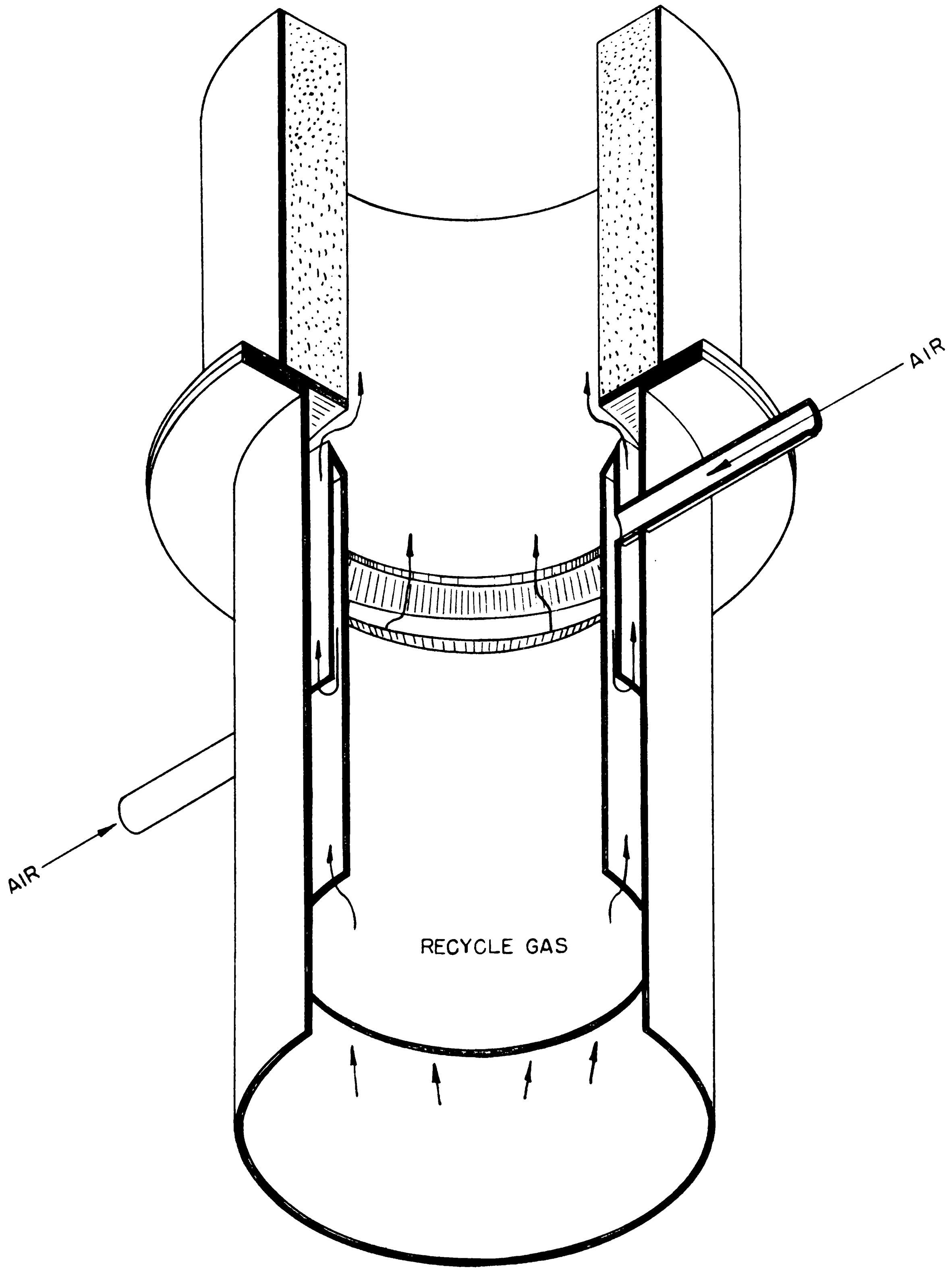


Figure 4. - Gas-Combustion process isometric section of peripheral type air-gas mixer.

of the lining of the retort above prevented shale from entering the annular space between the cylinder and the shell of the retort. Air entered the annular space where it mixed with recycle gas before entering the combustion zone in the retort. Runs 106 to 130 were made with this type of distributor.

It was soon found that there was considerable burning of recycle gas in the annular space. Clinker formation was reduced, but cracking of oil was moderate to severe, and the oil yields were not as high as desirable. In runs 131 to 161, opposite quarters of the annular space were blanked off to increase the gas velocity therein and prevent burning. However, burning in the distributor still occurred, and there was only a slight improvement in results.

Rectangular Retort

Studies of the design of commercial-sized retorts had shown that a rectangular vessel would have certain advantages, and it was thought that pilot-plant studies using a vessel with a rectangular shape was desirable. Accordingly, a rectangular unit was built and was used for runs 162 to 173. As shown schematically by retort J of figure 13 (appendix), the inside cross section was 15 by 24 inches. The air-gas mixer-distributors consisted of plates extending the full length of the long walls at a point about one-third the way up in the retort. Shale was prevented from entering the 3-inch space between the walls and the plates by the projecting refractory lining of the combustion and retorting zones above. As before, air entered the space through pipes in the side walls and mixed with preheated recycle gas entering the distributor at the bottom. The mixture then flowed through the opening at the top of the distributor into the combustion zone.

The average oil yield obtained with the rectangular retort was about 82 percent of the Fischer assay, although in a few tests the yield approached 90 percent. Clinkering was considered as moderate in about half the tests; in the others little or no clinker trouble was noted.

The comparatively low oil yields may have resulted from poor air-gas distribution across the retort or from corner affects of the rectangular retort. Dead corners in which little combustion or retorting took place probably had a marked influence on overall results in the small vessel.

At the same time the described changes were being made in the retort, a number of changes and relocations of recovery units were made in the oil-recovery system. The water scrubber was replaced with an electrostatic precipitator; high velocity centrifugal separators were tried in different locations; and a baffle-type separator containing woven wire mesh was installed. The details and chronology of these changes are given in the appendix.

Gas-Combustion Retort

As stated previously in the report, several preliminary experiments were made (runs 60 to 87) using a cylindrical air-gas mixer-distributor in the center of the retort. This distributor was constructed of mild steel about 1/8-inch thick and was considerably warped and burned at the end of the preliminary runs. However, this type of distributor was considered to have more promise than any of the others tried, and it was decided to resume testing with it. Several changes, intended to minimize warpage and metal deterioration, were incorporated into the design, and 18-8 stainless steel was used instead of mild steel. Details of design are shown in figure 5. It will be noted that the air is blown into the conical cover to cool

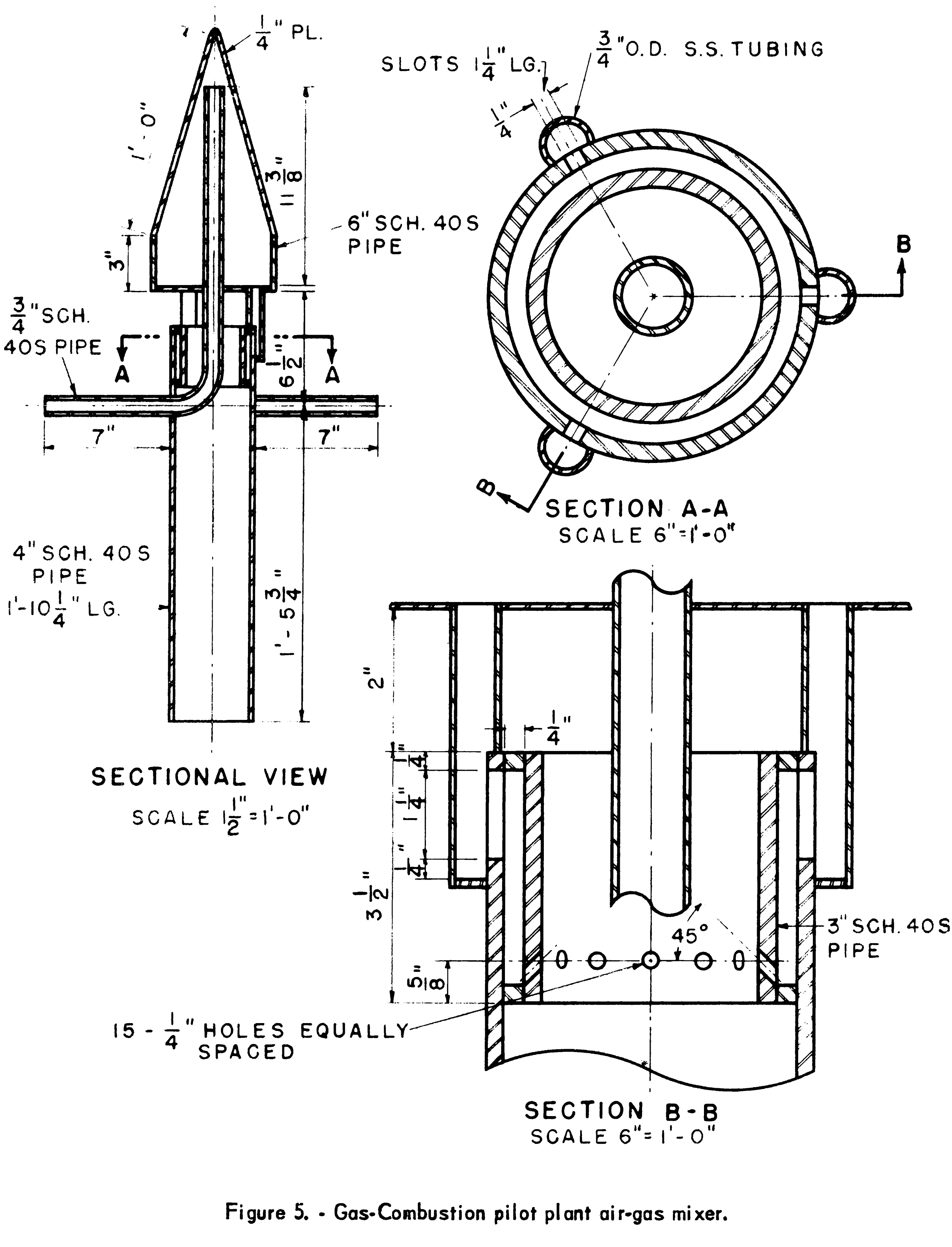


Figure 5. - Gas-Combustion pilot plant air-gas mixer.

it, after which the air enters the cylindrical mixer below. The air-gas mixture then flows through the space between the cylinder and cover into the combustion zone where it is burned.

Runs 174 to 222 were made with the revised Gas-Combustion retort, type K in the appendix. In these tests the raw shale, air, and recycle gas rates were varied to determine the best operating conditions, particularly in regard to operability of the process and oil yield. The grade of shale also was varied, over a range of about 21 to 32 gallons per ton, to provide a means of evaluating the importance of this variable. Operational difficulties were encountered during many of the runs in this exploratory program. In general it was found that clinkering became troublesome at air rates much over 4,000 cubic feet per ton of raw shale and that refluxing of oil in the upper portion of the retort bed was apt to become pronounced at recycle gas rates much over 18,000 cubic feet per ton of raw shale. It also was noted that refluxing of oil and agglomeration or coking together of shale particles was aggravated when charging shale assaying 30 gallons of oil per ton or more as compared with shale assaying 20 to 25 gallons. Oil yields varied from less than 80 percent of the Fischer assay to over 95 percent during this period, tending to increase as the operational difficulties mentioned decreased. The best conditions were found to be approximately as follows: Shale rate, 230 pounds per hour per square foot of bed cross sectional area; air rate, 3,800 cubic feet per ton of shale; recycle gas, 16,500 cubic feet per ton. This is an air-recycle gas ratio of approximately 1-4.3.

During the preliminary testing of the retort a 10-day evaluation run was made to determine the operability of the process during sustained operation. Shale averaging 24 gallons per ton was used during this run. Later the National Petroleum Council requested that a similar run be made using a shale of the grade that probably would be mined commercially, 28 to 30 gallons per ton. Therefore another 10-day demonstration was made feeding shale that averaged 29 gallons per ton.

Table 5 shows the average operating conditions and yields for the two, continuous, 10-day operating periods, table 6 lists the properties of the products, and tables 7 and 8 show material and heat balances. Yields and operating data were calculated for consecutive periods, 24 hours long in most cases. The period averages are listed under runs 79A to 79J and 222A to 222J in the appendix.

The results of the 10-day operations were much better than any obtained previously with other retorts. The oil yields averaged 96 and 94 volume-percent of the Fischer assay for the two runs, respectively, and the throughput of 230 pounds per hour per square foot of bed area was considered high. The outlet temperatures of the products were very low - 143° and 123° F. for the gas-oil mixture in the two runs and 157° and 185° F. for the spent shale.

A small amount of clinker was produced on one or two of the days during each run, but the amount was not enough to interfere seriously with the operations. The low API gravity (high specific gravity), the high viscosity, and high carbon residue of the crude oils produced indicate that refluxing and cracking of the oil in the retort was not excessive. The retort gas had a higher heating value than that from previously described processes and undoubtedly could be used at the plant site for power or steam production.

The material balances of table 7 show 98.9 percent and 98.1 percent recovery of total products, indicating that the measurements of flows were accurate. The heat balances of table 8 indicate that the heat required for the eduction of the oil is low but that considerable heat is used in decomposing the mineral carbonates in the shale. The sensible heat loss in oil, gas, and spent shale is unusually low for a retorting process owing to the low outlet temperatures of these products.

TABLE 5. - Gas-Combustion pilot plant; operating conditions and yield data; 10-day runs

Run history:		
Run Nos.	79A to 79J	222A to 222J
Length of run ... days	10	10
Shale feed:		
Fischer assay ... gal./ton	24.0	29.0
Mineral CO_2 ... wt.-pct.	19.5	17.0
Size range ... in.	1/4 - 1	1/4 - 1-1/4
Feed rate ... lb./hr./ x sq. ft. bed area	230	233
Operating conditions:		
Air rate ... std. c. f./ton shale	3,780	3,760
Recycle-gas rate ... do.	18,190	16,620
Superficial linear gas velocity ... ft./sec.	0.80	0.73
Gas outlet temperature ... °F.	143	123
Spent shale temperature ... do.	157	185
Yields:		
Oil collected (water-free) ... gal./ton shale	23.1	27.3
Oil ... vol.-pct.-Fischer assay	96.1	94.1
Oil ... wt.-pct.-Fischer assay	98.3	96.4
Gas ... std. c. f./ton shale	6,070	5,810

TABLE 6. - Gas-Combustion pilot plant; properties of retort products; 10-day runs

Run Nos.	79A to 79J	222A to 222J
Properties of crude oil:		
Gravity, °API .... 60° F.	19.3	20.1
Specific gravity......................... do.	0.9383	0.9334
Viscosity:		
Saybolt Universal at 130° F. .... sec.	147	127
Saybolt Universal at 210° F. .... do.	51	52
Ramsbottom carbon residue .... wt.-pct.	2.4	2.4
Water .... vol.-pct.	2.3	6.6
Nitrogen .... wt.-pct.	2.08	2.16
Sulfur .... do.	0.62	0.66
Ash .... do.	0.13	0.06
Vacuum distillation (1 mm. corrected to 760 mm):		
Initial boiling point at .... °F.	373	360
2 percent .... do.	417	405
5 percent .... do.	434	448
10 percent .... do.	512	505
20 percent .... do.	612	596
30 percent .... do.	692	680
40 percent .... do.	769	758
50 percent .... do.	833	837
60 percent .... do.	894	900
Cut point .... do.	900	-
Recovery .... vol.-pct.	61.7	59.4
Properties of product gas:		
Gross heating value .... B.t.u./std. c. f.	93	91
Water vapor content at outlet temp. ..vol.-pct.	12.6	12.6
Orsat analysis (dry basis):		
CO_2 .... vol.-pct.	27.5	27.0
Illuminants .... do.	1.2	1.4
O_2 .... do.	0.2	0.2
CO .... do.	4.3	4.8
H_2 .... do.	5.1	5.0
Hydrocarbons1/ .... do.	3.6	3.1
N_2 .... do.	58.1	58.5
Properties of retorted shale:		
Fischer assay .... gal./ton	0.3	0.4
Mineral carbon dioxide .... wt.-pct.	16.5	16.1

1/ Hydrocarbons consist of about 80 percent CH_4 and 20 percent C_2H_6 with traces of C_3 and C_4 compounds.

TABLE 7. - Gas-Combustion pilot plant; material balances; 10-day runs

Basis: 1 ton of raw shale feed.

Run Nos.	79A to 79J		222A to 222J	
	Pounds	Wt.-pct.	Pounds	Wt.-pct.
Material input:				
Shale feed	2,000	87.3	2,000	87.4
Air	290	12.7	289	12.6
Total	2,290	100.0	2,289	100.0
Material output:				
Shale oil, water-free	180	7.9	212	9.3
Gas, saturated at vent-gas temp.	453	19.8	448	19.6
Water condensed	25	1.1	26	1.1
Spent shale	1,602	70.1	1,560	68.1
Unaccounted for	30	1.1	43	1.9
Total	2,290	100.0	2,289	100.0

TABLE 8. - Gas-Combustion pilot plant; heat balances; 10-day runs

Basis: 1 ton raw shale feed
Datum temperature: 60° F.

Run Nos.	79A to 79J		222A to 222J	
	B.t.u.	Percent	B.t.u.	Percent
Heat input:				
Heat of combustion1/	378,000	73.2	376,000	74.4
Sensible heat:				
Air	2,200	.4	1,700	.3
Recycle gas, wet	20,600	4.0	22,200	4.4
Raw shale	0	0	0	0
Vaporization of water in recycle gas	115,700	22.4	105,500	20.9
Total	516,500	100.0	505,400	100.0
Heat output:				
Sensible heat:				
Oil, water-free	7,600	1.5	6,800	1.4
Gas, wet	40,900	7.9	30,000	5.9
Spent shale	33,600	6.5	40,600	8.0
Vaporization of water in gas	181,700	35.2	170,900	33.8
Carbonate decomposition2/	163,000	31.5	115,100	22.8
Radiation and convection, calc.	50,000	9.7	50,000	9.9
Unaccounted for (by difference)3/	39,700	7.7	92,000	18.2
Total	516,500	100.0	505,400	100.0

1/ Basis: 100 B.t.u. liberated per std. c. f. air.
2/ Basis: Heat of decomposition: 57,000 B.t.u./mol. $MgCO_3$.
77,900 B.t.u./mol. $CaCO_3$.
3/ Includes heat of eduction of oil.

Figure 6 shows a temperature profile in the shale bed from top to bottom of the retort. Figure 7 shows an isothermal cross section of temperatures throughout the retort. The highest temperature (1,400° F.) is at the lower part of the conical cover of the distributor just above the point of admission of the air-recycle gas mixture. Although there is considerable difference in temperature between the center and edge of the retort at the combustion level, the temperatures are quite

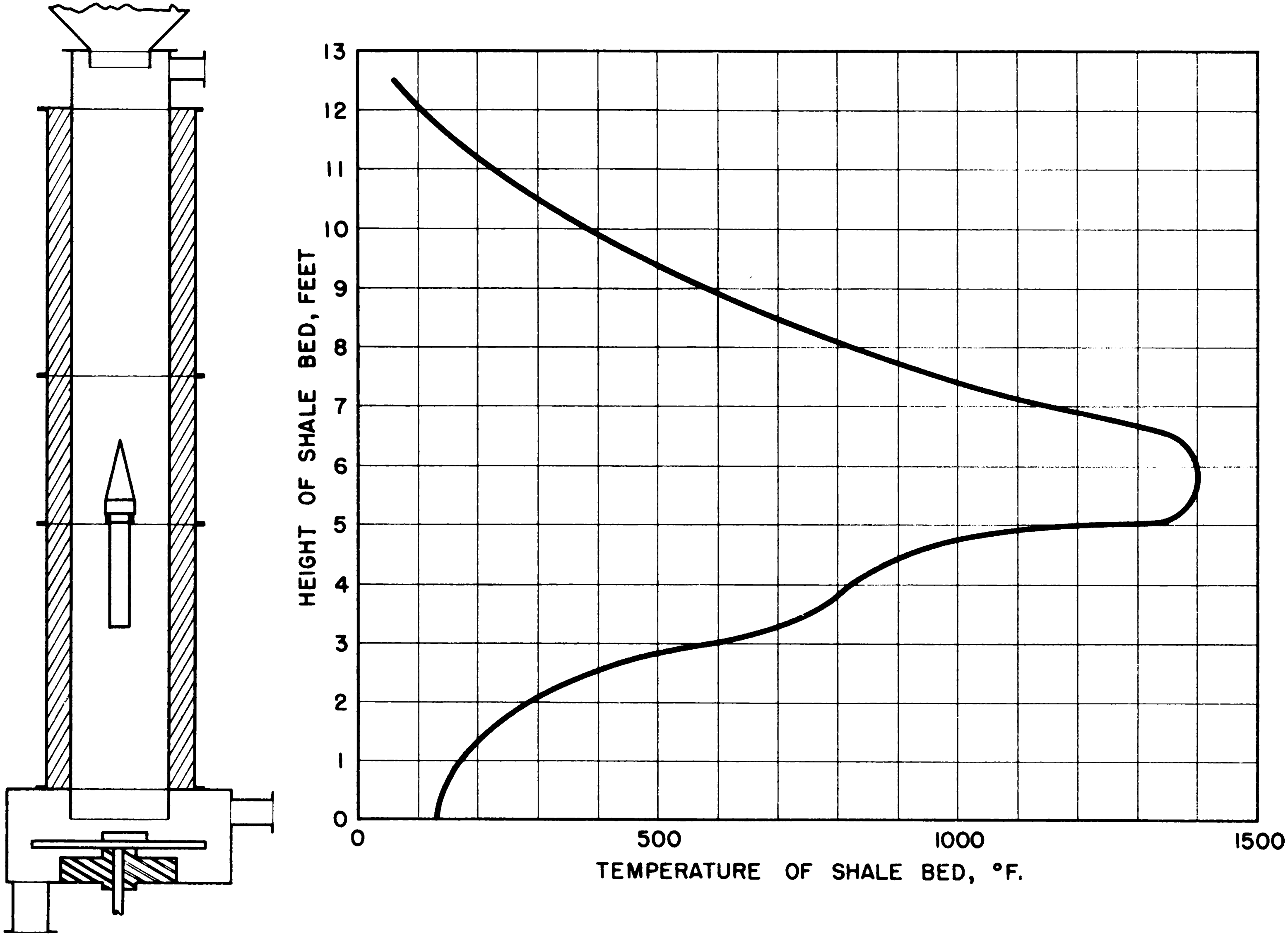


Figure 6. - Gas-Combustion retort bed temperature profile.

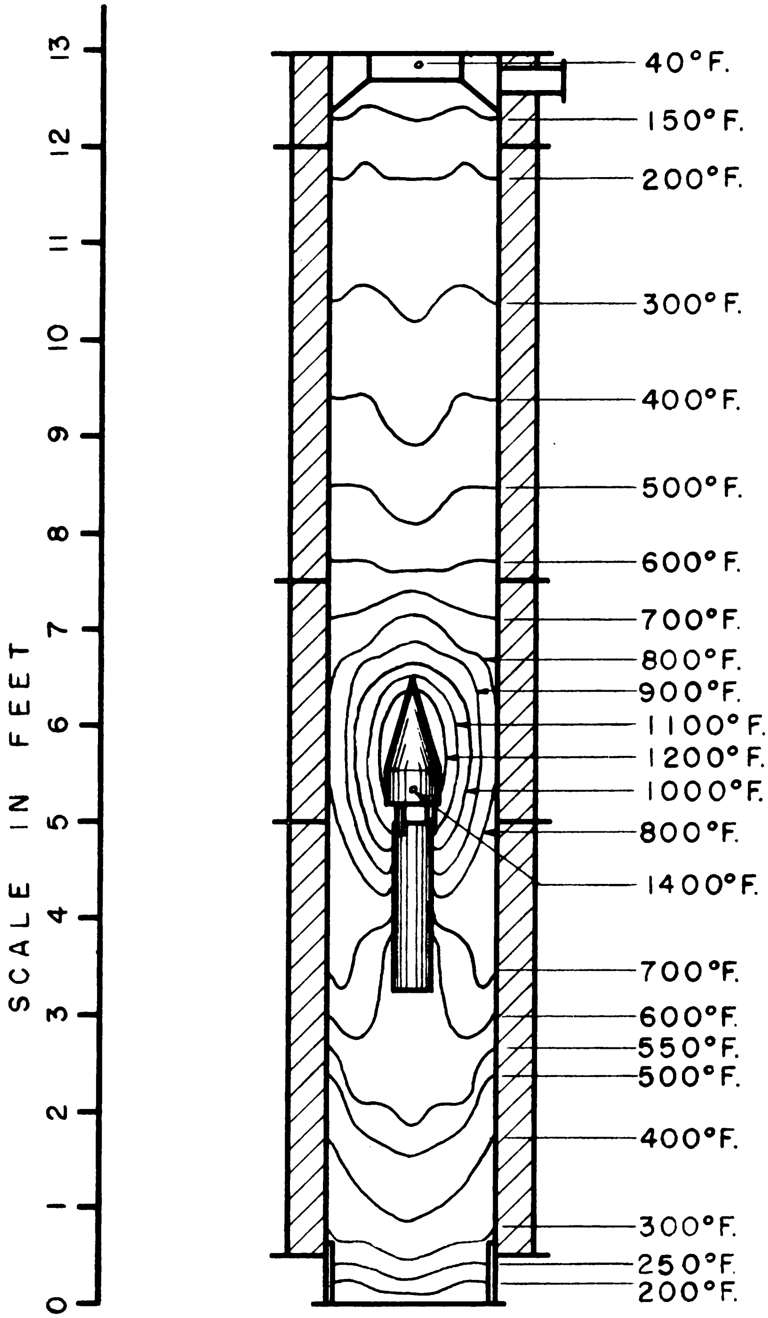


Figure 7. - Gas-Combustion pilot plant retort isothermal cross section.

uniform over the cross section a short distance above the combustion zone. The dips in the isothermals above and below the combustion zone (fig. 7) indicate that there probably was a slight difference in the flow rate of shale from wall to center of the retort or that there may have been some channeling of gas.

The 18-8 stainless steel distributor under the optimum conditions of retorting lasted for about sixty 24-hour tests, although at excessive air rates and high temperatures its life was somewhat shorter. By using a more heat-resistant alloy and heavier gage metal it is probable that the life of the distributor can be extended greatly.

During the investigation of the Gas-Combustion retort additional changes were made in the oil-recovery system. The main change was the substitution of a high-velocity centrifugal separator for the low-velocity separators previously used. Automatic controllers were installed in the gas and air lines, although the speed of rotation of the spent shale extractor was still controlled by hand. A flow diagram of the retort and the oil-recovery system as used at the end of this investigation is shown in figure 8. Details of the development are given in the appendix.

Oil-Mist Formation Studies

During the course of the development work a new idea for improving the process was conceived. As noted in a preceding part of this report, one of the conditions for the formation of a stable oil mist is that the gas stream be supersaturated with respect to the shale oil. A further condition is that a large enough quantity of suitable nuclei be present upon which the oil can condense as very fine droplets. It was thought that under certain conditions of operation there are an insufficient number of naturally occurring nuclei, which could be corrected by adding a material to the shale to form additional nuclei. In other chemical processes, uniform, stable mists are sometimes formed by cooling a dilute stream of a high-molecular-weight organic compound in the presence of minute crystals of sodium chloride. These crystals are formed by vaporizing the salt and then cooling. To test the idea on shale retorting, it was decided to add a small quantity of saturated sodium chloride brine to the raw shale charge.

Runs 134 and 135 were made at comparable operating conditions, but, during run 134, 1 gallon of saturated sodium chloride brine was added to each ton of raw shale. As shown in table 18 in the appendix, there was a marked difference in the oil yields - 71 percent for the run without brine and 89 percent for the one with brine. There were also significant differences in oil properties. Run 135, without brine, produced a comparatively light oil with an API gravity of 23.1 and a viscosity of 70 seconds (Saybolt Universal at 130° F.). Run 134, with brine, gave a heavier oil of 20.7 API gravity and 109 seconds viscosity.

Further to demonstrate the effect of adding brine, comparisons were made of the average results obtained during other brine runs with those for nonbrine runs. Of 30 consecutive runs (runs 131 to 161), 22 were made with brine and 8 without. During this time, the peripheral distributor with opposite quarters blanked off was used. In order to explore the characteristics of the retort, operating conditions were varied considerably, and for this reason it is not possible to isolate the effects of the brine. However, a comparison of the average yields and properties of oil obtained during the 22 brine runs with the averages for the 8 nonbrine runs has some significance and is indicative of the effect of the brine. Such a comparison is shown in table 9.

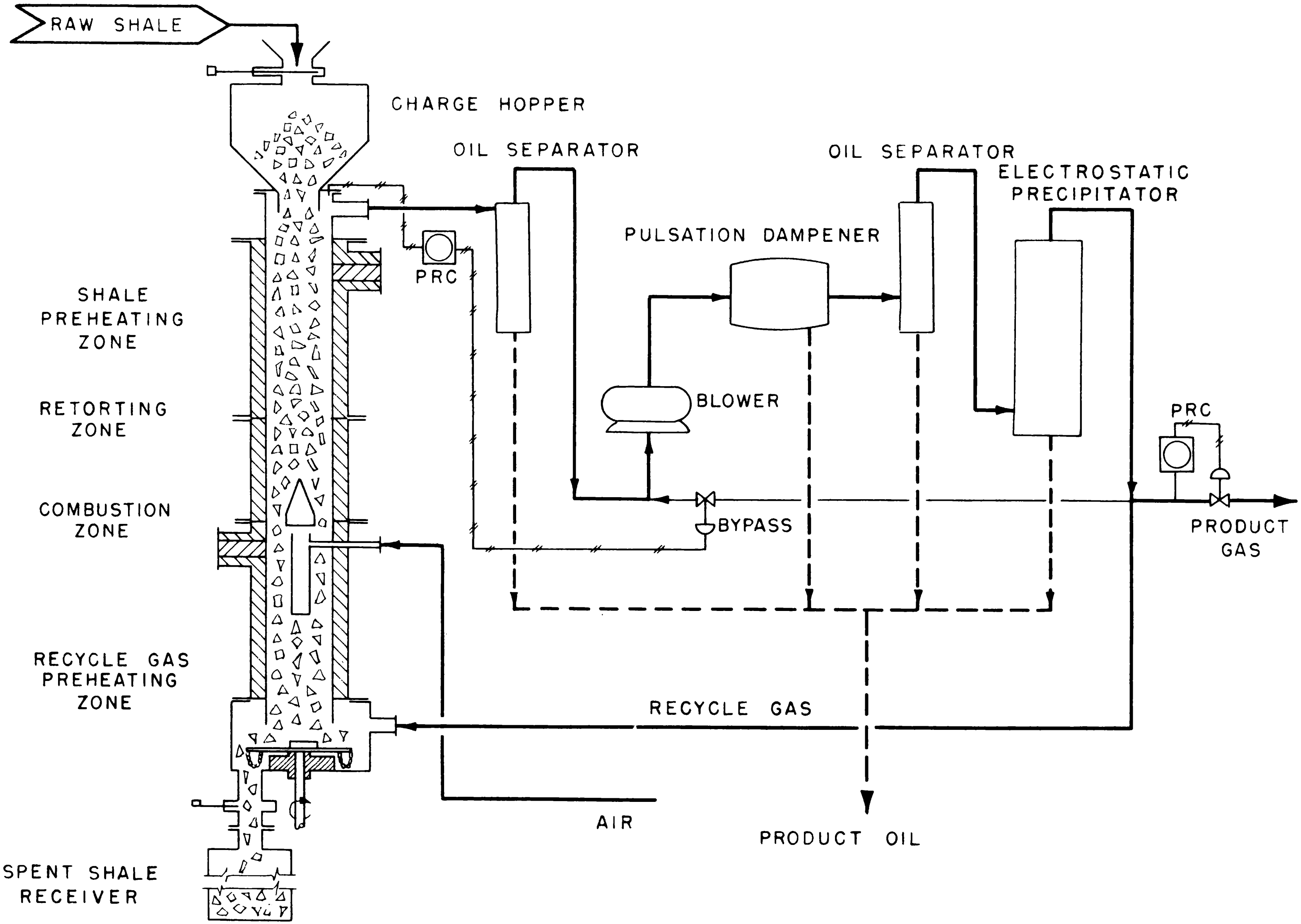


Figure 8. - Diagram of Gas-Combustion pilot plant.

TABLE 9. - Oil yields and properties with and without use of brine; runs 131 to 161

	With brine	Without brine
No. of runs in average	22	8
Shale rate .... lb./hr. x sq. ft. bed area	246	230
Shale, Fischer assay .... gal./ton	22.4	23.0
Recycle gas rate .... std. c. f./ton	18,200	18,400
Air rate .... do.	4,730	4,690
Oil recovered .... vol.-pct. of Fischer assay	90	81
Oil properties:		
Gravity, °API .... 60° F.	20.8	21.5
Viscosity, S.U. at 130° F. .... second	132	103
Ramsbottom carbon residue .... wt.-pct.	2.3	1.6

Brine was added during all runs of the rectangular retort (runs 162 to 173); consequently, there is no way of evaluating any effect the brine may have had during this period.

In the second period of testing the Gas-Combustion retort, brine was used in six consecutive runs toward the beginning of the period (runs 176B to 180). For comparison, the results of 3 runs preceding the brine runs and 3 following them were averaged (runs 175B, 175C, 176A, 181, 182, 183). The comparison is shown in table 10.

In table 10 it will be noted that more air was used in the brine runs than in those without brine. This was done to obtain higher bed temperatures on the premise that at the higher temperatures more satisfactory sublimation of the salt would take place. More recycle gas was also used during the brine runs so as to maintain a fairly constant air-recycle gas ratio for all runs.

TABLE 10. - Oil yields and properties with and without use of brine; runs 175B to 183

	With brine	Without brine
No. of runs in average	6	6
Shale rate .... lb./hr. x sq. ft. bed area	200	229
Shale, Fischer assay .... gal./ton	27.6	29.6
Recycyle gas rate .... std. c. f./ton	20,700	18,600
Air rate .... do.	4,750	4,080
Oil recovered .... vol.-pct. of Fischer assay	92	80
Oil properties:		
Gravity, °API .... 60° F.	19.8	21.6
Viscosity, S.U. at 130° F. .... second	135	85
Ramsbottom carbon residue ....wt.-pct.	2.6	1.6

The method of obtaining comparisons by averaging a number of tests with widely varying operating conditions is not the best. Yet the differences in average oil yields shown in tables 9 and 10 are large enough and consistent enough to indicate that brine has a beneficial effect. Apparently it is responsible for the formation of a more stable mist in the retort, which is more easily removed from the shale bed. The theory that the mist is more stable is substantiated by the fact that when brine is used more of the oil passes through the centrifugal separators in the first part of the oil-recovery system and separates later in the other recovery equipment.

Many tests have been run without brine in which high oil yields were obtained. The data show that in most of these tests there was little or no refluxing and cracking of oil. From this it appears that the addition of brine to the shale allows the retort to be operated under more varied conditions of shale, air, and recycle rates. Without brine these flows must be held within narrow limits to prevent refluxing. Refluxing is undesirable not only because it reduces the oil yield but also because it causes the shale to become coated with oil, resulting in the formation of agglomerated masses by the coking of the pitch remaining on the shale after redistillation of lighter portions of the oil.

At first glance it might seem that production of a lighter and more fluid oil by refluxing in the retort would be advantageous. However, refluxed oil of 23° API gravity is still too viscous and has too high a pour point to be transported far by pipeline without visbreaking or other processing. Therefore the advantage of the lighter oil is more than offset by the disadvantage of the much lower oil yield and attendant operational problems.

The use of a nucleating agent is regarded as having potentialities for improving the Gas-Combustion process, and it is planned to conduct extensive studies on nucleation techniques, on the mist formation phenomenon, and on controlling mist formation in the retort. The results of the studies will be disclosed in a future Report of Investigations.

DISCUSSION OF RESULTS

It will be noted in the report and appendix that the amounts of air used in the tests varied greatly with different types of retorts. In retorts where the air entered the bottom, the air rate was between 7,000 and 10,000 cubic feet per ton of shale for most of the tests, although there were exceptions when more or less air was used. Later, when air was admitted into the combustion zone 2 to 4 feet from the bottom of the retort, the air required decreased to 3,000 to 5,000 cubic feet per ton, again with exceptions.

The large difference in air requirement resulted mainly from the difference in temperature of the spent shale discharged from the retorts. When air was admitted at the bottom, as in the Dual-Flow and Countercurrent retorts, the combustion zone was low in the vessel and the spent shale was discharged at 500° to 600° F. or higher; but in the Gas-Combustion and other types of retorts in which the air was admitted higher in the retort, the spent shale was cooled with recycle gas and was discharged at 200° F. or lower. Since the spent shale comprises about 80 percent of the total material output of the retort, its outlet temperature is a major factor in the heat efficiency of the process. If the shale is discharged hot, more combustion, and therefore more air, is needed to replace the heat loss, which results in a hotter combustion zone and more clinker formation. Also, the retort gas produced is diluted with larger quantities of CO_2 and N_2, lowering the heating value and utility of the gas. The gas from the Dual-Flow and Countercurrent retorts had a heating value of 40 to 50 B.t.u. per cubic foot, probably too low for use as a fuel; whereas, that from the Gas-Combustion retort had a value of 90 to 100 B.t.u., about like blast-furnace gas, and undoubtedly could be used for fuel.

Similarly, it was found that for the best operations an air-recycle gas ratio of about 1-2 was required in the Dual-Flow and Countercurrent retorts, compared to ratios of about 1-4 to 1-5 in the Gas-Combustion retort. The use of the relatively larger quantity of recycle gas in the latter retort tended to lower the temperature of combustion, a definite advantage in preventing clinkering.

Although greater air rates give increased combustion rates and temperatures, the increase is not necessarily proportional to the air rate, owing to the greater decomposition of mineral carbonates in the shale. The raw shale contains about 18 percent mineral CO_2, mainly as $CaCO_3$ and $MgCO_3$. The mineral CO_2 in the spent shale from the Dual-Flow and Countercurrent retorts varied from less than 1 percent to 10 percent or more, depending on operating conditions and temperatures. Mineral CO_2 in spent shale from the Gas-Combustion retort was much higher, averaging 12 to 17 percent; thus, only a small proportion of the carbonates was decomposed in the latter retort, an important feature heat economy-wise.

The shale-particle-size range was narrow for some runs and fairly wide for others, varying from plus 1/2 minus 1 inch to plus 1/4 minus 1-3/4 inch. There was no apparent difference in oil yields attributable to the different sizes, but it appeared that when shales containing the finer 1/4-inch sizes were charged, coking of organic constituents and clinkering of inorganic materials increased. Investigation of the effects of sizing was not exhaustive and is continuing.

There is no question but that the mixer-distributor in the center of the Gas-Combustion retort holds up or restricts the flow of shale when clusters or agglomerates of unretorted shale are formed above or around the distributor. However, if the shale-air-recycle gas ratios are optimum within close limits, the retort can be operated continuously for extended periods without trouble. When large, dense agglomerates form, the masses of coked shale are not completely retorted in the retorting zone, and the oil contained in them is either burned in the combustion zone or is discharged and lost in the spent shale. Therefore, it is important to operate any retort under conditions such that agglomeration does not occur. If this is done the central distributor of the Gas-Combustion retort does not interfere with shale flow, and the higher oil yields obtained give it a distinct advantage over other process modifications tested in this investigation. Development of an air-injection device that will minimize the formation of agglomerates is being emphasized in the current research program.

APPENDIX

Description of Pilot-Plant Modifications

During the course of the investigation a number of different modifications of the basic retort were tested in an effort to improve yields, throughput, and operability. Likewise, several changes in the oil-recovery system were made in order to improve the efficiency of separation of oil mist from the retort gas. Figures 9 to 18 show diagrammatic sketches of the various retorts and oil-recovery systems used; tables 11 to 24 show results of the 222 runs, comprising more than 300 tests made from January 27, 1950, to January 26, 1952.

Retorts

Figure 1 shows the design and principal dimensions of the main body of the retort used during most of the investigation. In all, 11 modifications of the retort were made, most of which were directed toward improving the method of admission of air into the combustion zone. In one short series of runs a retort of rectangular cross section was used in place of the basic round retort. A line sketch of this retort is shown in figure 13, retort J.

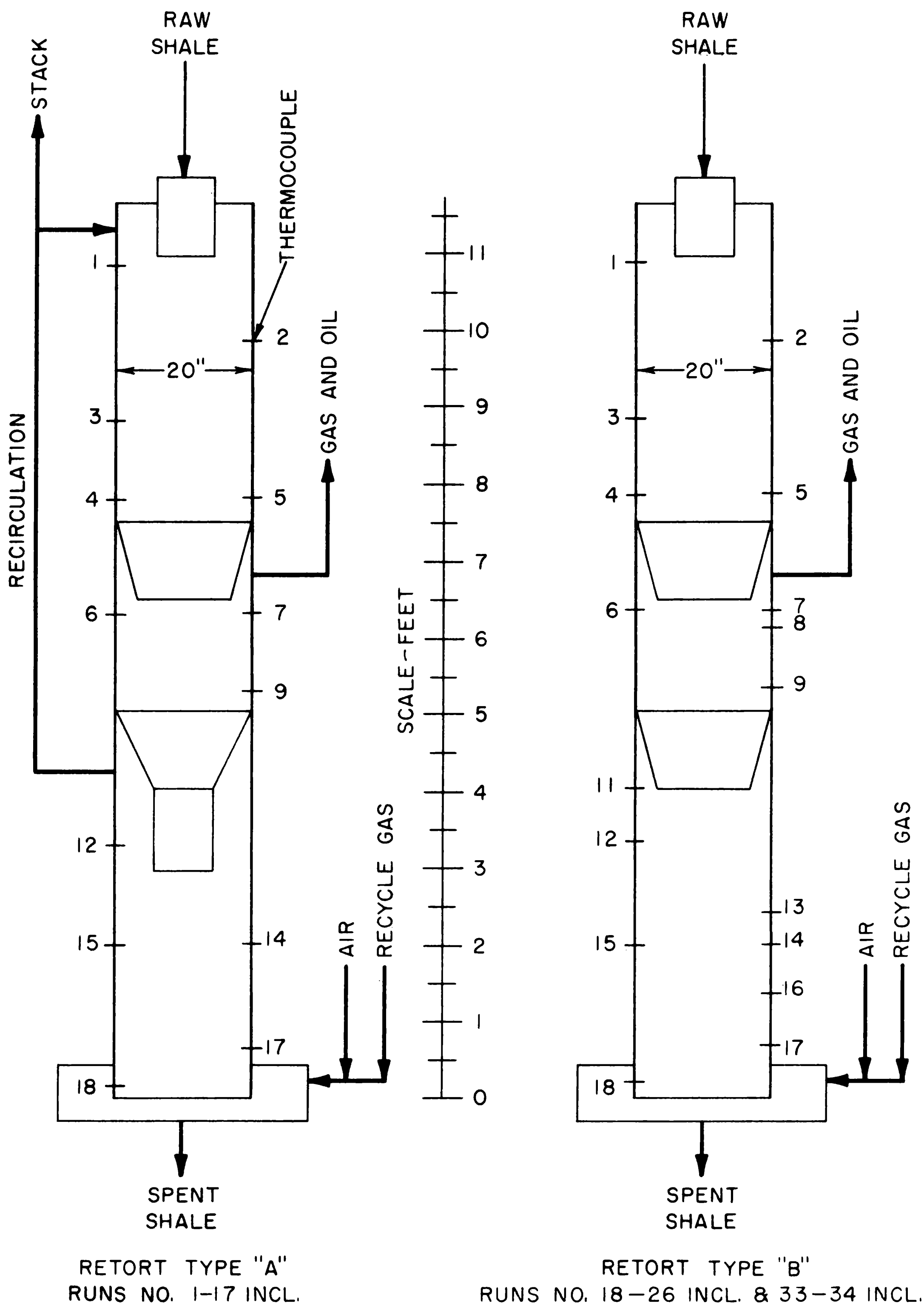


Figure 9. - Retort types and thermocouple locations.

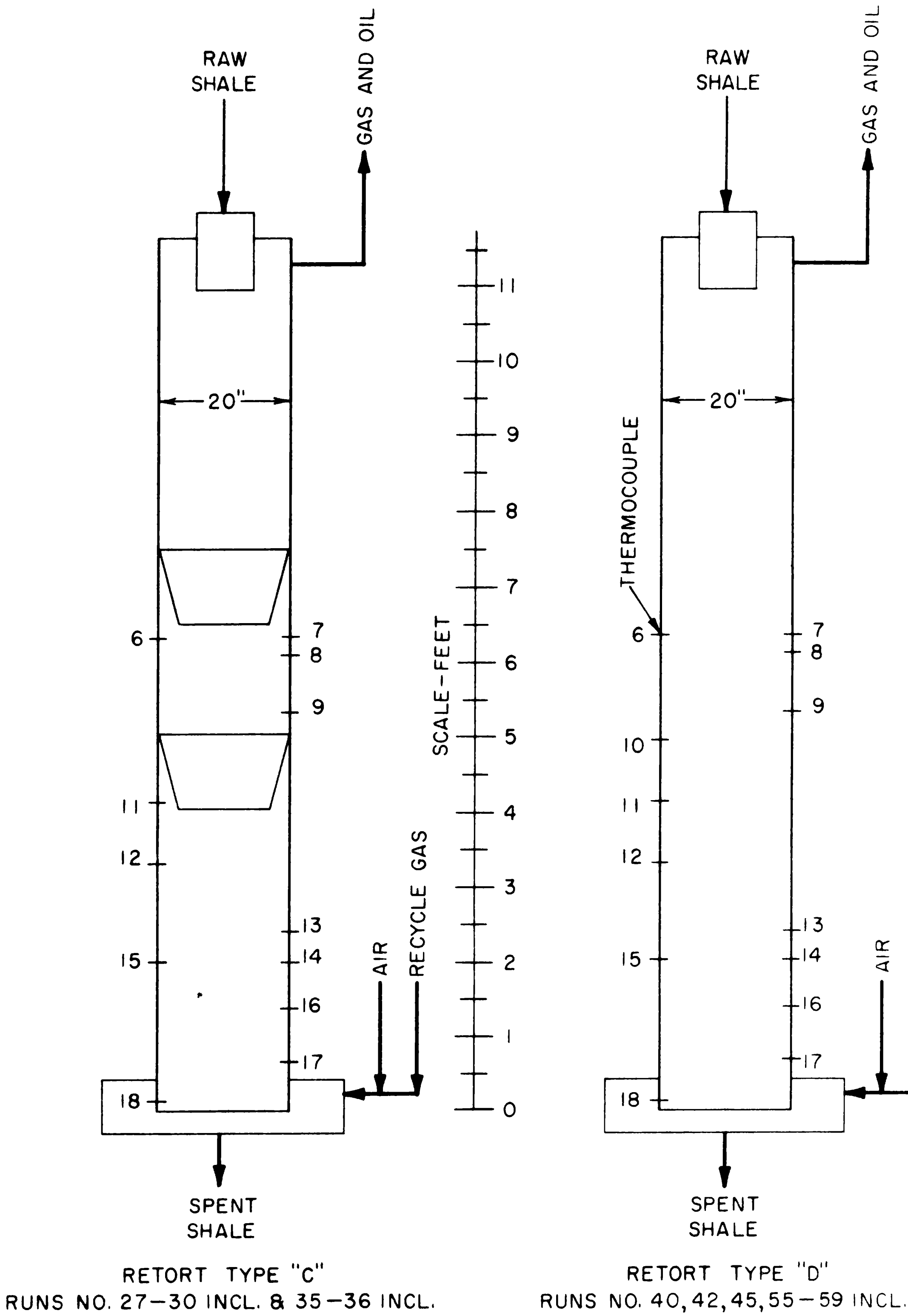


Figure 10. - Retort types and thermocouple locations.

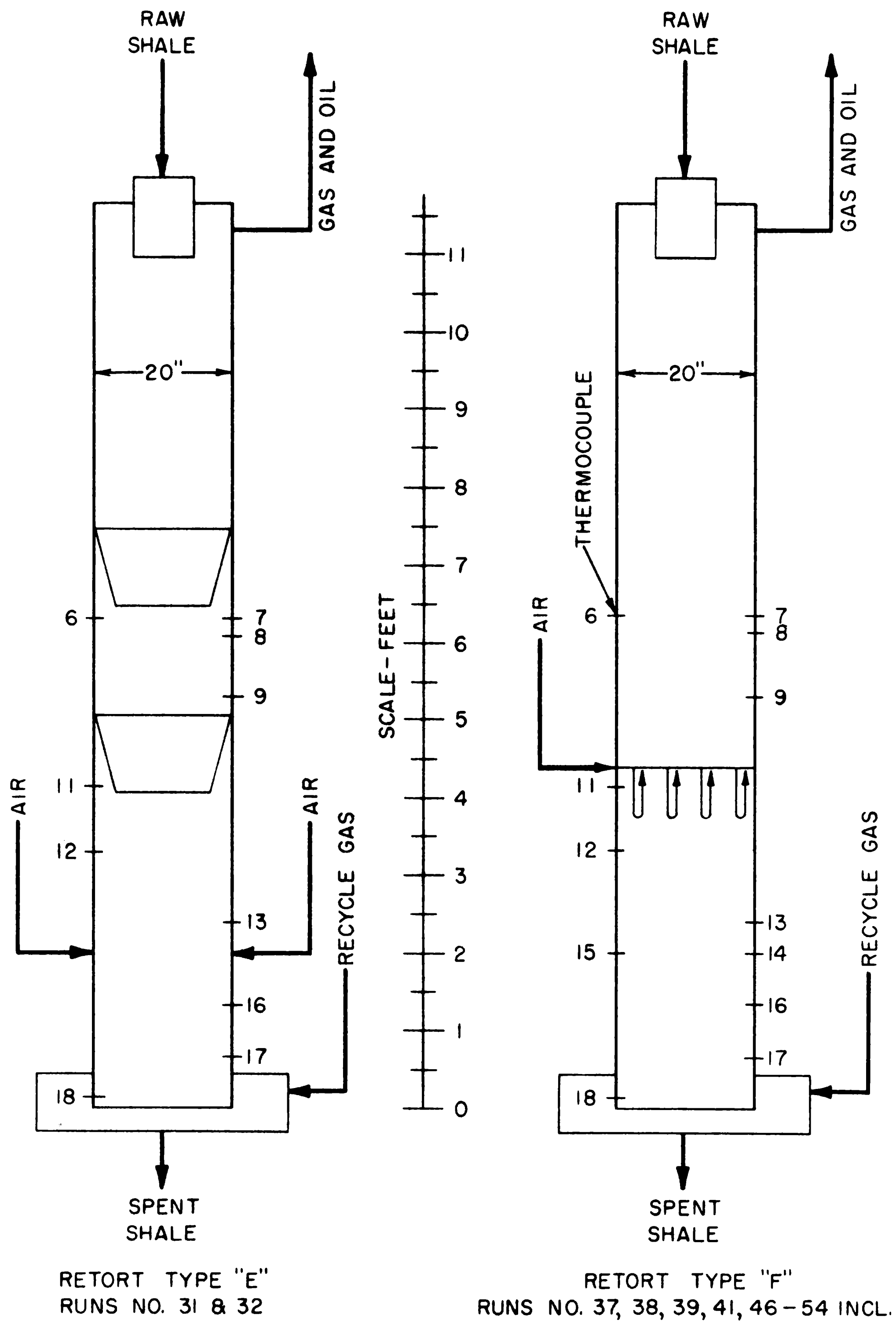


Figure 11. - Retort types and thermocouple locations.

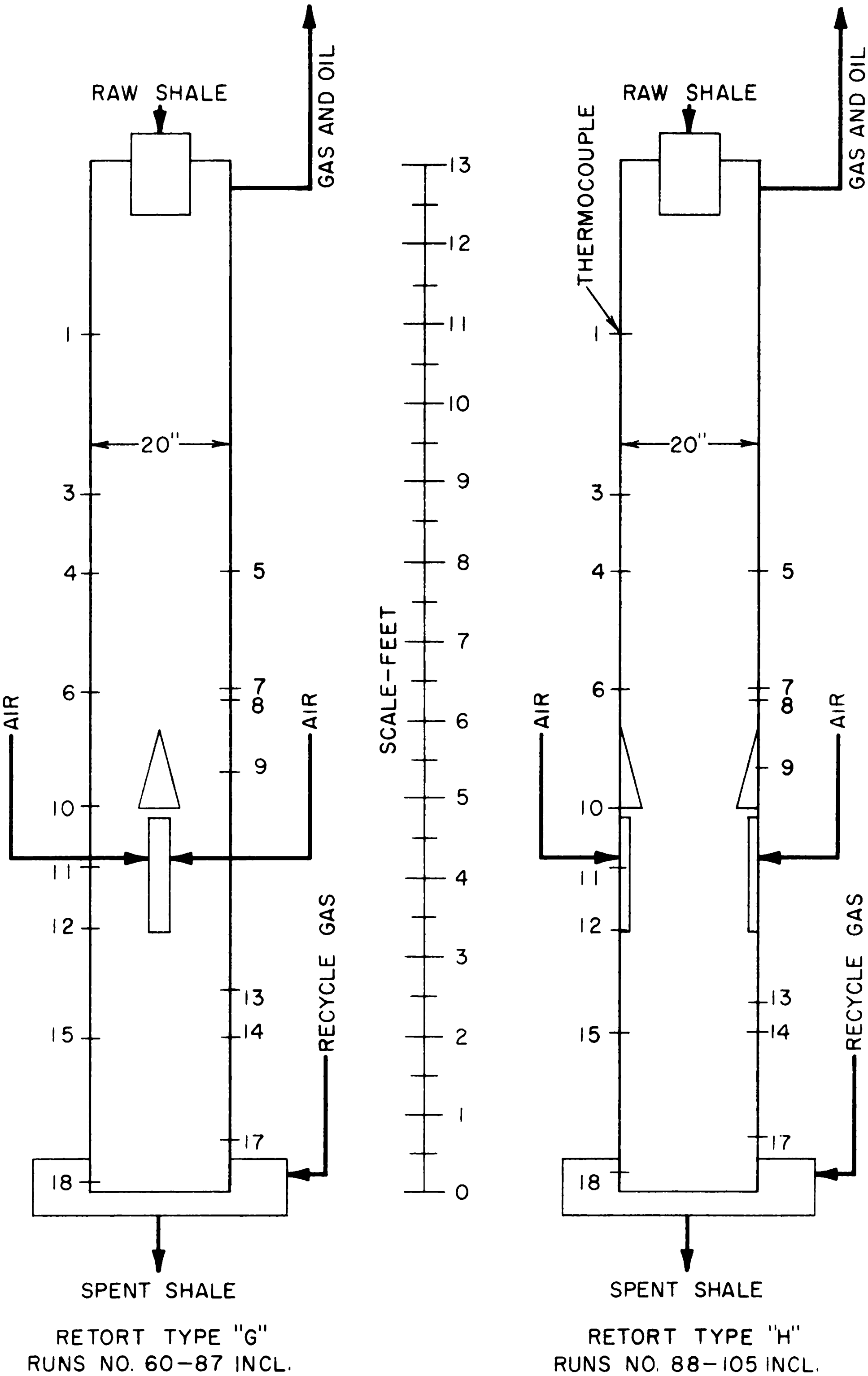


Figure 12. - Retort types and thermocouple locations.

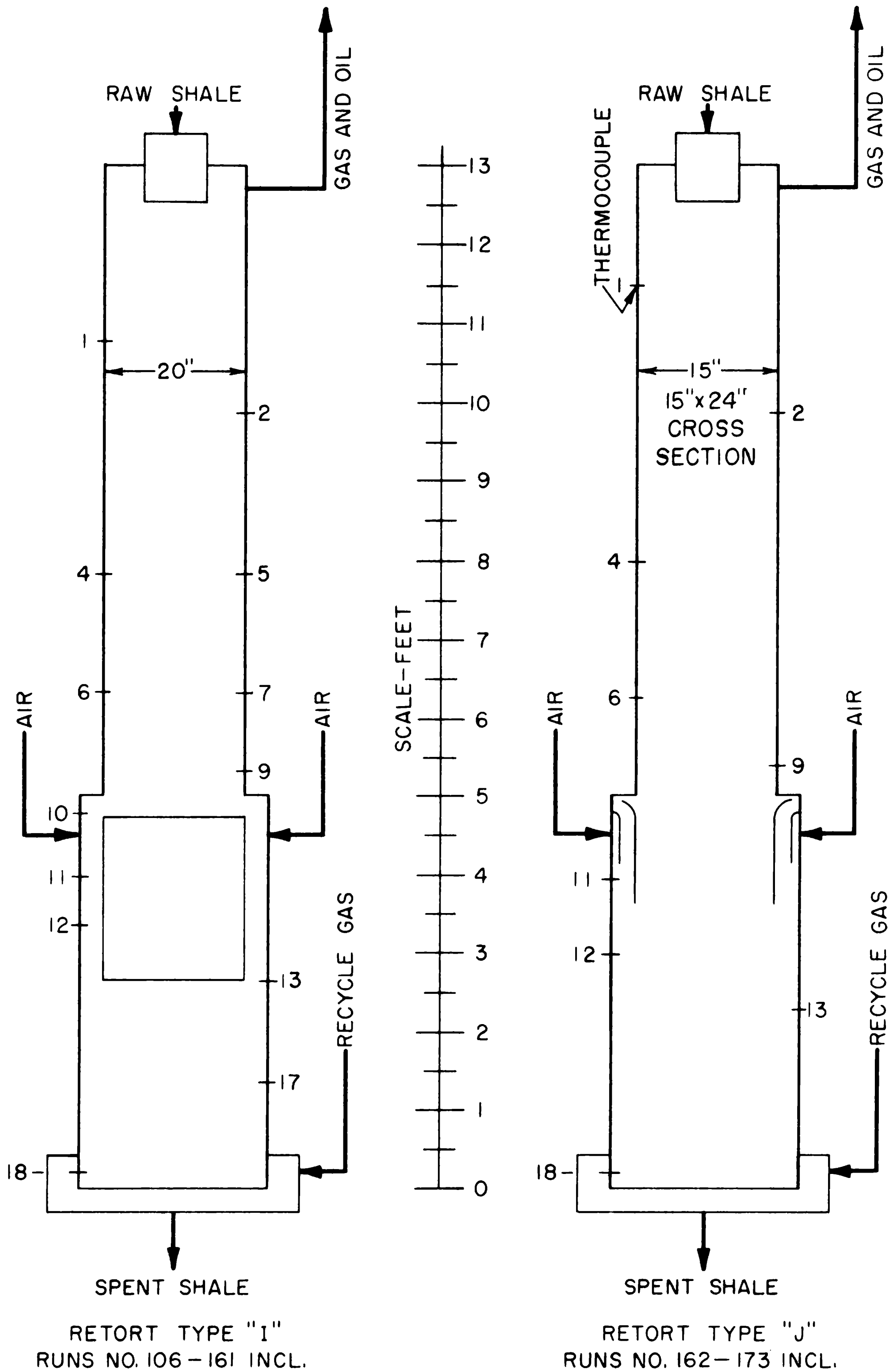
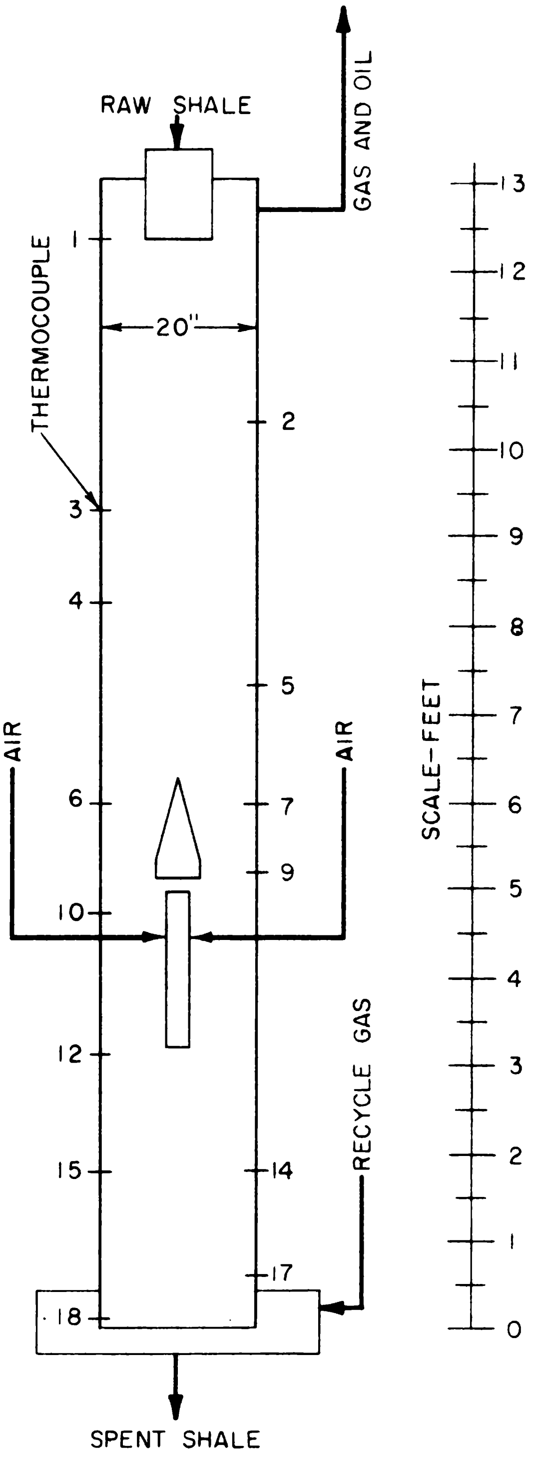
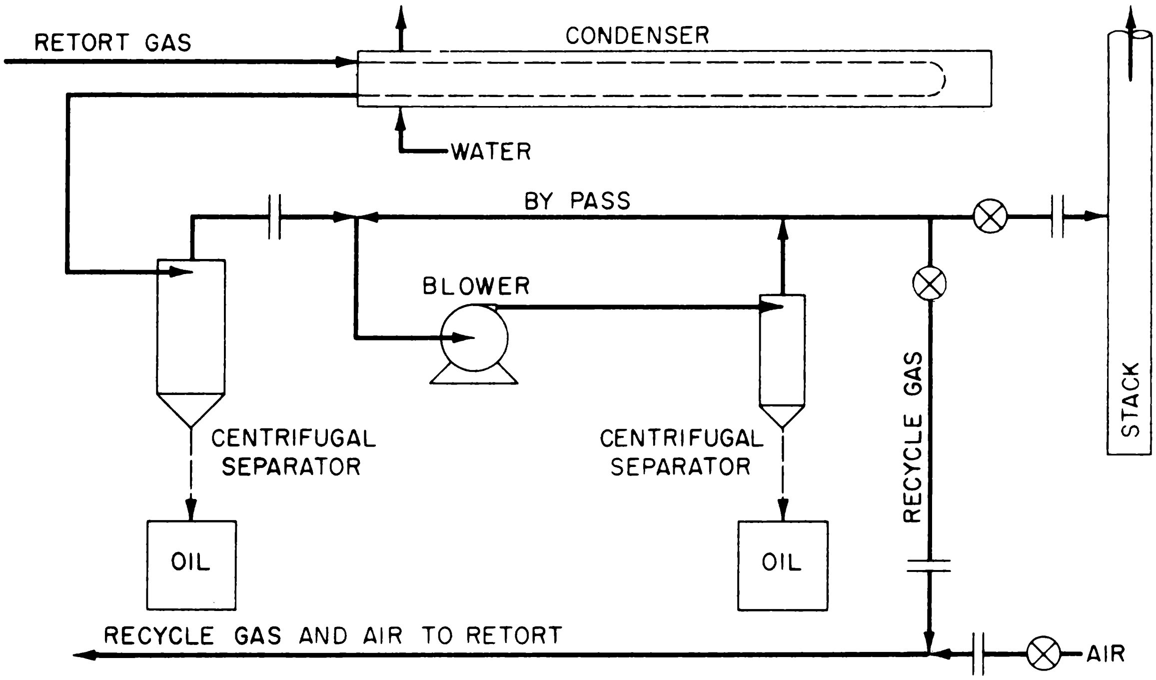


Figure 13. - Retort types and thermocouple locations.

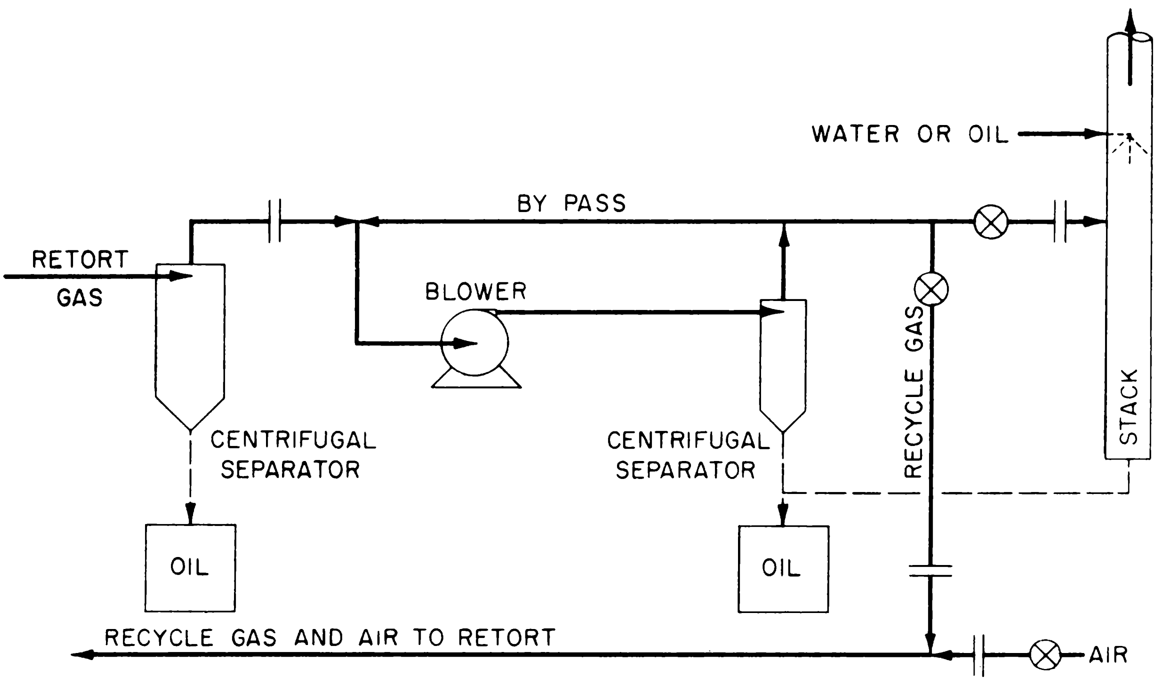


RETORT TYPE "K"
RUNS NO. 147–222 INCL.

Figure 14. - Retort types and thermocouple locations.

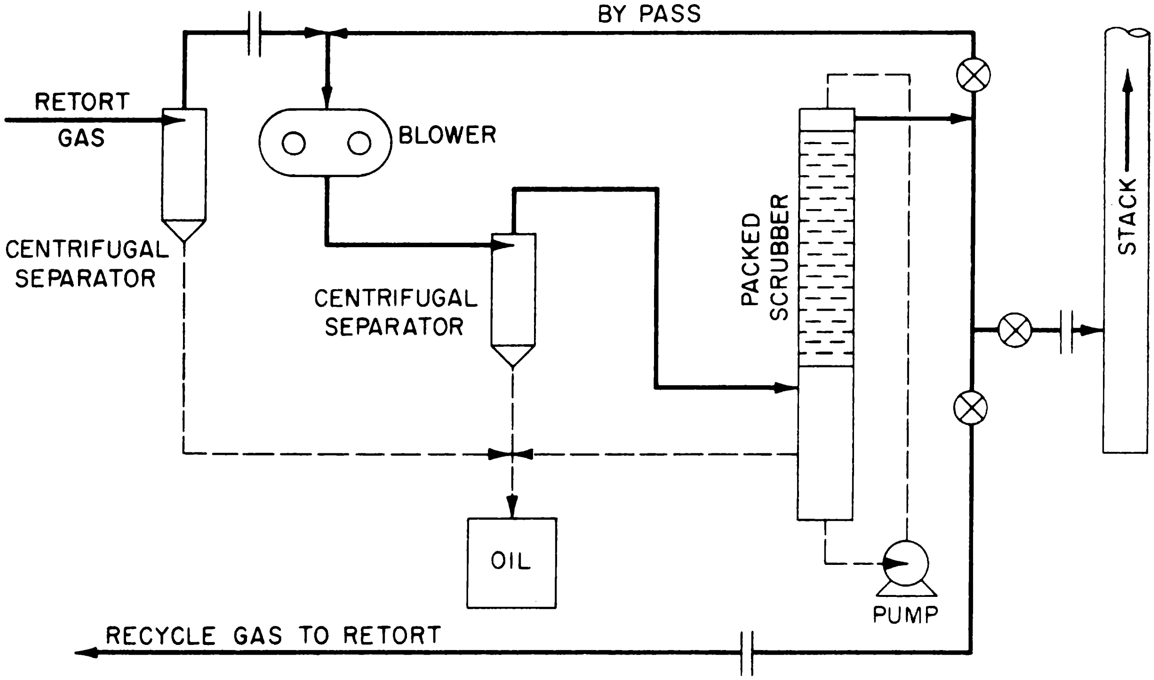


OIL RECOVERY – TYPE I
RUNS NO. 1 – 12 INCL.

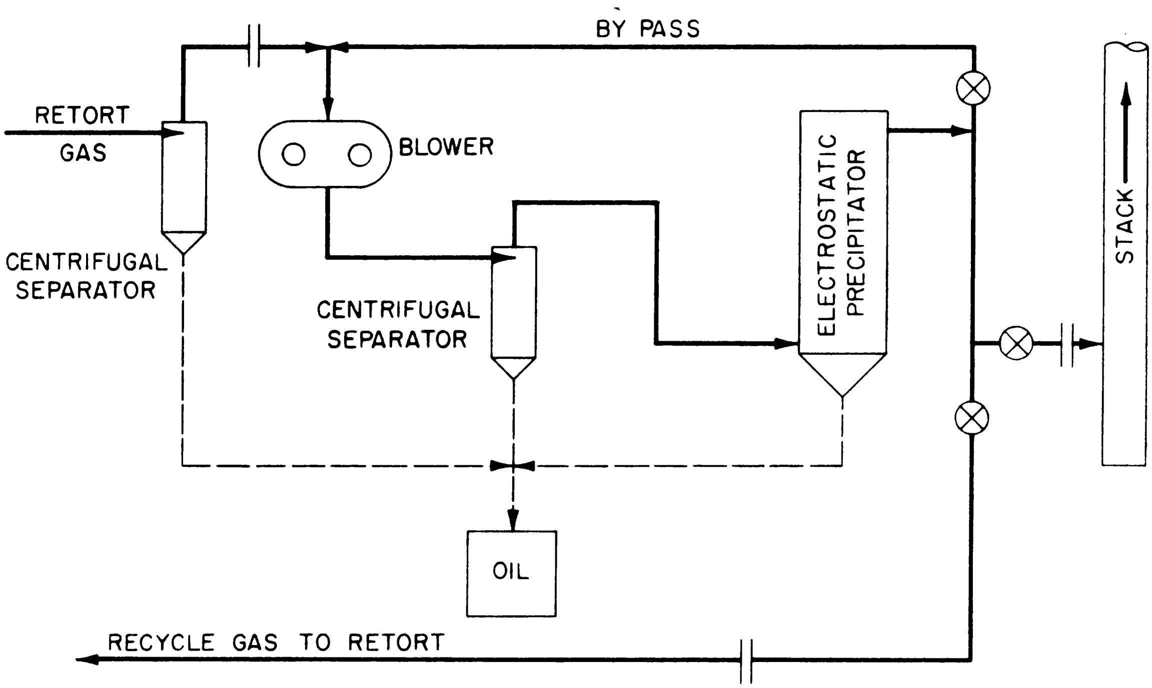


OIL RECOVERY – TYPE II
RUNS NO. 13 – 17 INCL.

Figure 15. - Oil-recovery flow diagrams.

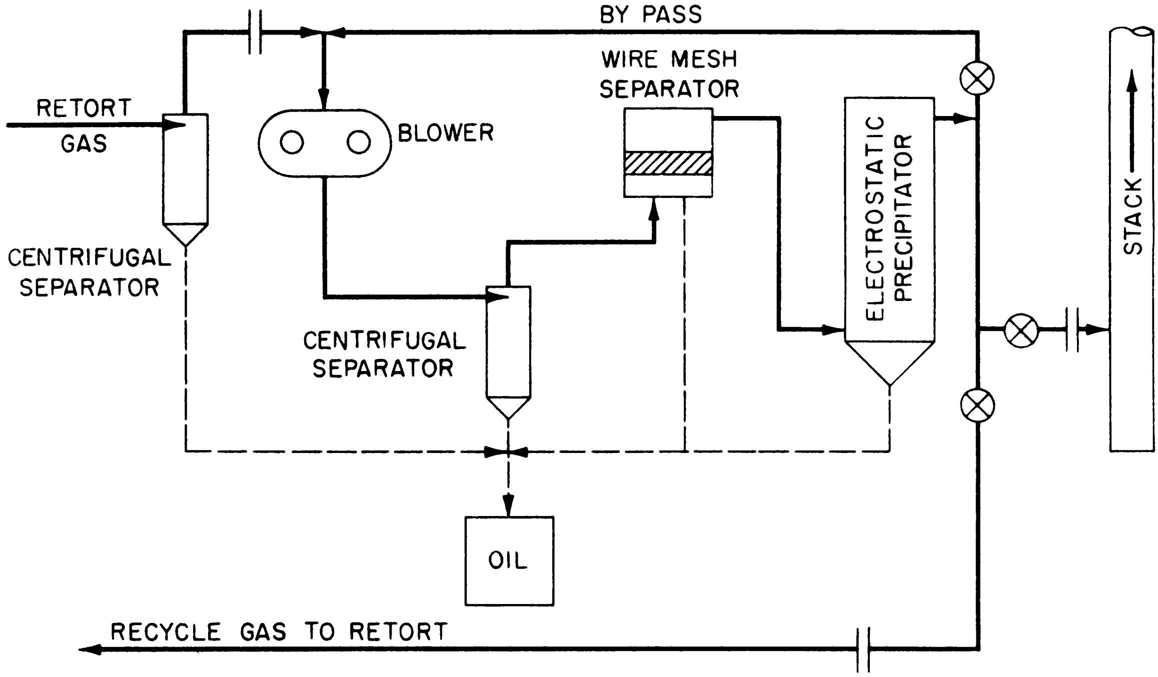


OIL RECOVERY – TYPE III
RUNS NO. 18 – 67 INCL.

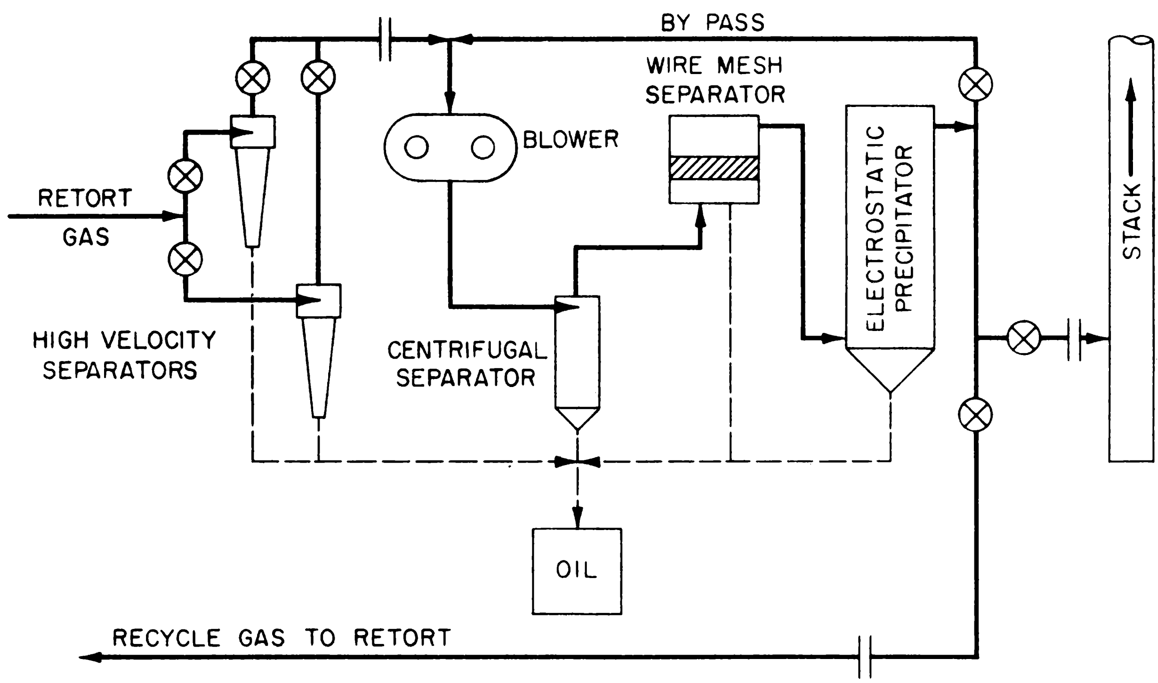


OIL RECOVERY – TYPE IV
RUNS NO. 68 – 91 INCL.

Figure 16. - Oil-recovery flow diagrams.



OIL RECOVERY – TYPE V
RUNS NO. 92 – 115 INCL.



OIL RECOVERY – TYPE VI
RUNS NO. 116 – 138 INCL.

Figure 17. - Oil-recovery flow diagrams.

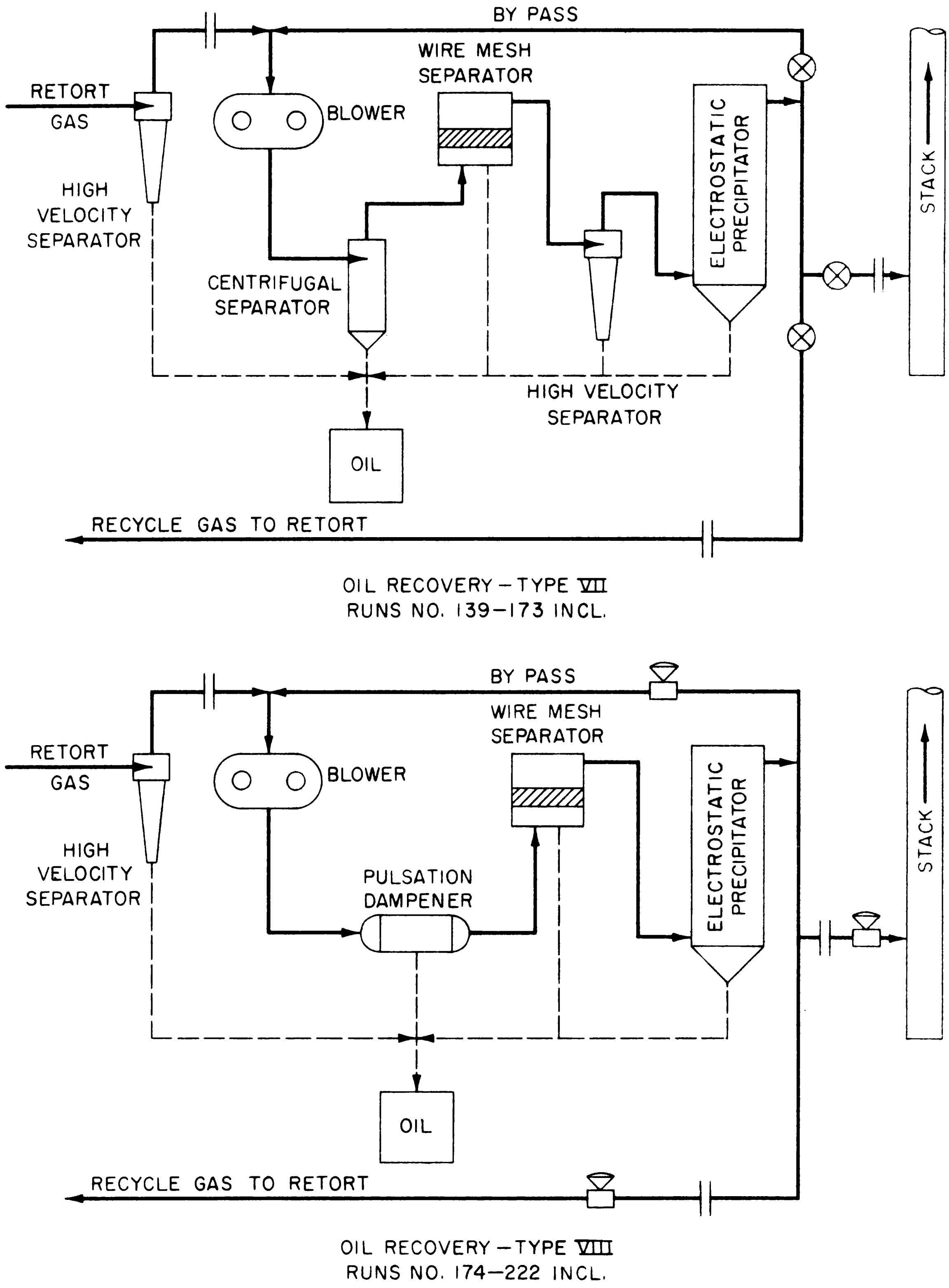


Figure 18. - Oil-recovery flow diagrams.

The raw shale was crushed and screened to the desired size range and charged by hand in weighed increments of about 70 pounds through a hopper at the top of the retort. The moisture content of the shale as charged was approximately 1 percent, or about the same moisture content as mined.

Several factors were used at different times to judge the required speed of the turntable and the resultant throughput of shale. These were: Temperature of the retort gas at the outlet; temperature of the spent shale; weight of raw shale input; and weight of spent-shale discharge. All of the methods gave fair control, and the one chosen for a particular series of runs depended in part on the characteristics and modifications of the retort under test.

Temperatures were taken with thermocouples at various locations along the length of the retort. The couples extended through the refractory walls about 2 inches; experience showed that a further extension than this caused stoppage of shale flow. The thermocouple locations are denoted by Arabic numerals in figures 9 to 14, and the temperature records in tables 11 through 24 are identified by these numerals.

Following are descriptions of the 11 modifications of retorts used during the investigation.

Type-A (fig. 9, runs 1 through 17, table 11)

In type-A the basic retort contained two funnels used to provide spaces at the sides of the retort from which exit gas could be withdrawn. During the first seven runs a portion of the gas from the combustion zone was withdrawn at the lower funnel and recirculated downward through the top of the retort to the gas exit at the upper funnel. The remainder of the combustion gas passed upward through the retorting zone where it entrained the distilling oil and exited at the outlet under the upper funnel. After run 7 the recycling of hot gas to the top of the retort was discontinued, and all of the gas flowed directly from the combustion zone to the retorting zone and thence to the side outlet.

Restriction and stoppage of shale flow in the narrow lower funnel occurred frequently in this retort.

Type-B (fig. 9, runs 18 through 26 and 33 and 34, tables 11 and 12

The design of type-B was the same as that of type-A except that the lower funnel was enlarged to provide freer shale flow.

Type-C (fig. 10, runs 27 through 30 and 35 through 36, table 12

In an attempt to raise the combustion zone, the gas outlet was moved from the center to the top of the retort, thus providing more area for heat exchange between the rising gas and the descending shale. Some stoppages of shale flow still occured owing to restriction by the two funnels.

Type-D (fig. 10, runs 40, 42, 45, and 55 through 59, tables 12, 13, and 14

The two funnels were removed from the retort since they caused irregularities in feeding and were no longer necessary to provide exit space for the gas. Shale flow was more constant but, as with all previous retorts, the combustion zone was near the bottom of the retort owing to the admission of air at this point. This resulted in high spent shale temperatures and a waste of heat.

Type-E (fig. 11, runs 31 and 32, table 12)

Before the funnels were removed two runs were made in which combustion air was admitted directly into the retort unmixed with recycle gas. The air entered through two pipes in the sides of the retort about 2 feet from the bottom. The object was to raise the location of the combustion zone and allow the spent shale to be cooled with recycle gas entering at the bottom. Distribution of air from the two side jets was poor, and channeling of air caused an uneven combustion zone.

Type-F (fig. 11, runs 37 through 39, 41, 46 through 54, tables 12 and 13)

In an attempt to obtain better air distribution, air was admitted through a perforated pipe extending across the center of the retort about 4 feet from the bottom. Air distribution still was poor.

Type-G (fig. 12, runs 60 through 87, tables 14, 15, 16)

A cylindrical air distributor was installed in the center of the retort, protected with a conical shield to prevent it being filled with shale. By this means better air distribution throughout the shale bed was obtained, and the combustion zone was moved upward to about the 5-foot level in the retort. This lowered the spent shale temperature owing to heat exchange below the combustion zone with recycle gas entering the bottom of the retort. After run 67 the height of the shale bed was increased from 11 feet to 12-1/2 feet to provide a longer column of shale for heat exchange with the ascending retort gas.

Type-H (fig. 12, runs 88 through 105, tables 16 and 17)

Since the center distributor of type-G was thought to interfere somewhat with shale flow, the distributor was cut in half longitudinally and the halves were mounted on opposing sides of the retort. Again, air distribution in the combustion zone was poor.

Type-I (fig. 13, runs 106 through 161, tables 17, 18, 19)

The bottom section of the retort was enlarged enough to install a cylindrical air distributor at the side walls. Descending shale was prevented from entering the air space around the cylinder by the projecting walls of the upper portion of the retort. This peripheral-type distributor did not give optimum air distribution, and often there was burning of recycle gas in the annular air space. Beginning with run 131, opposite quarters of the air space were blanked off to increase the velocity of air through the distributor and perhaps reduce the burning of gas in the annular air space, only a slight improvement was noted.

Type-J (fig. 13, runs 162 through 173, tables 19 and 20)

To study the effect of retort shape, a rectangular retort 15 by 24 inches cross section was constructed. Air was distributed by shields along the long walls under the projecting retort walls above. With such a small cross sectional area the corner effects were large, as evidenced by incomplete combustion and retorting.

Type-K (fig. 14, runs 174 through 222, tables 20, 21, 22, 23,24)

The K retort was the last design used in this investigation. In it were incorporated several of the best features of the previous retorts: Central air distributor with conical shield about 5 feet above the bottom of the retort, heat exchange between the spent shale and recycle gas, and 12-1/2-foot bed height to provide more heat exchange between retort gas and unretorted shale. Details and dimensions of the air distributor are shown in figure 5.

Oil-Recovery Systems

Type-I (fig. 15, runs 1 through 12, table 11)

The first unit in the recovery system was a water-cooled condenser, installed in the belief that much of the oil in the retort gas would be in the form of true vapor, which would require conventional condensation methods. Experience showed that almost all of the oil was in the form of fog or mist and could be separated mechanically. For this reason, and owing to cokelike deposits in the tubes, the condenser was eliminated in subsequent tests.

The two centrifugal separators were low-velocity types 12 inches and 8 inches in diameter and consequently were not particularly suited for the service intended. However, each removed a considerable portion of oil. The action of the impellors of the blower agglomerated some of the finer mists, conditioning them for removal in the smaller centrifugal after the blower.

Type-II (fig. 15, runs 13 through 17, table 11)

This system was similar to that of type-I without the condenser, except that a spray was placed in the vent-gas stack and operated alternately in different tests with water and oil. Only a slight additional amount of oil was recovered with the spray.

Type-III (fig. 16, runs 18 through 67, tables 11, 12, 13, 14)

Based on experience with the stack spray, a scrubber containing 5/8-inch Raschig rings was placed before the stack. Water was recirculated through the scrubber, the bottom section of which acted as an oil-water separator. The recovery of oil in the scrubber was small.

Type-IV (fig. 16, runs 68 through 91, tables 14, 15, 16)

The scrubber of type-III was replaced with an electrostatic precipitator to separate extremely fine droplets of mist. The precipitator was not of the best design for gas saturated with moisture, and only a slight improvement in oil recovery was noted.

Type-V (fig. 17, runs 92 through 115, tables 16 and 17)

A coalescer consisting of a layer of several inches of fine wire mesh was installed before the electrostatic precipitator of the type-IV recovery system. This unit recovered nearly all of the oil formerly obtained in the precipitator.

Type-VI (fig. 17, runs 116 through 138, tables 17 and 18)

The 12-inch diameter, low-velocity centrifugal separator after the retort was replaced with two high-velocity separators, which could be operated singly or in parallel. Two commercial types were tried, both of which were more effective than the low-velocity separator. No additional oil was recovered ultimately, however, since recovery in succeeding units in the system decreased proportionately.

Type-VII (fig. 18, runs 139 through 173, tables 18, 19, 20)

One of the high-velocity separators of type-VI was relocated just before the electrostatic precipitator. The pressure loss of this system was high, and little additional oil was recovered.

Type-VIII (fig. 18, runs 174 through 222, tables 20, 21, 22, 23, 24)

The high-velocity separator before the precipitator was removed, and a pulsation dampener was installed after the blower. Automatic flow controllers were located in the bypass line, line to the stack, and recycle line to the retort. This was the last modification of the oil-recovery system for this investigation and was the most efficient in terms of oil recovery.

TABLE 11. - Results of oil-shale pilot plant tests

Run No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Date	1-27-50	1-28	1-29	1-30	1-31	2-1	2-1	2-9	2-10	2-12	2-13	2-15	2-23	2-24	2-25	2-26	2-27	3-14	3-15	3-16	3-22	3-23	3-26
Duration, hr.	24	24	24	24	20	--	24	24	24	24	24	24	24	24	24	24	26	21.5	18.5	16	24	24	24
Retort type No.	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B
Oil recovery system type No.	I	I	I	I	I	I	I	I	I	I	I	I	II	II	II	II	II	III	III	III	III	III	III
Raw material flows:																							
Raw shale, lb./hr. x sq. ft. bed area	84	90	110	96	90		96	173	102	144	137	104	151	90	86	105	186	156	119	125	175	225	168
Recycle gas 1/, std.c.f./ton raw shale	20,200	26,400	22,100	32,400	23,400		26,500	0	0	15,800	27,100	16,800	0	0	13,500	21,700	20,100	15,100	20,100	13,900	7,300	10,500	0
Air 2/, do.	16,000	14,900	12,800	14,500	13,100		14,900	13,000	11,200	7,800	7,600	10,700	14,800	12,200	12,900	10,700	5,800	7,200	9,300	9,000	9,600	10,300	9,900
Products recovered:																							
Shale oil, vol.-pct. Fischer assay	71	61	77	69	55		72	66	80	93	88	92	78	83	90	76	72	73	103	101	84	84	74
Shale oil, gal./ton raw shale	17.0	12.9	16.0	14.3	13.2		15.2	14.6	18.6	21.3	20.3	20.8	17.9	19.5	21.8	18.3	16.8	17.2	39.2	38.9	18.0	19.2	17.1
Gas vented 3/, std.c.f./ton raw shale	18,600	17,100	19,100	17,200	16,700		17,800	16,800	13,700	9,600	9,600	13,800	19,900	16,400	17,000	14,400	7,000	8,800	12,300	10,700	12,000	10,200	12,700
Spent shale, lb./ton raw shale	1,370	1,380	1,530	1,560	1,380		1,500	1,400	1,420	1,420	1,370	1,380	1,380	1,370	1,380	1,420	1,600	1,620	1,400	1,400	1,420	1,630	1,390
Water condensed 4/, do.	58	64	81	57	63		44	38	34	41	55	36	16	48	32	27	62	36	11	28	58	85	55
Material output, wt.-pct. of input	95	93	103	98	95		99	96	94	93	92	97	100	97	100	98	97	97	99	95	93	96	96
Raw shale properties:																							
Fischer assay, gal./ton	24.0	21.2	20.7	20.6	23.8		21.2	22.1	23.3	23.0	23.0	22.5	23.0	23.7	24.3	24.2	23.4	23.5	37.9	38.5	21.5	22.8	23.0
Mineral CO_2, wt.-pct.	17.5	16.8	16.7	17.0	17.3		17.1	16.5	17.3	17.4	16.8	17.0	16.2	16.0	16.9	15.7	16.8	--	17.8	16.7	17.4	17.3	18.1
Particle size range, inch	½-1	½-1	½-1	½-1	½-1		½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1
Shale oil properties:																							
Gravity, °API	18.7	19.1	19.7	19.7	18.3		19.5	16.6	18.9	18.5	18.5	20.3	20.5	20.5	21.4	20.1	21.2	21.2	20.4	21.5	20.1	19.5	20.6
Viscosity, S.S.U. at 130° F.	127	121	121	104	159		121	144	83	157	142	104	88	100	100	121	90	94	100	--	126	151	92
S.S.U. at 210° F.	47	46	45	47	46		45	68	43	50	49	45	44	44	45	50	45	43	44	--	48	52	45
Ramsbottom carbon 5/, wt.-pct.	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gas properties:																							
Moisture 6/, vol.-pct.	3.8	6.0	9.4	8.3	10.2		8.0	8.8	6.4	6.6	6.6	6.3	8.7	7.0	7.5	9.9	6.3	8.3	9.3	8.8	11.3	11.6	9.1
Analysis, dry:																							
CO_2, vol-pct.	27.1	24.2	23.6	21.9	26.0		26.4	24.5	24.3	26.2	27.1	30.2	28.8	30.9	29.9	28.8	22.3	21.3	23.3	18.3	20.6	25.6	26.8
Ill. 7/, do.	0.2	0.0	0.3	0.4	0.4		0.0	1.6	1.2	0.4	0.5	0.3	1.3	0.9	1.2	0.4	1.1	0.5	0.7	0.8	0.0	0.3	0.9
O_2, do.	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
CO, do.	0.8	0.8	2.1	2.0	1.7		0.5	2.5	2.2	2.0	2.1	1.0	2.2	1.8	1.8	2.1	1.9	1.8	4.2	2.1	0.7	0.8	2.1
H_2, do.	0.6	1.5	0.0	1.9	1.4		0.5	1.2	1.0	2.1	2.4	1.3	1.8	0.9	0.3	2.3	1.2	1.4	3.8	3.6	0.7	1.2	1.1
Hydrocarbons 8/, do.	1.0	0.9	1.9	1.2	1.8		0.8	2.8	1.9	1.4	1.4	1.3	1.6	2.2	2.1	1.4	3.0	3.9	2.5	2.5	6.8	1.8	1.7
N_2, do.	70.3	72.6	72.1	72.6	68.7		71.8	67.4	69.4	67.9	66.5	65.9	64.3	63.3	64.7	65.0	70.5	71.1	65.5	72.7	71.2	69.7	67.4
Heating value, gross (calc.), B.t.u./std.c.f.	19	18	34	33	37	No data taken	13	71	51	36	39	27	53	49	51	37	63	63	66	67	84	33	45
Spent shale properties:																							
Fischer assay, gal./ton	0.2	1.1	0.5	0.5	0.8		1.1	0	0	0.3	0	0	0	0	0	0.5	1.6	--	4.7	2.1	0.3	0.3	0
Organic residue 9/, wt.-pct.	0.2	1.3	1.1	1.1	0.8		0.6	0.2	0	0.57	0.7	0.3	0.05	0	1.9	0.96	2.12	--	4.37	4.54	0.42	0.72	0.33
Mineral CO_2, do.	0.5	4.1	6.8	10.0	7.6		5.8	1.6	2.3	5.7	7.3	0.2	1.5	2.1	0.7	2.3	14.5	--	18.2	16.6	2.9	5.4	1.2
Operating data:																							
Press. drop/ft. bed height, in. H_2O	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Retort gas outlet temp., °F.	370	270	270	300	330		240	180	160	200	220	115	109	102	104	120	169	109	158	122	133	131	109
Recycle gas temp. 10/, do.	77	91	106	102	109		102	104	93	95	95	93	104	97	99	108	93	102	106	104	113	113	105
Air inlet temp., do.	50	48	57	55	61		61	57	57	50	59	66	64	61	64	59	59	59	77	57	73	72	84
Bed temps., thermocouple Nos.: 11/																							
1, °F.	120	950	1,190	1,170	690		610	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2, do.	120	--	1,150	800	530		300	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3, do.	190	570	740	830	510		290	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4, do.	150	--	--	--	460		280	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5, do.	720	340	380	1,030	350		150	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6, do.	850	410	420	540	350		230	390	330	440	390	160	--	--	--	--	--	120	230	110	100	190	140
7, do.	1,150	520	580	760	480		350	450	320	420	470	290	160	120	130	160	220	100	240	130	110	180	130
8, do.	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	120	250	370	--	--	--
9, do.	2,210	1,260	920	970	620		660	810	670	480	690	--	210	240	310	550	390	130	440	300	350	360	160
10, do.	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11, do.	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	320	540	540	1,190	580	610
12, do.	2,180	1,640	1,780	1,660	1,010		1,140	1,230	1,380	1,470	1,180	1,280	1,380	1,210	1,220	900	910	290	160	530	880	720	420
13, do.	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	560	1,460	710	1,520	1,270	1,150
14, do.	1,460	1,150	990	1,000	1,110		1,330	1,160	990	830	990	1,500	1,410	1,500	1,480	1,150	840	560	1,210	770	1,670	1,550	1,350
15, do.	1,550	1,140	1,040	1,070	1,180		1,340	1,530	1,180	1,000	970	1,400	1,480	1,400	1,410	1,070	840	730	1.050	660	1,500	1,210	1,040
16, do.	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	970	1,610	840	1,710	1,570	1,290
17, do.	--	--	--	--	1,270		1,330	1,320	1,160	--	--	990	1,080	720	860	880	880	1,020	1,040	1,070	1,240	1,520	1,020
18, spent shale temp., do.	--	--	--	--	--		--	580	600	380	370	420	500	520	510	540	400	570	540	680	660	740	720
Operating characteristics:																							
Degree of clinkering or coking 12/	Mod.	Mod.	Mod.	Mod.	Mod.		Mod.	Severe	Severe	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Negl.	Negl.	Mod.	Mod.	Mod.	Mod.	Severe
Degree of refluxing of oil 13/	Negl.	Negl.	Negl.	Negl.	Negl.		Negl.	Negl.	do.	Negl.	Negl.	do.	Severe	do.	do.	Negl.	Severe	Severe	do.	do.	Negl.	Negl.	Do.
Other troubles, see note No.	15	--	--	--	15	16	--	--	--	15	15	--	--	--	--	--	--	--	--	17	--	--	--
Evaluation of results 14/	Sat.	Unsat.	Unsat.	Sat.	Sat.		Sat.	Unsat.	Sat.	Unsat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Unsat.	Unsat.	Sat.	Sat.

TABLE 12. - Results of oil-shale pilot plant tests

Run No.	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40A	40B	40C	40D	40E	41	42A
Date	3-27	3-28	3-29	4-5	4-6	4-8	4-9	4-11	4-12	4-19	4-20	4-24	4-25	4-26	5-3	5-4	5-6	5-7	5-8	5-9	5-10	5-16	5-18
Duration---hr.--	24	24.5	32	8	24	24	24	24	24	24	15.5	24	20	24	24	20	24	24	24	24	20	32	24
Retort type No.	B	B	B	C	C	C	C	E	E	C	C	C	C	F	F	F	D	D	D	D	D	F	D
Oil recovery system type No.	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III
Raw material flows:																							
Raw shale--lb./hr. x sq. ft. bed area--	245	200	151	115	121	182	176	171	244	131	262	253	208	153	225	272	257	268	210	227	228	140	217
Recycle gas [1]-std.c.f./ton raw shale--	10,700	11,600	16,200	20,500	19,400	22,900	23,300	26,400	20,700	10,900	0	11,000	17,800	15,300	15,000	16,700	14,700	14,000	17,700	14,700	14,600	16,900	15,900
Air [2]---do---	10,700	5,600	7,800	9,900	9,500	6,200	4,600	4,000	4,000	10,600	12,700	10,800	8,800	5,600	3,200	2,700	7,700	6,600	8,700	8,000	8,080	6,290	8,600
Products recovered:																							
Shale oil-----vol.-pct. Fischer assay--	85	61	96	58	90	58	73	67	77	74	69	85	94	97	57	48	75	74	91	76	80	115	83
Shale oil---gal./ton raw shale--	18.1	14.3	19.3	12.6	18.0	11.2	15.6	14.9	16.2	15.0	14.1	17.8	19.7	20.9	12.6	10.1	16.4	16.4	20.4	17.4	18.0	30.2	23.9
Gas vented [3]--std.c.f./ton raw shale--	13,900	6,500	9,900	11,900	12,200	7,700	5,700	4,800	5,800	13,500	16,400	15,400	12,000	7,600	4,100	3,000	9,300	8,400	11,700	10,700	10,690	14,580	12,010
Spent shale---[4]--lb./ton raw shale--	1,460	1,700	1,480	1,460	1,420	1,660	1,770	1,700	1,640	1,400	1,480	1,380	1,480	1,490	1,740	1,820	1,560	1,440	1,590	1,530	1,400	1,440	1,400
Water condensed [4]---do---	8	60	41	80	52	36	53	28	27	40	43	49	29	69	38	112	20	49	42	47	59	68	31
Material output---wt.-pct. of input--	96	98	95	93	95	96	100	94	98	94	99	98	99	96	98	102	96	91	102	98	93	--	--
Raw shale properties:																							
Fischer assay---gal./ton--	21.2	23.3	20.2	21.7	19.9	19.4	21.5	22.3	21.1	20.2	20.6	21.0	20.9	21.5	22.1	21.1	21.8	22.3	22.3	22.8	22.6	26.2	28.8
Mineral CO_2---wt.-pct.--	17.3	17.5	16.6	16.6	16.6	19.0	--	--	--	17.1	16.9	16.6	17.5	17.5	--	--	--	--	17.4	--	--	19.7	19.3
Particle size range---inch--	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1
Shale oil properties:																							
Gravity---°API--	19.2	20.6	18.2	24.2	19.4	23.0	23.7	21.4	20.5	18.3	19.2	18.3	19.5	20.6	20.5	20.2	20.3	20.3	20.0	19.7	19.2	20.4	22.2
Viscosity---S.S.U. at 130° F.--	156	107	149	53	139	61	50	98	140	162	--	190	116	107	106	99	--	99	126	114	132	133	99
S.S.U. at 210° F.--	52	46	50	37	48	38	36	44	52	52	--	55	47	51	44	43	--	45	41	47	49	57	44
Ramsbottom carbon [5]---wt.-pct.--	--	--	--	--	--	--	--	--	--	--	--	--	3.0	3.6	2.8	3.1	--	2.2	2.1	2.1	--	--	2.3
Gas properties:																							
Moisture [6]---vol.-pct.--	11.6	9.6	10.4	7.9	10.6	13.3	12.4	11.7	14.8	9.3	9.7	12.0	10.1	8.2	9.2	10.0	10.2	12.0	11.8	11.6	11.3	8.1	9.8
Analysis, dry:																							
CO_2---vol.-pct.--	27.1	19.4	25.6	23.4	26.8	19.2	18.2	18.3	28.3	27.7	24.8	27.7	28.3	26.9	25.3	18.9	24.2	21.9	24.9	24.3	24.8	--	--
Ill. [7]---do---	0.0	0.8	0.4	0.2	0.1	0.6	0.7	0.6	0.5	0.0	0.8	0.0	0.3	0.1	0.3	0.5	0.8	1.0	0.4	0.6	0.6	--	--
O_2---do---	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	--	--
CO---do---	1.8	2.0	1.8	2.5	2.3	1.5	0.9	1.6	1.8	0.0	2.1	2.3	2.6	3.7	2.7	1.0	2.8	2.7	2.6	3.2	2.9	--	--
H_2---do---	0.9	0.4	1.4	0.8	1.4	3.5	4.0	2.6	3.2	2.2	2.7	4.0	2.9	4.4	2.6	0.8	3.5	2.2	2.3	2.9	3.0	--	--
Hydrocarbons [8]---do---	1.0	1.5	1.4	1.6	0.8	2.6	3.1	2.4	1.6	1.6	1.5	2.1	1.6	1.6	2.0	1.9	1.9	1.8	2.0	1.6	1.4	--	--
N_2---do---	68.9	75.9	69.4	71.5	68.6	72.6	73.1	74.5	64.0	68.5	68.1	63.0	64.3	63.3	67.1	76.9	66.8	70.4	67.0	67.4	67.3	--	--
Heating value, gross--B.t.u./std.c.f.--	22	39	34	33	23	58	69	54	51	34	47	51	42	47	51	36	63	57	46	52	48	83	53
Spent shale properties:																							
Fischer assay---gal./ton--	0	7.9	0	0	0	0.8	3.1	2.4	2.6	0.5	0	0	0	0	6.0	11.5	0	0.2	0	0	0	0.2	0
Organic residue [9]---wt.-pct.--	0.22	5.16	0	0.71	0.16	--	--	--	--	1.2	0	0.07	0.02	1.23	--	--	--	--	1.0	--	--	1.7	1.7
Mineral CO_2---do---	1.1	15.1	10.7	4.3	1.02	14.9	--	--	--	1.5	0.9	0.6	1.2	11.5	--	--	--	--	8.6	--	9.2	11.3	12.7
Operating data:																							
Press. drop/ft. bed height---in. H_2O--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Retort gas outlet temp.---°F.--	137	113	130	107	144	134	126	144	150	202	141	191	155	125	109	111	113	125	151	140	142	107	143
Recycle gas temp. [10]---do---	114	107	110	100	110	118	116	114	122	106	107	114	109	101	105	108	109	115	114	114	114	101	109
Air inlet temp.---do---	74	75	76	66	71	71	65	77	80	75	65	80	77	77	71	63	73	79	80	75	73	80	75
Bed temps., thermocouple Nos.: [11]																							
1---°F.--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2---do---	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3---do---	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	360
4---do---	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5---do---	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6---do---	180	150	170	480	700	570	530	690	850	470	590	1,490	750	830	480	230	510	570	820	780	640	660	1,500
7---do---	170	150	170	480	620	570	520	700	960	310	410	890	780	920	380	200	460	340	840	850	910	520	820
8---do---	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	530	480	1,030	1,020	800	840	990
9---do---	420	240	450	560	950	710	600	810	970	1,240	1,420	--	1,200	910	640	240	550	530	940	700	700	800	1,160
10---do---	--	--	--	--	--	--	--	--	--	--	--	--	--	1,050	1,500	1,340	910	1,090	1,450	990	980	1,590	1,150
11---do---	730	360	720	660	1,080	770	630	990	1,280	1,200	1,410	1,680	1,580	990	700	320	1,460	570	920	690	700	1,150	880
12---do---	1,120	450	780	810	1,300	880	720	770	790	1,490	1,590	1,800	1,670	1,060	750	610	1,440	1,420	1,370	1,180	1,270	630	1,390
13---do---	1,620	1,040	1,590	1,420	1,380	1,080	970	500	470	860	860	1,780	1,550	690	790	970	1,400	1,340	850	1,250	1,280	660	1,320
14---do---	1,740	1,400	1,290	1,410	1,380	1,050	960	510	500	870	1,300	1,320	790	640	510	390	1,130	1,100	1,070	810	730	560	850
15---do---	1,460	580	920	1,400	1,580	1,160	1,050	500	470	1,300	1,110	1,850	1,270	540	800	570	1,400	1,270	1,530	1,390	1,480	1,060	1,310
16---do---	1,750	1,350	1,110	1,240	1,290	1,070	1,070	480	460	890	660	1,840	1,040	670	740	930	1,220	1,550	1,210	1,460	1,480	740	1,410
17---do---	1,430	1,120	910	960	870	720	650	280	300	870	760	1,280	1,320	520	430	280	1,000	890	1,040	950	--	800	980
18, spent shale temp.---do---	710	570	440	390	300	330	300	190	190	480	710	620	600	270	330	300	510	470	430	540	470	280	510
Operating characteristics:																							
Degree of clinkering or coking [12]---	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Severe	Mod.	Mod.	Mod.	Mod.	Negl.	Mod.	Mod.	Negl.	Negl.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.
Degree of refluxing of oil [13]---	do.	Mod.	do.	Severe	do.	Severe	Severe	do.	Negl.	Negl.	Negl.	Negl.	Mod.	do.	do.	Mod.	Mod.	do.	Negl.	do.	Negl.	Negl.	Do.
Other troubles---see note No.--	--	--	--	--	--	18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results [14]---	Sat.	Unsat.	Sat.	Unsat.	Sat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Sat.	Unsat.	Sat.	Sat.	Unsat.	Unsat.	Sat.

TABLE 13. - Results of oil-shale pilot plant tests

Run No.	42B	42C	42D	43	44	45A	45B	45C	45D	45E	45F	45G	46	47	48	49	50	51	52	53	54	55	56
Date	5-19	5-20	5-21	5-23	5-24	6-1	6-2	6-3	6-4	6-5	6-6	6-7	6-16	6-21	6-27	6-28	6-29	6-30	7-1	7-2	7-6	7-16	7-17
Duration, hr.	24	24	24			24	24	24	24	24	24	24	24	36	23.75	24	24	24	24	14		24	17
Retort type No.	D	D	D	D	D	D	D	D	D	D	D	D	F	F	F	F	F	F	F	F	F	D	D
Oil recovery system type No.	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III	III
Raw material flows:																							
Raw shale-lb./hr. x sq. ft. bed area	186	207	219			214	224	223	193	200	206	207	147	239	140	166	182	202	265	297		143	185
Recycle gas [1] std.c.f./ton raw shale	18,700	16,900	15,700			14,620	14,600	14,250	16,020	13,860	13,060	15,190	18,730	13,970	23,580	20,290	18,120	16,230	14,610	13,560		9,730	18,500
Air [2] do.	9,920	8,880	8,530			7,760	7,500	7,630	8,830	8,500	8,250	8,300	6,490	4,960	3,280	4,120	4,910	5,880	5,600	3,950		5,490	6,000
Products recovered:																							
Shale oil, vol.-pct. Fischer assay	87	96	90			86	95	88	97	109	87	99	96	95	72	80	89	96	84	74		76	57
Shale oil, gal./ton raw shale	25.8	25.8	24.9			17.6	19.5	17.8	20.4	23.6	18.0	20.0	19.7	18.6	14.8	16.3	18.3	19.8	17.3	15.6		25.7	18.6
Gas vented [3]-std.c.f./ton raw shale	13,060	11,270	11,020			10,530	9,840	10,520	12,740	12,260	11,840	10,790	8,430	7,200	4,000	5,410	6,690	8,220	7,640	5,360		10,680	7,960
Spent shale, lb./ton raw shale	1,460	1,540	1,500			1,360	1,520	1,500	1,660	1,540	1,630	1,480	1,360	1,480	1,740	1,720	1,760	1,690	1,640	1,680		1,440	1,560
Water condensed [4] do.	44	79	54			44	53	80	88	44	58	41	112	43	96	104	111	33	55	78		93	70
Material output, wt.-pct. of input	99	100	98			90	95	98	108	102	101	95	91	94	99	102	107	103	99	98		—	96
Raw shale properties:																							
Fischer assay, gal./ton	29.6	26.9	27.8			20.6	20.6	20.2	21.1	21.6	20.6	20.2	20.4	19.6	20.6	20.4	20.6	20.6	20.6	21.1		33.8	32.6
Mineral CO_2, wt.-pct.	19.0	19.2	15.0			16.6	16.9	17.0	17.4	15.8	16.8	16.8	17.3	17.2	17.3	17.4	17.5	17.0	17.1	17.3		17.5	17.6
Particle size range, inch	½-1	½-1	½-1			½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1		½-1	½-1
Shale oil properties:																							
Gravity, °API	21.9	21.3	20.7			19.8	19.8	19.8	19.9	20.1	18.8	18.7	19.8	19.0	19.8	19.8	19.6	19.6	18.3	18.6		20.0	23.7
Viscosity, S.S.U. at 130° F.	141	117	117			114	114	134	134	—	134	134	140	147	133	140	139	148	142	151		119	58
S.S.U. at 210° F.	51	45	45			45	45	47	47	—	46	47	49	49	48	50	49	49	49	49		34	37
Ramsbottom carbon [5], wt.-pct.	2.6	2.1	2.0			5.4	5.4	4.4	4.4	—	3.0	3.0	3.3	2.7	2.3	2.5	2.2	2.9	4.0	4.2		2.5	0.7
Gas properties:																							
Moisture [6], vol.-pct.	8.7	8.9	9.4			11.0	9.5	10.6	11.8	11.8	11.2	10.4	11.5	13.8	11.1	12.1	13.4	13.9	13.6	15.1		12.2	13.2
Analysis, dry:																							
CO_2, vol.-pct.	23.2	21.3	22.7			24.2	19.3	25.2	25.7	25.9	24.6	25.1	24.2	27.4	23.5	22.8	25.2	27.8	23.9	18.8		—	20.6
Ill. [7] do.	0.7	0.8	0.9			0.1	1.0	0.4	0.9	0.8	0.3	0.3	0.3	0.3	0.0	0.9	1.1	0.2	0.7	1.5		—	1.3
O_2 do.	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		—	0.0
CO do.	5.0	3.7	3.7			2.2	2.8	2.7	3.5	2.8	3.3	1.0	2.8	3.2	1.2	2.5	2.9	1.9	2.2	1.1		—	2.0
H_2 do.	3.7	4.1	3.5			6.9	9.2	6.6	5.9	6.5	6.7	4.3	2.6	3.9	0.0	3.5	2.4	2.8	4.3	6.9		—	4.5
Hydrocarbons [8] do.	1.7	1.8	1.7			1.2	1.2	1.0	1.9	1.9	3.1	1.6	1.4	2.1	2.4	1.9	1.5	1.7	1.9	3.2		—	2.8
N_2 do.	65.7	68.3	67.5			65.4	66.5	64.1	62.1	62.1	62.0	67.7	68.7	63.1	72.9	68.4	66.9	65.6	67.0	68.5		—	68.6
Heating value, gross (calc.) B.t.u./std.c.f.	60	66	65	No data taken	No data taken	44	69	48	69	66	72	40	36	48	47	54	51	38	53	88	No data taken	—	75
Spent shale properties:																							
Fischer assay, gal./ton	0.3	0	0			0.2	0	0.1	0.2	0	0	0.2	0	0	3.4	1.7	1.9	0.2	1.0	1.2		2.2	0.2
Organic residue [9], wt.-pct.	1.1	0.8	1.4			1.3	1.6	1.0	0.8	0.9	0.7	0.7	1.3	1.6	3.5	2.0	2.6	1.5	2.2	2.9		3.6	3.4
Mineral CO_2 do.	9.6	10.9	13.4			5.5	8.8	9.2	8.7	8.5	8.8	6.3	8.3	11.2	12.2	13.8	12.9	10.2	12.3	14.3		13.9	17.1
Operating data:																							
Press. drop/ft. bed height, in. H_2O	—	1.22	1.7			1.93	—	—	—	--	--	1.98	0.25	0.49	0.25	0.25	0.27	0.34	0.57	0.54		—	0.18
Retort gas outlet temp., °F.	161	151	155			149	135	141	139	148	149	151	122	125	140	135	135	134	145	134		117	159
Recycle gas temp. [10] do.	105	106	108			112	108	112	116	116	114	112	115	120	112	115	119	120	120	124		115	119
Air inlet temp. do.	73	74	81			81	75	77	73	80	79	71	85	86	86	88	89	91	88	86		87	82
Bed temps., thermocouple Nos.: [11]																							
1, °F.	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
2 do.	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
3 do.	430	310	390			390	370	400	410	470	450	490	320	210	320	310	280	280	350	260		230	470
4 do.	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
5 do.	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—
6 do.	740	740	970			860	810	750	760	750	750	740	840	670	630	660	690	670	700	670		480	640
7 do.	770	780	750			770	790	820	790	780	750	820	1,770	690	650	620	680	730	1,580	1,410		600	640
8 do.	730	680	710			1,400	1,010	870	800	800	780	790	1,030	1,130	890	890	1,100	1,250	1,490	1,080		580	620
9 do.	730	840	1,210			1,010	903	820	820	830	840	830	1,050	760	670	720	760	830	780	740		570	680
10 do.	940	880	820			1,360	1,400	1,200	1,110	1,060	1,010	990	—	1,750	1,470	1,710	1,580	1,700	—	730		720	690
11 do.	860	840	1,340			1,100	1,070	990	1,000	970	1,000	990	1,230	870	740	810	870	900	870	820		640	700
12 do.	1,540	1,390	1,320			1,500	1,730	1,710	1,670	1,490	1,390	1,380	410	790	490	570	610	700	730	810		880	980
13 do.	810	1,420	1,220			1,630	1,730	1,540	1,470	1,450	1,390	1,380	480	720	420	490	570	690	790	860		934	1,040
14 do.	600	680	940			1,310	1,190	1,090	1,110	1,110	1,110	1,090	590	640	390	430	540	650	650	680		—	940
15 do.	1,580	1,420	1,240			1,220	1,770	1,720	1,510	1,390	1,320	1,350	350	330	700	850	900	1,020	990	1,040		—	1,430
16 do.	1,540	1,450	1,350			1,550	1,610	1,640	1,560	1,550	1,490	1,500	480	720	400	500	570	660	720	750		950	1,110
17 do.	800	990	1,050			1,350	1,200	1,170	1,200	1,240	1,180	1,270	590	550	240	320	420	550	520	550		570	790
18, spent shale temp. do.	630	630	580			670	610	590	540	580	510	550	330	270	160	180	220	250	320	340		520	420
Operating characteristics:																							
Degree of clinkering or coking [12]	Mod.	Mod.	Mod.			Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Severe	Severe	Mod.	Mod.	Mod.	Severe	Severe	Mod.	Severe	Severe	Mod.
Degree of refluxing of oil [13]	Negl.	do.	do.			Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	—	Mod.	Severe
Other troubles, see note No.	—	--	--	19	19	--	--	20	20	20	--	--	--	--	--	--	--	—	--	--	21	22	22
Evaluation of results [14]	Sat.	Sat.	Sat.			Unsat.	Sat.	Sat.	Unsat.	Unsat.	Sat.	Sat.	Unsat.	Unsat.	Sat.	Unsat.	Unsat.	Unsat.	Sat.	Sat.	Unsat.	Unsat.	Unsat.

TABLE 14. - Results of oil-shale pilot plant tests

Run No.	57	58	59	60	61	62	63	64	65	66	67
Date	7-18	7-28	7-29	8-8	8-9	8-10	8-11	8-12	8-13	8-14	8-16
Duration--hr.	21	24	21	20	24	24	24	24	24	36	24
Retort type No.	D	D	D	G	G	G	G	G	G	G	G
Oil recovery system type No.	III	III	III	III	III	III	III	III	III	III	III
Raw material flows:											
Shale oil-lb./hr. x sq. ft. bed area	214	157	137	127	164	171	215	109	148	225	144
Recycle gas 1/ std. c.f./ton raw shale	16,320	18,740	--	27,650	20,600	19,710	15,500	20,860	18,650	18,000	23,880
Air 2/--do	6,430	8,940	7,840	2,380	3,320	4,560	5,560	4,900	4,220	4,280	2,870
Products recovered:											
Shale oil--vol.-pct. Fischer assay	87	94	92	47	100	97	94	93	95	98	99
Shale oil--gal./ton raw shale	29.6	32.4	31.0	9.8	20.9	19.5	18.6	19.1	19.2	20.2	21.0
Gas vented 3/-std.c.f./ton raw shale	8,230	11,830	--	5,140	4,400	6,480	7,390	6,390	6,880	6,440	3,960
Spent shale--lb./ton raw shale	1,660	1,500	1,400	1,740	1,650	1,540	1,560	1,540	1,620	1,680	1,740
Water condensed 4/--do	49	116	--	32	42	79	44	54	42	28	33
Material output--wt.-pct. of input	--	103	--	--	97	96	94	94	--	100	100
Raw shale properties:											
Fischer assay--gal./ton	34.1	34.6	33.7	20.9	20.9	20.2	19.7	20.6	20.2	20.7	21.1
Mineral CO_2--wt. pct.	18.0	18.0	18.0	17.1	17.3	17.2	17.0	16.8	17.1	16.9	17.4
Particle size range--inch	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1
Shale oil properties:											
Gravity--°API	22.3	19.5	20.1	21.5	19.5	19.4	19.0	19.5	19.5	19.6	19.8
Viscosity--S.S.U. at 130° F.	77	141	—	87	160	169	189	153	152	162	139
S.S.U. at 210° F.	41	49	—	42	50	52	52	50	56	52	47
Ramsbottom carbon 5/--wt.-pct.	1.2	2.7	--	1.2	2.7	2.7	3.0	2.8	2.6	2.7	2.3
Gas properties:											
Moisture 6/--vol.-pct.	13.2	12.1	--	17.0	11.5	12.1	13.1	10.8	11.4	13.5	11.3
Analysis, dry:											
CO_2--vol.-pct.	--	20.6	--	--	23.0	26.5	24.3	23.1	--	25.7	23.8
Ill. 7/--do	--	1.1	--	--	0.9	1.0	0.2	0.0	--	0.1	0.9
O_2--do	--	0.0	--	--	0.0	0.0	0.0	0.0	--	0.0	0.0
CO--do	--	2.7	--	--	2.7	3.5	2.7	3.9	--	3.8	4.3
H_2--do	--	5.7	--	--	4.0	4.3	3.0	3.5	--	5.6	4.0
Hydrocarbons 8/--do	--	2.0	--	--	2.1	1.5	1.4	1.6	--	3.2	2.5
N_2--do	--	67.9	--	--	67.3	63.2	68.4	67.9	--	61.6	64.5
Heating value, gross (calc.) B.t.u./std.c.f.	92	68	--	45	60	65	38	37	95	68	76
Spent shale properties:											
Fischer assay--gal./ton	0	0	0	6.7	0.7	0.5	0	0	0.2	0.2	0.8
Organic residue 9/--wt.-pct.	3.3	2.2	2.4	4.8	2.5	2.3	1.2	1.2	1.4	1.6	2.2
Mineral CO_2--do	17.2	13.0	13.7	15.2	14.5	13.0	9.6	10.5	11.8	13.4	14.6
Operating data:											
Press. drop/ft. bed height--in. H_2O	0.68	0.23	--	0.12	0.13	0.25	0.25	0.13	0.13	0.27	0.13
Retort gas outlet temp.--°F.	147	158	146	127	128	132	138	127	128	131	137
Recycle gas temp. 10/--do	120	116	113	125	113	115	118	111	113	119	112
Air inlet temp.--do	83	82	85	85	83	80	83	86	86	83	86
Bed temps., thermocouple Nos.: 11/											
1--°F.	--	--	--	--	--	--	--	--	--	--	--
2--do	--	--	--	--	--	--	--	--	--	--	--
3--do	500	490	450	330	340	390	420	380	360	330	380
4--do	--	--	--	--	--	--	--	--	--	--	--
5--do	--	--	--	--	--	--	--	--	--	--	--
6--do	660	1,080	980	--	590	680	740	660	600	620	590
7--do	500	970	900	530	650	1,000	1,400	1,240	990	1,030	870
8--do	545	760	760	470	590	690	750	720	680	650	610
9--do	670	1,250	960	—	--	--	--	--	--	--	--
10--do	590	760	720	390	650	780	1,000	920	820	890	740
11--do	700	1,130	1,000	--	--	--	--	--	--	--	--
12--do	1,010	1,110	1,010	350	610	740	940	860	820	840	690
13--do	1,120	1,080	970	340	610	710	890	820	780	800	680
14--do	820	1,460	1,240	210	630	490	720	740	480	510	320
15--do	1,500	1,510	1,400	280	770	820	970	920	840	860	730
16--do	1,260	810	850	--	--	--	--	--	--	--	--
17--do	640	730	780	200	520	390	600	540	380	440	260
18, spent shale temp.--do	470	510	510	130	210	190	310	260	190	220	160
Operating characteristics:											
Degree of clinkering or coking 12/	Mod.	Mod.	Severe	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/	Severe	Negl.	Mod.	Severe	do.	do.	do.	do.	do.	do.	do.
Other troubles--see note No.	22	22	22	--	--	--	--	--	--	--	--
Evaluation of results 14/	Sat.	Unsat.	Unsat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.

Run No.	68	69	70	71	72	73	74	75	76A	76B	76C	76D
Date	9-23	9-28	9-29	9-30	10-1	10-4-50	10-6	10-6	10-6	10-7	10-8	10-9
Duration--hr.	24	18	22	22	24	16	8	12	17	24	24	20
Retort type No.	G	G	G	G	G	G	G	G	G	G	G	G
Oil recovery system type No.	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Raw material flows:												
Shale oil-lb./hr. x sq. ft. bed area	279	287	202	245	413	355	275	271	327	323	301	245
Recycle gas 1/ std. c.f./ton raw shale	19,760	18,810	18,630	18,320	14,070	15,300	23,000	17,900	14,900	15,100	16,000	17,300
Air 2/--do	3,660	3,510	3,990	4,280	3,220	3,290	2,280	3,900	3,220	3,270	3,530	3,840
Products recovered:												
Shale oil--vol.-pct. Fischer assay	78	68	88	100	82	73	38	73	82	82	87	106
Shale oil--gal./ton raw shale	21.8	16.0	21.8	24.8	19.2	18.1	9.8	18.6	21.7	22.3	23.5	24.5
Gas vented 3/-std.c.f./ton raw shale	5,620	5,090	5,840	6,420	4,710	4,810	2,720	5,890	4,800	5,050	5,560	6,010
Spent shale--lb./ton raw shale	1,700	1,640	1,680	1,540	1,660	1,760	1,960	1,700	1,620	1,640	1,700	1,660
Water condensed 4/--do	32	14	14	19	19	22	36	44	21	21	19	21
Material output--wt.-pct. of input	100	95	100	95	96	99	--	102	96	97	102	102
Raw shale properties:												
Fischer assay--gal./ton	27.8	23.8	24.7	23.8	23.5	24.7	25.7	25.4	26.5	27.0	27.0	23.2
Mineral CO_2--wt. pct.	17.5	18.3	18.9	18.3	18.7	18.6	18.8	18.0	18.4	17.8	17.4	18.3
Particle size range--inch	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1
Shale oil properties:												
Gravity--°API	21.0	21.4	21.0	19.4	19.1	22.0	23.6	19.9	22.4	22.4	21.4	20.8
Viscosity--S.S.U. at 130° F.	95	75	101	158	137	72	61	166	75	71	76	100
S.S.U. at 210° F.	42	40	45	50	48	42	42	49	41	40	42	44
Ramsbottom carbon 5/--wt.-pct.	1.7	1.6	2.4	3.2	3.0	1.2	0.6	2.5	1.3	1.4	1.4	2.3
Gas properties:												
Moisture 6/--vol.-pct.	18.0	16.8	13.9	13.4	15.7	15.9	16.3	13.6	15.2	15.6	14.8	14.0
Analysis, dry:												
CO_2--vol.-pct.	18.1	20.5	22.2	24.0	21.4	20.9	--	25.2	22.6	22.8	26.5	30.3
Ill. 7/--do	1.3	1.1	0.8	0.6	1.2	1.9	--	1.6	2.3	2.4	2.2	1.0
O_2--do	0.0	0.0	0.0	0.0	0.0	0.0	--	0.0	0.1	0.0	0.2	0.0
CO--do	5.3	4.2	4.7	5.7	4.8	2.6	--	4.6	3.0	3.0	3.3	4.1
H_2--do	8.6	4.9	6.2	6.6	5.9	6.1	--	4.9	5.2	6.4	4.8	3.9
Hydrocarbons 8/--do	4.0	3.9	3.4	2.3	2.7	4.3	--	3.2	4.4	4.8	4.2	2.0
N_2--do	62.7	65.4	62.7	60.8	64.0	64.2	--	60.5	62.4	60.6	58.8	58.7
Heating value, gross (calc.) B.t.u./std.c.f.	125	112	98	88	93	—	95	109	137	145	127	75
Spent shale properties:												
Fischer assay--gal./ton	1.0	3.8	1.9	0.2	2.6	--	7.7	6.2	1.7	1.9	1.2	1.0
Organic residue 9/--wt.-pct.	3.2	4.3	2.2	2.2	3.6	--	7.51	5.45	3.80	3.85	3.49	2.92
Mineral CO_2--do	16.3	16.8	16.4	14.6	17.9	--	19.4	17.2	16.9	16.5	16.7	16.1
Operating data:												
Press. drop/ft. bed height--in. H_2O	0.74	0.53	0.25	0.36	0.72	0.69	0.47	0.43	0.55	0.55	0.57	0.46
Retort gas outlet temp.--°F.	162	154	137	143	131	149	146	143	152	155	156	140
Recycle gas temp. 10/--do	130	127	120	119	125	125	125	119	123	124	122	120
Air inlet temp.--do	83	87	93	89	82	86	91	87	84	85	87	91
Bed temps., thermocouple Nos.: 11/												
1--°F.	--	--	--	--	--	--	--	--	--	--	--	--
2--do	--	--	--	--	--	--	--	--	--	--	--	--
3--do	--	490	460	480	390	480	450	440	480	470	470	460
4--do	--	730	610	670	640	670	630	640	640	640	640	640
5--do	--	780	610	680	580	640	630	650	650	640	630	650
6--do	--	700	680	740	710	690	680	690	700	690	690	690
7--do	--	670	740	840	810	680	680	700	720	690	680	640
8--do	--	640	720	800	760	650	650	640	750	730	780	750
9--do	--	770	630	880	790	740	690	700	740	690	660	640
10--do	--	680	760	880	890	770	670	820	810	760	810	850
11--do	--	620	700	840	740	670	680	640	700	750	780	750
12--do	--	570	620	480	640	780	490	620	760	770	760	730
13--do	--	—	--	--	--	—	—	--	--	--	--	--
14--do	--	620	670	690	770	720	670	600	670	710	730	660
15--do	--	520	590	460	610	590	560	550	530	600	740	510
16--do	--	--	--	--	--	—	--	--	--	--	--	--
17--do	--	370	330	280	460	400	610	430	350	390	390	320
18, spent shale temp.--do	--	200	220	190	310	330	220	210	240	270	270	210
Operating characteristics:												
Degree of clinkering or coking 12/	Mod.	Mod.	Negl.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/	do.	Severe	Mod.	do.	Negl.	Severe	Severe	do.	Severe	Severe	Severe	Mod.
Other troubles--see note No.	--	20	--	--	--	--	--	--	--	--	--	—
Evaluation of results 14/	Unsat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Unsat.	Sat.	Sat.	Unsat.	Unsat.

TABLE 15. - Results of oil-shale pilot plant tests

Run No.	76B	77	78	79A	79B	79C	79D	79E	79F	79G	79H	79I	79J	79K	80A	80B	81A	81B	82	83	84A	84B	84C
Date	10-10	10-11	10-12	10-13	10-14	10-15	10-17	10-18	10-19	10-20	10-21	10-22	10-23	10-24	10-25	10-26	10-29	10-30	11-1	11-2	11-3	11-4	11-5
Duration--hr.	8	16	24	24	24	34	24	24	24	24	24	23	22.5	24	24	24	24	24	22	--	24	24	24
Retort type No.	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Oil recovery system type No.	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Raw material flows:																							
Raw shale--lb./hr. x sq. ft. bed area	248	226	242	227	230	226	228	227	242	230	225	235	230	219	227	283	221	224	226		229	239	244
Recycle gas [1]--std.c.f./ton raw shale	17,200	16,800	18,600	19,300	18,100	18,500	18,500	18,600	17,300	18,300	18,300	17,700	18,100	18,500	16,900	16,800	19,400	19,400	18,800		19,300	18,000	17,700
Air [2]--do.	3,730	3,180	3,610	3,480	3,780	3,840	3,810	3,830	3,590	3,780	3,855	3,700	3,780	3,890	3,580	3,140	4,060	4,130	4,370		4,030	3,890	3,820
Products recovered:																							
Shale oil--vol.-pct. Fischer assay	107	79	69	100	95	92	99	93	97	100	98	95	95	92	88	58	92	95	91		95	91	87
Shale oil--gal./ton raw shale	22.3	18.4	16.7	24.3	22.8	22.6	22.9	22.2	22.9	23.6	23.8	23.3	23.3	26.0	24.2	17.1	27.0	27.2	26.7		28.1	27.1	26.4
Gas vented [3]--std.c.f./ton raw shale	6,350	6,730	5,300	5,030	6,250	6,180	6,280	5,570	5,610	6,120	5,320	6,010	6,220	6,190	5,720	5,370	6,100	5,850	6,690		5,930	5,850	5,790
Spent shale--lb./ton raw shale	1,640	1,700	1,740	1,620	1,580	1,600	1,600	1,640	1,580	1,600	1,620	1,620	1,560	1,580	1,600	1,620	1,580	1,560	1,580		1,560	1,560	1,560
Water condensed [4]--do.	40	19	21	24	15	25	23	25	27	24	28	25	30	31	21	37	26	26	23		28	31	31
Material output--wt.-pct. of input	102	--	100	97	98	100	101	99	98	100	98	101	99	99	100	97	99	98	100		99	98	98
Raw shale properties:																							
Fischer assay--gal./ton	20.8	23.3	24.1	24.2	24.0	24.6	23.1	23.9	23.3	23.5	24.2	24.6	24.6	28.4	27.6	29.5	29.3	28.7	29.3		29.7	29.8	30.2
Mineral CO_2--wt.-pct.	18.5	19.3	19.5	18.3	20.0	20.0	19.7	19.3	19.9	19.8	18.6	19.4	19.7	19.9	16.9	20.0	20.0	19.5	19.2		18.0	17.1	19.0
Particle size range--inch	½-1	½-1	½-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1		¼-1	¼-1	¼-1
Shale oil properties:																							
Gravity--°API	18.3	21.0	21.9	19.8	19.4	19.7	19.6	19.8	19.3	19.7	19.4	19.3	19.3	20.6	22.0	23.7	22.5	21.8	21.4		21.3	22.3	22.1
Viscosity--S.S.U. at 130° F.	102	92	74	131	144	134	133	--	140	142	148	144	159	127	105	67	119	120	149		128	136	98
S.S.U. at 210° F.	44	43	40	48	50	49	48	--	49	50	49	49	50	47	43	39	47	47	50		47	49	44
Ramsbottom carbon [5]--wt.-pct.	2.2	1.7	1.2	2.4	2.2	2.4	2.2	--	2.5	2.5	2.5	2.6	2.5	2.2	0.2	0.9	2.0	1.7	2.4		0.2	0.2	1.4
Gas properties:																							
Moisture [6]--vol.-pct.	14.7	13.6	13.7	12.5	13.3	12.7	12.5	12.9	13.0	12.3	12.3	12.3	12.7	13.1	13.9	13.9	11.7	11.7	12.3		13.4	13.0	13.4
Analysis, dry:																							
CO_2--vol.-pct.	31.5	--	23.0	21.4	25.7	29.6	31.4	25.1	29.9	30.7	20.5	30.0	30.5	26.6	28.8	25.6	25.4	21.0	25.5		22.1	24.5	23.6
Ill. [7]--do.	1.5	--	2.5	1.0	1.4	1.3	1.3	1.3	1.0	1.3	0.8	1.8	1.3	1.4	1.1	1.7	1.2	1.0	0.6		1.2	0.3	1.6
O_2--do.	0.0	--	0.0	0.0	0.0	0.2	0.2	0.5	0.2	0.1	0.8	0.2	0.1	0.1	0.1	0.1	0.0	0.7	0.2		0.0	0.1	0.0
CO--do.	2.9	--	1.6	4.0	3.9	4.2	4.6	3.8	4.0	4.3	4.9	4.8	4.9	4.9	5.0	3.6	4.1	4.9	6.3		5.1	5.1	4.9
H_2--do.	6.5	--	6.1	6.0	7.8	5.4	5.0	4.0	4.5	4.6	3.6	4.8	5.1	5.6	4.6	7.0	6.3	5.8	5.9		5.9	5.8	5.5
Hydrocarbons [8]--do.	3.2	--	4.5	5.1	6.1	3.1	2.7	2.9	2.3	3.4	4.2	3.2	3.1	4.3	3.0	8.4	3.5	2.9	2.7		3.8	3.9	4.3
N_2--do.	54.4	--	62.3	62.5	55.1	56.2	54.8	62.4	58.1	55.6	65.2	55.4	55.0	57.1	57.4	53.6	59.5	63.7	58.8		61.9	60.3	60.1
Heating value, gross (calc.) B.t.u./std.c.f.	111	--	136	107	130	98	83	80	70	89	94	98	89	106	86	143	107	99	92	No data taken	94	84	107
Spent shale properties:																							
Fischer assay--gal./ton	1.2	1.2	4.6	0.8	0.5	0.5	0.2	1.0	0.5	0.5	0.2	0.5	0.1	1.1	1.1	7.4	1.0	0.8	0.5		0.3	0.1	1.4
Organic residue [9]--wt.-pct.	2.91	3.15	4.48	2.48	2.20	2.35	2.34	2.38	2.24	2.25	2.33	2.29	2.51	2.43	3.76	5.61	2.74	2.48	2.71		2.52	1.41	2.97
Mineral CO_2--do.	16.5	17.5	16.8	17.2	16.8	17.0	16.5	17.0	16.7	16.4	16.0	16.3	16.3	16.7	14.6	18.8	16.9	16.8	14.8		16.2	15.9	17.0
Operating data:																							
Press. drop/ft. bed height--in. H_2O	0.61	0.58	0.83	0.40	0.46	0.43	0.44	0.38	0.40	0.35	0.38	0.35	0.35	0.50	0.65	0.72	0.43	0.45	0.46		0.43	0.51	0.54
Retort gas outlet temp.--°F.	142	150	159	143	141	144	147	140	140	141	145	143	140	146	151	154	145	144	169		150	150	155
Recycle gas temp. [10]--do.	122	119	120	116	118	116	116	117	117	115	115	115	116	117	119	119	113	113	115		118	117	118
Air inlet temp.--do.	96	90	94	90	95	92	92	91	91	91	90	91	92	91	92	88	94	91	89		87	86	85
Bed temps., thermocouple Nos.: [11]																							
1--°F.	220	230	290	240	270	290	220	240	230	250	230	260	250	240	230	240	170	160	180		150	150	160
2--do.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--
3--do.	460	460	480	470	480	500	490	470	460	460	480	480	430	490	480	480	560	580	630		500	510	520
4--do.	650	650	650	670	670	680	670	660	670	670	690	620	650	760	720	650	680	700	720		680	700	700
5--do.	630	620	620	650	670	660	650	640	640	660	670	620	660	690	680	626	700	760	930		660	670	760
6--do.	720	690	670	730	730	730	720	720	690	730	770	730	730	790	790	703	890	920	1,090		770	780	900
7--do.	720	650	600	700	680	660	660	650	680	700	720	720	720	730	700	590	750	800	930		800	770	740
8--do.	740	700	690	740	710	690	690	710	720	720	680	880	690	650	580	620	850	970	970		900	980	980
9--do.	850	680	720	860	850	840	840	850	860	870	870	870	870	890	830	590	920	980	940		990	1,060	1,020
10--do.	880	820	780	890	840	850	850	840	840	870	880	900	900	970	1,000	920	910	900	840		940	1,020	960
11--do.	690	650	640	620	600	570	590	630	670	640	630	630	630	590	580	650	610	720	600		710	780	710
12--do.	760	660	660	640	630	580	610	590	640	590	600	600	620	450	610	670	360	350	390		400	480	570
13--do.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--
14--do.	640	610	590	540	510	470	500	560	600	580	--	580	570	480	510	670	490	640	360		660	720	630
15--do.	480	490	430	400	390	310	320	420	380	340	--	340	360	320	350	490	250	300	520		280	310	360
16--do.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--
17--do.	280	280	270	230	230	200	220	200	230	210	200	200	210	190	210	320	180	220	260		180	230	250
18, spent shale temp.--do.	190	200	210	160	170	160	150	160	160	150	150	150	150	150	180	240	140	160	140		160	170	180
Operating characteristics:																							
Degree of clinkering or coking [12]	Mod.	Mod.	Negl.	Mod.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Mod.	Severe	Severe	Mod.	Negl.	Negl.	Severe	Mod.	Negl.	Negl.
Degree of refluxing of oil [13]	Negl.	do.	Severe	Negl.	do.	Negl.	do.	do.	do.	do.	do.	do.	do.	Negl.	Mod.	do.	do.	Mod.	Mod.		Mod.	Mod.	Severe
Other troubles--see note No.	--	--	--	--	--	--	--	--	--	--	20	20	--	--	--	--	--	--	--	21	--	--	--
Evaluation of results [14]	Unsat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	--	Sat.	Sat.	Sat.

TABLE 16. - Results of oil-shale pilot plant tests

Run No.	85A	85B	85C	85D	86A	86B	86C	87A	88	89	90A	90B	91A	91B	92	93	94	95	96	97	98	99	100
Date	11-15	11-16	11-16	11-17	11-17	11-18	11-19	11-20	12-13	12-17	12-18	12-19	12-19	12-20	1-11-51	1-12	1-14	1-15	1-16	1-17	1-24	1-25	1-26
Duration---hr.	12	12	12	12	12	24	24	24		20	24	12	24	18	24	21	24	21	24	15	24	24	24
Retort type No.	G	G	G	G	G	G	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Oil recovery system type No.	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	V	V	V	V	V	V	V	V	V
Raw material flows:																							
Raw shale--lb./hr. x sq. ft. bed area	243	254	254	250	236	250	222	231		287	273	230	257	251	198	217	230	264	287	254	276	292	306
Recycle gas 1/-std.c.f./ton raw shale	17,700	16,600	17,000	17,000	18,700	17,500	18,400	18,400		14,200	15,100	17,400	15,000	14,000	17,000	17,500	16,300	15,400	15,500	14,700	14,700	15,100	15,700
Air 2/---do	3,800	3,880	4,145	4,450	4,730	4,730	5,330	4,810		4,010	4,350	5,080	4,400	4,500	6,060	6,450	5,660	5,290	5,350	5,160	5,090	5,190	5,090
Products recovered:																							
Shale oil---vol.-pct. Fischer assay	62	61	76	87	83	91	96	88		72	91	98	81	87	90	98	90	92	93	104	82	90	86
Shale oil---gal./ton raw shale	15.5	15.7	19.0	23.0	25.7	26.8	27.3	25.8		22.6	26.7	28.5	25.1	26.8	22.6	25.9	23.9	23.8	24.2	26.3	22.4	24.5	22.8
Gas vented 3/--std.c.f./ton raw shale	5,570	6,470	6,410	6,470	7,000	7,210	7,820	7,160		5,730	7,050	7,950	6,260	6,360	8,720	8,960	7,860	7,560	7,470	7,240	7,400	7,710	7,470
Spent shale---lb./ton raw shale	1,720	1,600	1,600	1,500	1,760	1,560	1,640	1,500		1,620	1,480	1,640	1,640	1,540	1,500	1,550	1,510	1,560	1,560	1,600	1,520	1,550	1,580
Water condensed 4/---do	37	43	36	32	25	22	30	19		43	27	32	26	29	52	52	39	35	29	39	26	26	42
Material output---wt.-pct. of input	100	--	98	94	106	99	102	95		--	--	105	100	--	97	99	96	98	96	--	--	98	99
Raw shale properties:																							
Fischer assay---gal./ton	25.0	25.7	25.2	26.5	31.0	29.3	28.5	29.5		31.4	29.3	29.0	30.8	30.8	25.0	26.4	26.6	25.9	25.9	25.2	27.4	27.4	26.5
Mineral CO_2---wt.-pct.	--	--	--	--	--	20.0	20.0	19.9		17.4	18.0	19.1	--	18.1	18.3	18.2	17.4	18.4	20.0	--	16.8	17.0	17.7
Particle size range---inch	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1		¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1	¼-1
Shale oil properties:																							
Gravity---°API	25.0	22.8	23.0	19.9	21.1	19.5	19.7	19.7		23.6	21.0	19.9	20.8	20.7	21.5	21.4	21.6	21.3	21.2	--	21.5	21.2	21.9
Viscosity---S.S.U. at 130° F.	--	--	--	--	--	132	126	143		56	101	132	--	--	103	98	98	99	106	--	83	94	102
S.S.U. at 210° F.	--	--	--	--	--	47	46	48		36	44	47	--	--	44	44	44	45	44	--	43	43	44
Ramsbottom carbon 5/---wt.-pct.	--	--	--	--	--	2.7	2.5	2.4		0.5	2.1	2.4	--	--	2.3	2.0	2.2	2.3	2.7	--	1.7	2.2	2.0
Gas properties:																							
Moisture 6/---vol.-pct.	12.6	13.7	13.4	13.6	14.0	13.3	13.3	13.2		13.7	12.1	12.4	12.9	12.5	12.4	12.8	12.8	13.9	14.6	14.6	15.5	15.0	15.8
Analysis, dry:																							
CO_2---vol.-pct.	22.6	--	26.4	23.5	21.8	24.4	21.1	22.0		--	--	26.2	21.3	--	27.0	20.9	24.1	25.0	21.3	--	--	26.0	23.0
Ill. 7/---do	1.8	--	1.6	1.4	1.8	1.6	1.2	1.2		--	--	1.2	2.3	--	0.5	0.6	0.9	0.9	0.6	--	--	0.7	1.1
O_2---do	0.0	--	0.4	0.6	0.3	0.5	0.3	0.1		--	--	0.2	0.0	--	0.2	0.0	0.3	0.4	0.5	--	--	0.5	0.5
CO---do	4.3	--	4.7	3.5	4.5	5.2	5.7	5.3	No data taken	--	--	5.4	3.0	--	3.5	4.3	3.5	3.4	4.0	--	--	3.9	3.9
H_2---do	5.4	--	4.7	4.5	5.7	5.3	6.0	6.6		--	--	4.8	4.7	--	4.8	7.8	4.0	4.2	5.5	--	--	4.6	4.5
Hydrocarbons 8/---do	4.3	--	3.2	3.7	3.9	3.3	3.6	3.5		--	--	4.6	4.7	--	1.5	1.2	1.9	1.9	2.0	--	--	1.7	2.9
N_2---do	61.6	--	59.0	62.8	62.0	59.7	62.1	61.3		--	--	57.6	64.0	--	62.5	65.2	65.3	64.2	66.1	--	--	62.6	64.1
Heating value, gross (calc.) B.t.u./std.c.f.	113	--	99	92	113	105	98	99		--	--	91	108	--	60	76	70	70	72	--	--	68	86
Spent shale properties:																							
Fischer assay---gal./ton	6.0	5.8	3.4	1.3	2.4	0.7	0.5	0.0		2.9	0.5	2.6	--	0.8	0.0	0.1	0.0	0.0	0.0	--	0.3	1.1	0.3
Organic residue 9/---wt.-pct.	--	--	--	--	--	2.38	1.78	2.43		4.12	2.49	3.31	--	3.07	1.30	0.95	1.20	1.34	2.01	--	2.24	2.32	1.48
Mineral CO_2---do	--	--	--	--	--	16.6	15.2	15.4		18.1	15.9	14.1	--	16.7	11.1	11.9	12.0	12.9	14.6	--	15.4	14.4	14.8
Operating data:																							
Press. drop.ft. bed height---in. H_2O	0.60	0.60	0.56	0.49	0.58	0.53	0.44	0.45		0.63	0.60	0.55	0.58	0.48	0.47	0.69	0.49	0.72	1.01	0.94	0.78	0.88	0.99
Retort gas outlet temp.---°F.	150	161	149	147	187	157	154	161		150	150	167	170	180	150	170	150	180	170	160	150	150	160
Recycle gas temp. 10/---do	116	119	118	119	120	118	118	118		119	115	116	117	116	116	117	117	120	122	122	124	123	125
Air inlet temp.---do	82	82	83	85	86	84	86	86		80	77	78	78	79	78	76	81	82	85	83	82	81	82
Bed temps., thermocouple Nos.: 11/																							
1---°F.	310	380	380	360	460	390	400	420		410	380	420	500	520	450	530	460	490	580	570	440	430	580
2---do	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--
3---do	370	460	530	540	610	560	580	610		550	570	540	630	570	670	830	660	730	770	760	630	850	1,120
4---do	640	660	640	900	830	940	720	750		710	910	1,070	1,130	950	1,070	950	1,160	1,250	1,160	1,080	890	970	1,090
5---do	630	650	650	760	740	800	880	930		670	810	710	750	740	1,050	1,280	1,090	1,160	1,100	1,280	1,150	1,350	1,240
6---do	880	800	730	850	840	960	1,050	1,070		980	1,020	1,100	1,360	1,320	1,260	1,390	1,170	1,300	1,270	1,330	1,300	1,370	1,310
7---do	680	680	700	770	730	780	790	800		800	810	710	790	890	--	--	--	--	--	--	--	--	--
8---do	790	820	820	830	870	810	830	800		--	--	--	--	--	--	--	--	--	--	--	--	--	--
9---do	855	840	880	950	850	920	970	1,010		810	950	910	930	940	850	1,030	980	950	870	1,320	1,070	1,290	1,190
10---do	810	800	820	900	890	970	1,050	1,050		980	1,200	1,070	1,100	1,160	950	1,000	1,170	1,170	1,080	990	1,260	1,380	1,470
11---do	620	615	620	670	670	690	650	590		630	640	680	690	710	650	730	750	850	800	770	670	640	640
12---do	720	660	650	710	660	660	580	550		650	660	580	660	730	670	770	750	740	860	880	700	710	700
13---do	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--
14---do	580	560	560	640	700	630	520	460		710	660	660	720	770	730	780	750	1,020	690	940	670	650	660
15---do	470	480	450	570	760	580	530	520		640	610	510	620	660	610	700	650	690	720	710	790	730	610
16---do	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--
17---do	320	290	300	340	420	310	280	250		430	450	400	460	490	370	450	430	480	630	520	540	530	420
18, spent shale temp.---do	270	280	260	210	230	210	160	150		270	230	230	260	250	220	230	250	260	290	310	280	280	270
Operating characteristics:																							
Degree of clinkering or coking 12/	Negl.	Negl.	Negl.	Negl.	Severe	Negl.	Negl.	Negl.	Severe	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Mod.	Mod.	Negl.
Degree of refluxing of oil 13/	Severe	Severe	Severe	do.	Mod.	do.	do.	do.		Severe	Mod.	do.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	--	do.	do.	Mod.
Other troubles---see note No.	--	--	--	--	--	--	--	--	21	23	--	--	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Unsat.	Sat.	Unsat.	Sat.		Unsat.	Sat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Sat.	Sat.	Sat.

TABLE 17. - Results of oil-shale pilot plant tests

Run No.	101	102	103	104	105	106	107	108	109	110	111
Date	1-27	1-28	1-29	1-30	1-31	2-10	2-11	2-12	2-13	2-14	2-23
Duration---hr.	24	24	23	24	24	24	24	24	24	24	24
Retort type No.	H	H	H	H	H	I	I	I	I	I	I
Oil recovery system type No.	V	V	V	V	V	V	V	V	V	V	V
Raw material flows:											
Raw shale---lb./hr. x sq.ft..bed area	347	391	246	299	298	284	306	275	287	283	224
Recycle gas 1/-std.c.f./ton raw shale	15,300	13,900	18,000	15,300	15,300	16,200	14,800	16,400	15,800	16,000	13,700
Air 2/---do	4,750	4,660	6,400	5,230	5,290	5,160	4,860	5,360	5,130	5,200	6,440
Products recovered:											
Shale oil---vol.-pct. Fischer assay	79	67	81	97	85	78	85	90	86	82	80
Shale oil---gal./ton raw shale	21.2	17.9	22.5	28.0	33.6	16.5	18.5	17.0	16.3	17.1	16.4
Gas vented 3/--std.c.f./ton raw shale	7,040	6,180	9,500	7,780	7,440	6,250	6,680	7,100	7,100	7,180	8,650
Spent shale---lb./ton raw shale	1,670	1,580	1,520	1,600	1,600	1,680	1,620	1,680	1,620	1,720	1,600
Water condensed 4/---do	50	43	72	57	38	33	32	35	28	29	27
Material output---wt.-pct. of input	101	93	100	101	--	97	97	99	98	101	97
Raw shale properties:											
Fischer assay---gal./ton	27.0	26.7	28.0	28.8	39.3	21.0	21.8	18.9	18.9	20.9	20.4
Mineral CO_2---wt.-pct.	16.9	17.5	15.7	15.6	15.7	16.5	16.2	17.0	16.4	16.6	16.8
Particle size range---inch	¼-1	¼-1	¼-1	¼-1	¼-1	3/4-1¼	3/4-1¼	¼-1	¼-1	3/8-3/4	½-1
Shale oil properties:											
Gravity---°API	22.6	22.2	21.0	22.0	21.6	21.1	21.6	21.4	21.9	22.0	21.9
Viscosity---S.S.U. at 130° F.	70	77	100	81	93	80	79	80	78	68	79
S.S.U. at 210° F.	39	40	43	41	42	42	40	41	39	39	41
Ramsbottom carbon 5/---wt.-pct.	1.0	1.2	2.2	1.5	1.9	1.5	1.5	1.4	1.2	1.0	1.5
Gas properties:											
Moisture 6/---vol.-pct.	16.6	20.5	17.0	14.5	13.4	14.7	15.9	14.3	13.5	13.5	12.1
Analysis, dry:											
CO_2---vol.-pct.	18.6	18.3	22.8	22.1	--	14.9	21.1	24.1	24.7	24.5	23.9
Ill. 7/---do	1.5	0.9	1.1	1.2	--	0.8	1.3	0.6	0.6	1.0	0.4
O_2---do	0.7	0.0	0.2	0.3	--	0.0	0.0	0.1	0.4	0.5	1.2
CO---do	3.8	1.7	4.3	5.6	--	1.9	2.3	1.9	2.5	2.8	2.5
H_2---do	7.7	2.3	5.0	6.2	--	3.3	4.0	2.0	3.7	3.1	3.0
Hydrocarbons 8/---do	3.8	2.0	2.3	2.7	--	2.4	3.1	1.6	2.0	1.8	1.2
N_2---do	63.9	74.8	64.3	61.9	--	76.7	68.2	69.7	66.1	66.3	67.8
Heating value, gross (calc.) .B.t.u./std.c.f.	116	62	87	100	--	72	88	51	61	67	45
Spent shale properties:											
Fischer assay---gal./ton	2.9	2.6	0.8	2.6	7.1	0.3	0.3	0.1	0.3	0.3	0.2
Organic residue 9/---wt.-pct.	2.28	2.19	2.53	3.88	4.66	1.24	1.66	1.64	1.28	1.59	1.29
Mineral CO_2---do	16.6	16.3	11.9	14.2	16.2	15.0	12.9	12.2	12.2	12.0	11.1
Operating data:											
Press. drop/ft. bed height---in. H_2O	1.25	1.48	0.74	0.91	1.02	0.38	0.42	0.88	0.73	0.88	0.33
Retort gas outlet temp.--- °F.	160	150	180	160	190	170	160	160	170	160	150
Recycle gas temp. 10/---do	127	135	128	122	119	122	125	121	119	119	115
Air inlet temp.---do	81	81	77	79	77	81	86	81	78	81	80
Bed temps., thermocouple Nos.: 11/											
1--- °F.	530	350	500	510	630	520	480	590	580	560	460
2---do	--	--	--	--	--	640	620	710	740	640	560
3---do	800	650	940	750	820	--	--	--	--	--	--
4---do	1,030	1,040	1,120	950	1,000	1,120	1,050	1,260	1,080	1,090	750
5---do	1,130	1,220	1,360	1,410	1,220	850	850	1,130	1,100	870	690
6---do	1,330	1,200	1,280	1,340	1,230	1,870	1,750	1,160	1,280	1,320	1,000
7---do	--	--	--	--	--	1,230	1,280	1,460	1,380	1,240	950
8---do	--	--	--	--	--	--	--	--	--	--	--
9---do	1,150	1,090	760	1,200	1,200	1,130	1,210	1,000	1,090	1,260	1,390
10---do	1,220	1,080	1,090	1,290	1,270	720	740	640	670	720	1,470
11---do	790	630	630	680	930	730	750	630	660	710	1,540
12---do	730	670	410	650	670	780	800	700	710	780	1,490
13---do	--	--	--	--	--	860	870	810	820	880	1,190
14---do	760	650	590	660	740	--	--	--	--	--	--
15---do	660	650	380	610	670	--	--	--	--	--	--
16---do	--	--	--	--	--	830	820	790	800	740	860
17---do	520	460	240	430	420	--	--	--	--	--	--
18, spent shale temp.---do	300	280	200	240	260	220	230	200	220	230	240
Operating characteristics:											
Degree of clinkering or coking 12/	Negl.	Negl.	Negl.	Negl.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/	Severe	Severe	Mod.	Severe	Mod.	do.	Mod.	Mod.	Severe	Severe	Severe
Other troubles---see note No.	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/	Sat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.

Run No.	112	113	114	115	116	117	118	119	120	121	122	123
Date	2-24	2-25	2-26	2-27	3-9	3-10	3-11	3-12	3-13	3-14	3-21	3-22
Duration---hr.	24	24	24	24	28	24	24	20	24	24	24	24
Retort type No.	I	I	I	I	I	I	I	I	I	I	I	I
Oil recovery system type No.	V	V	V	V	VI	VI	VI	VI	VI	VI	VI	VI
Raw material flows:												
Raw shale---lb./hr. x sq.ft..bed area	217	212	201	212	260	250	226	281	254	264	195	300
Recycle gas 1/-std.c.f./ton raw shale	16,100	19,400	22,600	23,400	18,900	21,500	25,000	20,800	19,200	16,000	16,000	15,800
Air 2/---do	6,000	4,450	3,530	2,670	2,990	2,510	2,310	3,420	4,540	5,450	8,630	5,010
Products recovered:												
Shale oil---vol.-pct. Fischer assay	85	87	85	87	88	89	58	60	91	85	89	85
Shale oil---gal./ton raw shale	18.1	18.2	18.7	19.0	17.8	17.8	12.0	12.8	19.2	18.6	18.5	17.9
Gas vented 3/--std.c.f./ton raw shale	8,350	5,910	4,550	3,210	3,670	2,940	2,530	4,260	5,440	7,530	10,930	6,840
Spent shale---lb./ton raw shale	1,650	1,700	1,720	1,720	1,700	1,780	1,840	1,820	1,680	1,640	1,540	1,660
Water condensed 4/---do	9	31	23.3	36	21	23	27	23	21	23	29	17
Material output---wt.-pct. of input	98	99	98	96	96	99	99	100	97	99	94	95
Raw shale properties:												
Fischer assay---gal./ton	21.3	20.9	22.1	21.8	20.3	20.1	20.5	21.4	21.1	21.8	20.7	21.0
Mineral CO_2---wt.-pct.	16.3	15.7	16.1	16.4	16.8	16.8	17.4	--	17.5	17.4	13.1	16.1
Particle size range---inch	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1	½-1
Shale oil properties:												
Gravity---°API	20.7	21.3	21.6	22.4	21.4	22.7	23.1	22.5	21.0	20.8	21.2	22.1
Viscosity---S.S.U. at 130° F.	86	87	88	76	85	78	67	70	95	92	94	95
S.S.U. at 210° F.	42	44	43	40	44	41	39	40	45	44	42	44
Ramsbottom carbon 5/---wt.-pct.	1.5	1.2	1.4	1.3	1.2	1.2	0.7	0.8	1.7	2.0	1.6	1.5
Gas properties:												
Moisture 6/---vol.-pct.	12.5	11.9	11.4	9.8	13.8	12.2	10.6	14.9	10.9	13.5	11.7	13.8
Analysis, dry:												
CO_2---vol.-pct.	26.2	22.6	19.0	14.6	13.2	11.2	12.6	16.9	17.0	24.8	20.4	24.5
Ill. 7/---do	0.5	0.9	1.0	1.2	1.1	1.0	0.6	0.7	1.2	0.5	0.4	0.9
O_2---do	0.6	0.4	1.0	0.3	1.2	0.6	0.0	0.0	0.0	0.0	2.2	0.6
CO---do	2.7	2.5	2.2	2.2	1.8	1.7	1.5	1.1	2.2	3.3	1.5	1.8
H_2---do	4.0	3.8	4.5	4.8	4.3	4.0	1.3	2.6	1.9	4.0	3.7	3.3
Hydrocarbons 8/---do	1.5	1.9	2.7	3.5	4.0	4.5	3.2	4.4	3.6	1.2	1.0	1.7
N_2---do	64.5	67.9	69.6	73.4	74.4	77.0	80.8	74.3	74.1	66.2	70.8	67.2
Heating value, gross (calc.) .B.t.u./std.c.f.	51	66	80	102	93	106	74	91	89	52	41	61
Spent shale properties:												
Fischer assay---gal./ton	0.3	0.3	0.5	1.1	0.5	0.5	5.0	5.2	0.3	0.3	0.5	0.3
Organic residue 9/---wt.-pct.	1.48	1.00	2.22	2.52	2.16	2.64	3.73	4.62	2.34	2.35	0.55	1.40
Mineral CO_2---do	12.4	14.8	16.4	17.5	17.4	17.9	18.5	13.9	15.2	16.4	8.7	10.9
Operating data:												
Press. drop/ft. bed height---in. H_2O	0.29	0.32	0.34	0.32	0.43	0.44	0.33	0.54	0.46	0.49	0.33	0.61
Retort gas outlet temp.--- °F.	150	160	160	150	150	150	150	160	160	150	150	150
Recycle gas temp. 10/---do	116	114	114	108	119	115	110	122	111	119	114	120
Air inlet temp.---do	78	81	82	80	83	79	76	82	80	80	86	82
Bed temps., thermocouple Nos.: 11/												
1--- °F.	460	490	480	490	470	470	470	450	460	420	480	450
2---do	560	560	570	560	580	570	580	550	550	560	540	570
3---do	--	--	--	--	--	--	--	--	--	--	--	--
4---do	680	690	660	690	750	730	690	780	790	720	710	790
5---do	680	700	700	700	720	710	620	720	740	710	1,010	950
6---do	980	1,020	980	840	1,000	960	760	1,080	1,060	980	1,050	1,140
7---do	940	1,010	970	850	950	--	--	1,050	1,190	1,000	1,550	1,530
8---do	--	--	--	--	--	--	--	--	--	--	--	--
9---do	1,230	1,190	1,030	790	830	720	490	890	1,140	1,320	1,740	1,540
10---do	1,340	1,140	940	680	670	600	500	700	820	1,470	1,480	1,070
11---do	1,280	1,020	840	670	640	580	400	620	780	1,360	1,330	820
12---do	1,270	970	840	670	660	590	410	640	780	1,270	1,330	830
13---do	1,100	1,010	940	810	880	830	770	840	860	1,170	1,190	1,020
14---do	--	--	--	--	--	--	--	--	--	--	--	--
15---do	--	--	--	--	--	--	--	--	--	--	--	--
16---do	800	640	470	450	570	500	480	840	640	740	830	820
17---do	--	--	--	--	--	--	--	--	--	--	--	--
18, spent shale temp.---do	220	170	150	140	160	140	130	200	170	210	250	250
Operating characteristics:												
Degree of clinkering or coking 12/	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/	Mod.	Mod.	Mod.	Severe	Mod.	Severe	Severe	Severe	Mod.	Mod.	Mod.	Mod.
Other troubles---see note No.	--	--	--	--	--	--	20	24	--	--	--	--
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Unsat.	Sat.	Sat.	Sat.	Sat.

TABLE 18. - Results of oil-shale pilot plant tests

Run No.	124	125	126	127	128	129	130	131	132	133	134	135
Date	3-23	3-24	3-25	3-26	3-27	3-28	4-4	4-18	4-19	4-20-51	4-21	4-22
Duration - hr.	24	24	24	24	24	20	24	24	24	24	24	24
Retort type No.	I	I	I	I	I	I	I	I	I	I	I	I
Oil recovery system type No.	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI
Raw material flows:												
Raw shale-lb./hr.x sq.ft. bed area	269	313	339	379	396	438	279	242	225	199	205	209
Recycle gas 1/ std.c.f./ton raw shale	18,100	16,900	16,900	16,700	17,000	16,600	17,400	15,000	18,000	19,700	21,400	20,900
Air 2/ - do	4,260	3,670	3,520	3,730	3,890	3,760	4,950	5,240	4,520	4,910	3,710	3,630
NaCl brine added to shale gal./ton	--	--	--	--	--	--	--	--	--	1.0	1.0	0.0
Products recovered:												
Shale oil-vol.-pct. Fischer assay	88	86	87	89	85	85	88	79	89	99	89	71
Shale oil 3/ - gal./ton raw shale	18.7	18.6	18.7	19.3	18.2	17.8	20.0	15.8	17.5	19.7	17.5	14.7
Gas vented 2/ std.c.f./ton raw shale	5,770	5,040	4,690	4,940	5,430	5,580	6,550	7,010	5,640	6,920	4,730	4,700
Spent shale - lb./ton raw shale	1,680	1,660	1,660	1,680	1,740	1,700	1,640	1,590	1,660	1,680	1,680	1,740
Water condensed 4/ - do	15	18	16	15	14	11	19	14	10	16	22	20
Material output-wt.-pct. of input	98	96	96	97	100	99	97	93	95	101	97	98
Raw shale properties:												
Fischer assay - gal./ton	21.2	21.5	21.5	21.7	21.5	21.0	22.8	19.9	19.7	19.9	19.7	20.6
Mineral CO_2 - wt.-pct.	16.6	16.6	16.2	15.2	15.7	16.0	16.4	17.7	16.2	17.1	16.7	16.3
Particle size range - inch	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1
Shale oil properties:												
Gravity - °API	22.0	21.2	21.0	20.9	20.6	20.2	20.9	20.8	20.4	19.7	20.7	23.1
Viscosity - S.S.U. at 130° F.	88	95	93	97	95	107	100	86	100	165	109	72
S.S.U. at 210° F.	42.0	43	48	47	48	50	46	45	48	58	50	41
Ramsbottom carbon 5/ - wt.-pct.	1.5	1.6	1.5	1.6	1.7	1.7	1.8	1.2	1.6	2.5	1.8	0.7
Gas properties:												
Moisture 6/ - vol.-pct.	14.0	14.8	15.6	16.0	16.7	17.2	13.1	16.4	16.1	14.3	15.0	13.8
Analysis, dry:												
CO_2 - vol.-pct.	22.3	23.4	21.7	20.1	22.8	22.5	19.2	21.0	19.7	27.9	17.4	19.8
Ill. 7/ - do	1.0	1.2	1.1	1.0	1.0	1.3	0.7	0.5	0.7	0.6	0.7	1.2
O_2 - do	1.0	0.0	0.9	0.9	0.4	1.0	2.5	1.9	1.3	0.2	2.1	1.1
CO - do	1.3	2.4	2.1	1.8	2.5	3.9	3.4	2.0	1.8	2.3	2.1	2.1
H_2 - do	4.2	3.0	1.8	3.0	3.4	4.0	4.1	2.1	2.5	2.0	3.3	2.9
Hydrocarbons 8/ - do	2.6	2.6	2.0	2.2	1.9	3.0	1.3	1.3	1.9	1.3	1.6	2.4
N_2 - do	67.6	67.4	70.4	71.0	68.0	64.3	68.8	70.6	72.1	65.7	72.8	70.5
Heating value, gross B.t.u./std.c.f.	81	77	66	71	69	98	58	42	47	44	56	74
Spent shale properties:												
Fischer assay - gal./ton	0.3	0.3	0.3	0.3	0.5	1.3	0.3	0.8	0.0	0.3	0.0	2.9
Organic residue 9/ - wt.-pct.	1.10	1.37	1.53	1.78	2.18	2.44	0.86	0.94	0.76	1.13	1.74	0.79
Mineral CO_2 - do	14.6	14.8	15.2	15.9	15.3	15.1	14.6	12.6	14.6	12.6	14.9	15.4
Operating data:												
Press. drop/ft. bed height-in.H_2O	0.53	0.55	0.66	0.78	0.90	1.04	0.78	0.34	0.33	0.31	0.27	0.28
Retort gas outlet temp. - °F.	160	150	150	150	150	140	160	150	150	150	150	160
Recycle gas temp. 10/ - do	120	123	124	125	127	128	118	126	125	121	123	120
Air inlet temp. - do	99	82	83	79	80	78	79	86	84	82	82	83
Bed temps., thermocouple Nos.: 11/												
1 - °F.	470	420	420	390	410	430	470	--	420	450	460	470
2 - do	570	550	560	550	570	620	620	--	570	600	590	570
3 - do	--	--	--	--	--	--	--	--	--	--	--	--
4 - do	850	780	790	780	780	780	760	--	1,020	1,110	720	820
5 - do	770	710	750	800	1,030	1,290	1,750	--	860	1,150	980	800
6 - do	1,110	1,040	1,020	980	950	1,270	1,300	--	1,350	1,390	960	1,290
7 - do	1,040	980	1,000	1,000	1,150	1,310	1,760	--	1,310	1,400	1,150	1,450
8 - do	--	--	--	--	--	--	--	--	--	--	--	--
9 - do	1,140	1,070	1,040	1,030	860	800	1,720	--	1,520	1,110	680	800
10 - do	870	900	880	900	780	640	1,040	--	1,200	750	630	680
11 - do	680	710	690	690	640	530	670	--	1,300	660	560	580
12 - do	690	710	690	690	640	540	670	--	1,350	700	560	560
13 - do	960	940	930	930	940	980	910	--	980	960	890	860
14 - do	--	--	--	--	--	--	--	--	--	--	--	--
15 - do	--	--	--	--	--	--	--	--	--	--	--	--
16 - do	870	860	860	850	820	780	830	--	420	350	340	380
17 - do	--	--	--	--	--	--	--	--	--	--	--	--
18, spent shale temp. - do	210	210	220	220	240	230	330	340	270	210	180	200
Operating characteristics:												
Degree of clinkering or coking 12/	Negl.	Negl.	Negl.	Negl.	Negl.	Mod.	Mod.	Severe	Negl.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/	Mod.	Mod.	Mod.	Mod.	Mod.	do.	do.	Mod.	Mod.	do.	do.	Severe
Other troubles - see note No.	--	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Sat.	Sat.	Sat.	Sat.

Run No.	136	137	138	139	140	141	142	143	144	145	146
Date	4-23	4-24	4-25	5-1-51	5-2	5-3	5-4	5-6	5-6	5-7	5-8
Duration - hr.	24	24	24	24	24	24	24	--	24	22	24
Retort type No.	I	I	I	I	I	I	I	I	I	I	I
Oil recovery system type No.	VI	VI	VI	VII	VII	VII	VII	VII	VII	VII	VII
Raw material flows:											
Raw shale-lb./hr.x sq.ft. bed area	214	211	196	174	236	372	457		258	260	251
Recycle gas 1/ std.c.f./ton raw shale	22,300	22,900	19,000	19,400	18,600	14,600	14,600		17,200	17,300	17,600
Air 2/ - do	2,790	3,860	6,230	3,980	4,800	3,700	3,190		3,960	3,900	4,580
NaCl brine added to shale gal./ton	1.0	0.0	1.0	1.0	1.0	1.0	1.0		3/4	1/2	1/4
Products recovered:											
Shale oil-vol.-pct. Fischer assay	50	49	96	89	95	80	73		85	85	94
Shale oil 3/ - gal./ton raw shale	10.3	9.9	19.2	17.7	19.7	16.7	15.2		17.6	18.1	19.5
Gas vented 2/ std.c.f./ton raw shale	3,640	3,460	7,800	5,180	6,450	5,090	4,340		5,500	5,360	6,490
Spent shale - lb./ton raw shale	1,760	1,860	1,570	1,700	1,580	1,700	1,720		1,660	1,660	1,640
Water condensed 4/ - do	24	23	14	45	39	28	26		34	40	33
Material output-wt.-pct. of input	97	100	94	100	97	100	100		99	100	98
Raw shale properties:											
Fischer assay - gal./ton	20.7	20.2	19.9	19.9	20.7	21.0	20.7		20.7	21.2	20.7
Mineral CO_2 - wt.-pct.	17.0	17.0	16.5	17.0	16.6	17.3	15.7		16.9	16.7	15.4
Particle size range - inch	3/8-1	3/8-1	3/8-1	1/2-1	1/2-1	1/2-1	1/2-1		1/2-1	1/2-1	1/2-1
Shale oil properties:											
Gravity - °API	24.0	25.1	19.6	21.3	20.5	21.0	21.4		21.2	22.5	20.7
Viscosity - S.S.U. at 130° F.	53	51	151	93	107	112	88		76	83	75
S.S.U. at 210° F.	36	36	51	44	48	47	44		42	46	39
Ramsbottom carbon 5/ - wt.-pct.	0.5	0.3	2.6	1.8	1.9	2.0	1.6		1.3	1.3	1.6
Gas properties:											
Moisture 6/ - vol.-pct.	14.4	13.2	14.4	12.2	14.8	17.4	17.1		14.8	14.7	14.4
Analysis, dry:											
CO_2 - vol.-pct.	19.7	15.2	17.5	21.5	23.0	21.3	20.1		24.4	21.4	25.5
Ill. 7/ - do	1.2	1.2	0.6	1.0	0.5	0.6	1.4		1.3	1.4	1.0
O_2 - do	0.0	1.5	1.0	1.5	1.2	3.6	2.4		0.5	1.5	0.1
CO - do	1.8	1.8	2.6	2.2	2.4	1.9	1.9		1.9	1.5	3.5
H_2 - do	3.7	2.8	3.4	1.5	2.4	1.6	2.3		2.6	4.0	2.9
Hydrocarbons 8/ - do	2.7	2.4	1.2	3.3	1.5	1.6	1.9		2.4	2.9	2.1
N_2 - do	70.9	75.1	73.5	69.0	69.0	69.4	70.0		66.9	67.3	64.9
Heating value, gross B.t.u./std.c.f.	81	74	49	68	50	45	64	No data taken	71	84	68
Spent shale properties:											
Fischer assay - gal./ton	6.3	8.9	0.0	0.3	0.0	1.8	3.4		0.0	0.0	0.3
Organic residue 9/ - wt.-pct.	3.25	3.87	1.22	2.29	1.78	1.82	1.87		1.97	1.90	1.65
Mineral CO_2 - do	16.6	16.6	10.0	14.4	12.3	14.4	15.9		14.9	15.5	14.2
Operating data:											
Press. drop/ft. bed height-in.H_2O	0.26	0.26	0.28	0.21	0.36	0.47	0.71		0.39	0.36	0.36
Retort gas outlet temp. - °F.	160	150	160	160	150	160	140		160	160	160
Recycle gas temp. 10/ - do	121	118	122	115	122	128	128		122	122	121
Air inlet temp. - do	85	82	88	81	82	83	85		84	85	83
Bed temps., thermocouple Nos.: 11/											
1 - °F.	470	--	460	500	440	370	260		440	470	480
2 - do	560	--	610	600	580	550	450		580	590	610
3 - do	--	--	--	--	--	--	--		--	--	--
4 - do	760	--	1,140	920	800	780	870		880	870	990
5 - do	800	--	1,110	910	930	1,140	1,120		1,110	1,090	1,120
6 - do	1,070	--	1,630	1,140	1,250	1,220	1,260		1,300	1,320	1,400
7 - do	870	--	1,250	880	1,140	840	860		890	910	1,020
8 - do	--	--	--	--	--	--	--		--	--	--
9 - do	750	--	1,520	740	780	720	810		730	750	880
10 - do	640	--	760	690	680	700	770		710	710	700
11 - do	570	--	640	610	580	600	640		620	620	610
12 - do	560	--	680	600	610	610	650		620	620	650
13 - do	0	--	1,030	910	950	890	900		930	930	930
14 - do	--	--	--	--	--	--	--		--	--	--
15 - do	--	--	--	--	--	--	--		--	--	--
16 - do	380	--	380	480	370	470	450		380	390	350
17 - do	--	--	--	--	--	--	--		--	--	--
18, spent shale temp. - do	180	--	200	220	240	290	300		250	330	220
Operating characteristics:											
Degree of clinkering or coking 12/	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.		Negl.	Negl.	Mod.
Degree of refluxing of oil 13/	Severe	Severe	do.	Mod.	Mod.	Mod.	Mod.		Mod.	Severe	Do.
Other troubles - see note No.	--	--	--	--	--	--	--	25	--	--	--
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.		Sat.	Sat.	Sat.

TABLE 19. - Results of oil-shale pilot plant tests

Run No.	147	148	149	150	151	152	153	154	155	156A	156B	157	158	159	160	161	162	163	164A	164B	165	166	167
Date	5-9	5-11	5-15-51	5-17	5-18	5-19	5-20	5-21	5-22	5-31-51	6-1	6-2	6-3	6-4	6-5	6-6	7-10	7-11	7-12	7-17	7-18	7-19	7-25
Duration--------hr.	24	—	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	16	12	24	24	24	24
Retort type No.	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	J	J	J	J	J	J	J
Oil recovery system type No.	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII
Raw material flows:																							
Raw shale-lb./hr. x sq. ft. bed area	273		209	198	215	225	258	290	372	203	208	213	206	203	220	263	255	451	300	260	272	258	242
Recycle gas [1]-std.c.f./ton raw shale	16,300		17,400	19,600	18,900	18,700	17,500	17,500	15,400	18,600	18,500	18,200	19,000	19,200	17,800	17,100	14,600	13,700	12,100	14,000	12,400	13,700	15,000
Air [2]--------do	4,190		6,220	5,830	4,860	4,120	5,230	5,230	4,480	6,430	5,610	5,500	5,670	5,790	5,240	5,040	5,090	3,720	4,500	5,020	4,430	4,300	5,290
NaCl brine added to shale---gal./ton	0.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	½	¼	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Products recovered:																							
Shale oil----vol.-pct. Fischer assay	86		97	97	98	92	93	97	91	95	94	96	94	88	93	89	91	48	80	84	81	90	87
Shale oil--------gal./ton raw shale	18.7		21.6	24.0	22.9	21.2	21.9	23.5	22.1	23.9	24.1	24.7	23.8	23.9	25.7	24.5	24.7	11.9	19.0	22.7	22.6	23.3	24.2
Gas vented [3]-std.c.f./ton raw shale	6,070		9,180	8,330	7,010	5,920	7,870	7,850	6,460	9,500	8,280	7,790	8,500	8,550	7,130	7,490	7,560	5,660	6,610	7,430	6,810	6,810	8,490
Spent shale--------lb./ton raw shale	1,700		1,480	1,520	1,520	1,540	1,480	1,520	1,540	1,430	1,620	1,490	1,480	1,470	1,500	1,500	1,540	1,700	1,560	1,540	1,580	1,540	1,420
Water condensed [4]--------do	33		8	11	9	10	7	8	7	3	2	3	2	2	2	1	2	1	2	2	1	1	2
Material output----wt.-pct. of input	101		97	97	95	94	95	96	95	95	101	94	95	95	94	95	97	98	94	97	97	97	94
Raw shale properties:																							
Fischer assay--------gal./ton	21.7		22.3	24.6	23.3	23.1	23.6	24.1	24.4	25.2	25.7	25.7	25.4	27.2	27.5	27.5	27.0	24.7	23.8	27.0	28.0	25.9	27.8
Mineral CO_2--------wt.-pct.	16.4		15.5	16.0	17.9	17.7	17.2	17.7	16.1	15.7	16.8	17.1	17.6	17.6	17.3	16.9	17.3	16.4	17.5	17.2	16.7	17.3	16.9
Particle size range--------inch	1/2-1		3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1
Shale oil properties:																							
Gravity--------°API	21.4		21.8	20.5	19.9	22.5	19.7	19.6	20.9	20.3	19.9	20.4	20.0	21.0	20.0	20.4	19.6	21.2	21.0	19.7	20.1	19.7	20.1
Viscosity--------S.S.U. at 130° F.	79		150	160	183	120	136	161	125	203	194	189	184	153	153	133	141	90	134	139	138	133	140
S.S.U. at 210° F.	42		68	53	53	60	50	60	42	59	59	55	57	70	57	49	66	48	49	52	50	51	50
Ramsbottom carbon [5]--------wt.-pct.	0.9		2.5	2.8	2.8	1.7	2.9	2.8	2.4	3.0	3.4	3.2	2.9	2.8	2.8	2.5	2.7	2.4	2.5	2.8	2.7	2.8	2.5
Gas properties:																							
Moisture [6]--------vol.-pct.	15.2		13.3	14.1	14.5	14.2	13.7	16.1	16.5	15.4	15.4	15.2	15.6	14.8	14.7	15.4	17.3	20.5	17.2	17.2	18.3	18.8	18.2
Analysis, dry:																							
CO_2--------vol.-pct.	24.0		30.1	27.7	25.3	24.4	29.0	26.3	24.6	30.8	27.8	29.4	28.9	28.5	23.1	27.4	25.8	—	22.8	27.0	26.2	27.5	26.9
Ill. [7]--------do	1.6		0.4	0.5	0.8	1.0	1.0	1.2	1.3	0.3	0.5	0.0	0.4	0.5	0.8	1.3	2.0	—	1.6	1.4	0.7	1.5	1.3
O_2--------do	0.0		0.9	0.8	1.4	2.6	0.7	1.3	1.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	—	0.9	0.0	0.8	0.7	0.3
CO--------do	2.8		3.1	2.6	2.9	2.5	3.1	2.2	2.5	3.7	3.5	3.0	3.8	4.1	3.9	4.9	2.7	—	3.2	2.6	3.5	2.5	3.9
H_2--------do	3.9		2.6	2.2	3.2	3.1	3.2	4.0	2.8	2.6	2.9	2.8	4.4	3.7	2.6	3.5	5.1	—	4.6	2.7	4.0	3.5	3.6
Hydrocarbons [8]--------do	3.3	No data taken	1.2	2.0	2.5	2.2	2.2	2.2	2.4	1.5	2.6	1.8	1.6	1.7	1.6	1.8	2.5	—	2.1	1.7	1.9	3.2	3.9
N_2--------do	64.4		61.7	64.2	63.9	64.2	60.8	62.8	65.4	61.1	62.7	63.0	60.9	61.5	67.9	61.1	61.9	—	64.8	64.6	62.9	61.1	60.1
Heating value, gross (calc.) B.t.u./std.c.f.	96		46	46	62	65	63	69	71	47	56	42	52	53	56	80	100	—	88	97	70	90	124
Spent shale properties:																							
Fischer assay--------gal./ton	0.3		0.5	1.1	0.5	0.3	0.3	0.5	0.8	0.3	0.3	0.3	0.3	0.0	0.4	0.5	0.0	9.6	3.1	1.1	0.3	0.3	0.0
Organic residue [9]--------wt.-pct.	1.69		0.56	0.30	1.71	2.24	1.57	1.16	2.55	1.31	1.80	1.72	1.68	1.73	1.67	2.20	2.91	3.54	2.95	2.05	1.45	1.29	1.45
Mineral CO_2--------do	14.5		7.8	10.3	12.3	14.0	11.1	12.5	12.3	8.1	10.2	10.3	10.3	9.0	11.6	13.2	14.1	15.9	14.2	16.1	14.9	15.1	14.7
Operating data:																							
Press. drop/ft. bed height---in. H_2O	0.37		0.43	0.31	0.38	0.37	0.46	0.56	0.82	0.43	0.35	0.28	0.33	0.32	0.30	0.53	0.59	1.48	0.54	0.42	0.38	0.41	0.50
Retort gas outlet temp.--------°F.	160		170	160	170	170	180	160	170	170	170	170	170	170	160	160	170	160	160	160	160	160	170
Recycle gas temp. [10]--------do	143		119	121	122	121	120	126	127	124	124	123	124	122	122	124	128	135	128	128	130	131	130
Air inlet temp.--------do	82		82	86	88	91	86	89	87	89	88	91	92	91	94	94	117	123	107	107	109	103	118
Bed temps., thermocouple Nos.: [11]																							
1--------°F.	470		550	510	540	480	530	520	510	540	510	520	490	500	450	430	300	370	270	300	270	290	450
2--------do	600		800	640	660	610	660	660	660	720	750	710	650	650	640	620	450	750	450	470	420	420	540
3--------do	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4--------do	870		1,450	830	890	760	790	880	1,070	1,290	1,220	1,210	1,000	940	930	890	810	1,020	940	910	810	870	680
5--------do	1,130		1,820	1,310	1,440	1,130	1,190	1,230	1,130	1,080	980	960	970	950	810	780	—	—	—	—	—	—	—
6--------do	1,430		1,340	1,010	1,120	1,010	990	1,120	1,090	1,260	1,550	1,400	1,350	1,250	1,230	1,190	1,050	920	1,110	1,180	1,150	1,140	970
7--------do	940		2,010	1,380	1,090	850	630	740	980	1,430	1,300	1,280	1,280	1,170	1,050	1,040	—	—	—	—	—	—	—
8--------do	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9--------do	790		1,750	1,110	790	820	530	650	830	1,700	1,670	1,690	1,650	1,460	56	—	910	890	910	960	1,010	940	970
10--------do	730		840	610	560	560	470	540	610	1,260	1,390	1,360	1,060	1,300	1,150	1,210	—	—	—	—	—	—	—
11--------do	630		690	540	490	500	430	450	520	1,360	1,550	1,470	1,130	1,260	1,280	1,160	670	560	580	590	620	610	650
12--------do	670		770	590	540	540	470	510	570	1,580	1,800	1,820	1,590	1,660	1,640	1,560	620	600	610	620	650	600	620
13--------do	950		1,110	890	850	850	810	900	930	1,130	1,090	1,080	1,050	1,060	1,050	1,040	670	580	670	670	680	690	630
14--------do	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15--------do	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16--------do	380		470	280	260	300	300	350	380	480	420	420	390	380	600	600	—	—	—	—	—	—	—
17--------do	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18, spent shale temp.--------do	240		230	230	190	190	200	230	250	200	200	230	250	230	230	250	290	250	280	260	280	270	260
Operating characteristics:																							
Degree of clinkering or coking [12]	Negl.		Severe	Mod.	Negl.	Mod.	Negl.	Negl.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Mod.	Negl.	Negl.	Mod.
Degree of refluxing of oil [13]	Mod.		Mod.	Negl.	do.	do.	do.	do.	Mod.	Negl.	do.	do.	do.	do.	do.	do.	do.	Mod.	Mod.	Negl.	do.	do.	Negl.
Other troubles--------see note No.	—	25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Evaluation of results [14]	Sat.		Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.

TABLE 20. - Results of oil-shale pilot plant tests

Run No.	168	169A	169B	170A	170B	170C	171	172	173A	173B	173C	174A
Date	7-26	7-27	7-28	7-29	7-30	7-31-51	8-1	8-11	8-12	8-13	8-14	8-23
Duration----hr.--	24	16	24	20	24	18	24	24	18	12	18	24
Retort type No.	J	J	J	J	J	J	J	J	J	J	J	K
Oil recovery system type No.	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VIII
Raw material flows:												
Raw shale-lb./hr. x sq. ft. bed area--	215	245	263	218	237	229	252	258	270	225	251	173
Recycle gas 1/-std.c.f./ton raw shale--	15,600	14,400	15,500	17,500	15,800	16,300	15,800	14,300	14,600	17,400	17,700	24,000
Air 2/----do----	5,500	4,490	4,780	4,600	4,210	4,360	3,510	4,800	4,160	4,970	5,210	5,100
NaCl brine added to shale---gal./ton--	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0
Products recovered:												
Shale oil----vol.-pct. Fischer assay--	90	60	68	60	85	87	86	75	70	74	93	91
Shale oil----gal./ton raw shale--	24.4	18.1	17.2	16.3	24.8	23.8	24.7	15.8	15.3	15.7	19.9	20.9
Gas vented 3/-std.c.f./ton raw shale--	8,220	6,620	7,200	6,750	6,210	6,310	5,110	7,130	5,690	7,230	7,690	7,040
Spent shale----lb./ton raw shale--	1,480	1,560	1,640	1,620	1,560	1,560	1,600	1,620	1,660	1,540	1,540	1,640
Water condensed 4/----do----	1	2	1	1	1	2	2	7	4	4	3	15
Material output----wt.-pct. of input--	95	94	98	96	95	95	96	97	96	94	96	99
Raw shale properties:												
Fischer assay----gal./ton--	27.0	30.1	25.4	27.0	29.1	27.5	28.8	21.0	21.7	21.2	21.4	23.1
Mineral CO_2----wt.-pct.--	--	16.5	15.5	17.1	15.2	15.7	17.1	17.6	14.1	17.5	17.1	14.8
Particle size range----inch--	3/8-1	3/8-1	3/16-½	3/16-½	3/8-1	1/4-1	3/8-1	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1
Shale oil properties:												
Gravity----°API--	20.3	22.5	22.2	20.4	19.0	19.6	19.9	19.1	18.4	17.0	15.2	18.6
Viscosity----S.S.U. at 130° F.--	124	76	76	104	149	144	112	114	110	157	194	132
5/ S.S.U. at 210° F.--	48	42	42	45	51	53	49	50	46	59	56	51
Ramsbottom carbon 5/----wt.-pct.--	2.3	1.4	0.5	1.7	2.7	2.7	2.3	2.9	3.1	3.6	4.2	3.0
Gas properties:												
Moisture 6/----vol.-pct.--	16.4	17.3	19.8	19.7	18.4	18.9	18.9	17.6	17.6	17.3	16.7	13.1
Analysis, dry:												
CO_2----vol.-pct.--	26.5	25.0	23.0	24.1	23.7	21.6	23.3	28.0	22.9	27.0	28.8	27.0
Ill. 7/----do----	1.1	1.6	1.8	1.4	1.9	1.1	1.2	1.1	1.1	0.9	0.8	0.6
O_2----do----	0.5	0.0	0.7	0.0	0.0	1.8	0.0	0.3	1.1	0.8	0.1	0.4
CO----do----	3.1	2.6	2.3	2.4	2.4	2.6	2.7	1.7	1.4	1.8	1.8	3.0
H_2----do----	3.6	3.9	4.5	4.1	4.1	3.9	3.3	2.5	2.0	1.9	2.3	2.0
Hydrocarbons 8/----do----	2.2	2.9	2.5	2.3	3.4	1.8	2.7	1.8	1.3	2.1	1.7	1.3
N_2----do----	64.7	64.0	65.2	65.7	64.5	67.2	66.8	64.6	70.2	65.5	64.5	65.7
Heating value, gross (calc.) B.t.u./std.c.f.--	78	96	99	88	108	77	78	60	41	55	52	46
Spent shale properties:												
Fischer assay----gal./ton--	0.0	2.1	5.5	7.3	0.5	1.3	2.4	2.6	1.3	2.1	0.8	0.3
Organic residue 9/----wt.-pct.--	1.72	5.29	5.41	5.83	5.43	5.5	4.4	6.0	4.0	4.8	4.7	4.4
Mineral CO_2----do----	12.0	14.7	14.2	14.2	13.1	14.7	16.5	14.7	13.3	14.3	12.3	12.7
Operating data:												
Press. drop/ft. bed height---in. H_2O--	0.52	0.62	1.51	1.39	0.60	0.6	0.4	0.6	0.7	0.6	0.5	0.3
Retort gas outlet temp.----°F.--	180	170	170	200	180	160	170	150	160	220	220	160
Recycle gas temp. 10/----do----	126	128	133	133	130	131	131	129	129	128	127	118
Air inlet temp.----do----	116	101	111	108	107	108	102	105	114	114	95	85
Bed temps., thermocouple Nos.: 11/												
1----°F.--	500	470	380	420	420	290	290	370	390	510	570	--
2----do----	600	590	510	660	640	510	450	730	780	1,120	1,010	450
3----do----	--	--	--	--	--	--	--	--	--	--	--	--
4----do----	770	640	990	860	780	720	560	800	900	900	910	--
5----do----	--	--	--	--	--	--	--	--	--	--	--	650
6----do----	1,030	1,100	1,060	840	1,000	960	970	970	920	1,010	1,020	900
7----do----	--	--	--	--	--	--	--	--	--	--	--	880
8----do----	--	--	--	--	--	--	--	--	--	--	--	--
9----do----	1,080	1,040	920	750	890	830	860	820	810	780	780	1,240
10----do----	--	--	--	--	--	--	--	--	--	--	--	810
11----do----	650	620	570	400	420	430	550	550	590	530	450	--
12----do----	700	690	610	490	520	510	640	640	630	780	900	260
13----do----	690	610	520	460	540	530	600	500	500	390	460	--
14----do----	--	--	--	--	--	--	--	--	--	--	--	180
15----do----	--	--	--	--	--	--	--	--	--	--	--	190
16----do----	--	--	--	--	--	--	--	--	--	--	--	--
17----do----	--	--	--	--	--	--	--	--	--	--	--	150
18, spent shale temp.----do----	250	240	250	200	210	230	220	240	250	200	210	130
Operating characteristics:												
Degree of clinkering or coking 12/----	Mod.	Negl.	Mod.	Mod.	Negl.	Mod.	Negl.	Mod.	Negl.	Negl.	Mod.	Mod.
Degree of refluxing of oil 13/----	Negl.	Severe	Severe	do.	do.	Negl.	Mod.	Negl.	do.	do.	Negl.	Negl.
Other troubles----see note No.--	--	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/----	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.

Run No.	174B	175A	175B	175C	176A	176B	176C	177	178	179	180
Date	8-24	8-25	8-26	8-27	8-28	8-29	8-29	8-30	8-31	9-1	9-1
Duration----hr.--	18	12	24	24	24	14	18	18	14	18	18
Retort type No.	K	K	K	K	K	K	K	K	K	K	K
Oil recovery system type No.	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
Raw material flows:											
Raw shale-lb./hr. x sq. ft. bed area--	213	210	246	226	225	187	208	203	191	192	219
Recycle gas 1/-std.c.f./ton raw shale--	19,800	19,900	17,300	19,100	18,100	21,700	19,600	20,500	22,100	21,300	18,900
Air 2/----do----	4,120	4,130	3,550	3,950	4,340	5,230	4,700	4,670	4,400	5,060	4,440
NaCl brine added to shale---gal./ton--	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0
Products recovered:											
Shale oil----vol.-pct. Fischer assay--	--	--	88	79	77	98	99	96	85	92	82
Shale oil----gal./ton raw shale--	18.2	19.5	24.1	23.3	22.8	28.2	30.1	29.1	26.7	21.9	17.2
Gas vented 3/-std.c.f./ton raw shale--	5,740	5,720	4,780	5,510	6,340	7,490	6,730	7,030	6,860	7,150	5,870
Spent shale----lb./ton raw shale--	1,640	1,740	1,640	1,640	1,620	1,620	1,500	1,600	1,600	1,600	1,640
Water condensed 4/----do----	8	10	9	5	5	13	9	9	13	14	9
Material output----wt.-pct. of input--	96	101	98	97	98	101	95	101	101	98	95
Raw shale properties:											
Fischer assay----gal./ton--	--	--	27.3	29.4	29.5	28.7	30.3	30.4	31.5	23.8	21.1
Mineral CO_2----wt.-pct.--	--	--	16.7	15.4	16.3	--	--	--	--	--	--
Particle size range----inch--	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	1/2-1	1/4-1¼	1/4-1½
Shale oil properties:											
Gravity----°API--	21.8	22.4	22.6	22.3	20.9	20.0	20.0	19.6	19.9	19.6	20.0
Viscosity----S.S.U. at 130° F.--	77	--	72	72	98	128	135	150	137	134	127
5/ S.S.U. at 210° F.--	41	--	42	42	49	49	49	51	50	49	51
Ramsbottom carbon 5/----wt.-pct.--	1.3	--	1.1	1.0	2.0	2.5	2.8	2.5	2.8	2.7	2.5
Gas properties:											
Moisture 6/----vol.-pct.--	12.8	14.4	13.9	12.8	14.7	14.6	14.6	14.6	14.8	16.0	16.8
Analysis, dry:											
CO_2----vol.-pct.--	25.6	--	22.0	21.5	22.9	24.0	22.8	27.3	26.5	25.7	22.2
Ill. 7/----do----	1.4	--	2.0	1.7	1.8	1.2	1.4	1.4	0.7	1.0	1.0
O_2----do----	0.2	--	0.5	0.7	0.3	0.0	0.4	0.0	0.0	0.0	0.0
CO----do----	2.0	--	2.3	2.1	3.9	3.2	3.2	2.4	3.1	1.7	0.4
H_2----do----	3.6	--	3.7	4.4	4.3	4.9	4.6	4.9	4.4	2.0	2.0
Hydrocarbons 8/----do----	2.6	--	4.1	4.7	3.2	2.5	2.9	2.6	2.7	2.9	2.6
N_2----do----	64.6	--	65.4	64.9	63.6	64.2	64.7	61.4	62.6	66.7	71.8
Heating value, gross (calc.) B.t.u./std.c.f.--	85	--	113	114	100	86	89	81	74	64	58
Spent shale properties:											
Fischer assay----gal./ton--	1.1	1.3	0.8	1.1	3.7	1.1	0.0	0.5	2.4	--	2.4
Organic residue 9/----wt.-pct.--	4.7	4.9	4.6	4.6	--	--	--	--	--	--	--
Mineral CO_2----do----	14.4	14.8	15.7	13.3	--	--	--	--	--	--	--
Operating data:											
Press. drop/ft. bed height---in. H_2O--	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.6
Retort gas outlet temp.----°F.--	150	140	140	160	160	150	150	150	150	150	150
Recycle gas temp. 10/----do----	117	121	120	117	122	122	122	122	122	125	127
Air inlet temp.----do----	89	103	93	83	87	79	84	82	81	85	83
Bed temps., thermocouple Nos.: 11/											
1----°F.--	--	--	--	--	200	160	160	170	170	180	160
2----do----	450	330	380	450	440	540	560	550	520	470	530
3----do----	--	--	--	--	--	--	--	--	--	--	--
4----do----	--	--	--	--	--	--	--	--	--	--	--
5----do----	650	610	620	610	680	730	620	700	740	860	890
6----do----	910	760	740	980	970	950	680	1,020	1,130	1,020	990
7----do----	830	730	710	830	750	760	730	740	710	850	880
8----do----	--	--	--	--	--	--	--	--	--	--	--
9----do----	1,240	1,170	1,220	1,210	1,170	1,180	1,290	1,460	1,550	900	880
10----do----	910	1,020	1,040	1,010	980	940	1,060	1,000	950	890	830
11----do----	--	--	--	--	--	--	--	--	--	--	--
12----do----	470	690	640	600	600	490	560	740	660	770	810
13----do----	--	--	--	--	--	--	--	--	--	--	--
14----do----	310	460	450	380	450	370	330	510	540	510	530
15----do----	420	610	610	480	480	340	380	430	480	550	600
16----do----	--	--	--	--	--	--	--	--	--	--	--
17----do----	250	360	390	270	370	240	200	330	470	580	640
18, spent shale temp.----do----	150	200	200	170	190	150	140	150	160	180	190
Operating characteristics:											
Degree of clinkering or coking 12/----	Negl.	Negl.	Negl.	Negl.	Negl.	Mod.	Mod.	Negl.	Negl.	Mod.	Mod.
Degree of refluxing of oil 13/----	Mod.	Severe	Severe	Severe	Mod.	Negl.	Negl.	do.	do.	Negl.	Negl.
Other troubles----see note No.--	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/----	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.

TABLE 21. - Results of oil-shale pilot plant tests

Run No.	181	182	183	184	185	186A	186B	187	188	189	190	191
Date	9-5	9-6	9-7	9-8	9-9	9-10	9-11	9-12	9-13	9-15	9-16	9-17
Duration--hr.	18	18	24	24	24	24	24	24	24	18	18	--
Retort type No.	K	K	K	K	K	K	K	K	K	K	K	K
Oil recovery system type No.	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
Raw material flows:												
Raw shale--lb./hr. x sq. ft. bed area	218	231	230	247	229	211	229	235	243	219	234	
Recycle gas 1/-std.c.f./ton raw shale	19,600	19,300	18,100	15,900	18,200	18,900	17,400	18,700	20,400	20,800	22,800	
Air 2/--do.	4,260	4,170	4,250	3,720	3,890	4,670	4,300	4,580	4,490	4,970	5,290	
Products recovered:												
Shale oil--vol.-pct. Fischer assay	75	72	80	81	82	87	81	86	89	85	82	No data taken
Shale oil--gal./ton raw shale	22.9	22.2	24.0	24.0	25.9	27.9	25.7	27.1	27.1	25.4	25.1	
Gas vented 3/-std. c.f./ton raw shale	6,020	6,010	6,800	5,260	5,590	6,710	6,230	6,930	6,400	6,670	7,420	
Spent shale--lb./ton raw shale	1,600	1,600	1,600	1,600	1,640	1,580	1,620	1,620	1,620	1,640	1,600	
Water condensed 4/--do.	16	17	21	16	20	17	20	17	5	13	5	
Material output--wt.-pct. of input	97	96	99	97	99	98	99	101	99	99	98	
Raw shale properties:												
Fischer assay--gal./ton	30.7	31.0	30.1	29.7	31.6	32.1	31.8	31.5	30.4	29.8	30.8	
Mineral CO_2--wt.-pct.	--	--	--	--	--	--	--	--	--	--	--	
Particle size range--inch	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1	
Shale oil properties:												
Gravity--°API	21.7	21.3	20.8	19.5	19.9	20.6	20.2	22.4	20.7	21.8	22.7	
Viscosity--S.S.U. at 130° F.	77	83	111	134	143	102	117	93	97	49	73	
S.S.U. at 210° F.	41	48	76	49	56	50	49	45	48	46	41	
Ramsbottom carbon 5/--wt.-pct.	1.5	1.6	2.6	3.3	2.7	2.0	2.5	1.9	1.8	1.4	1.0	
Gas properties:												
Moisture 6/--vol.-pct.	13.2	14.3	13.5	12.9	12.5	12.5	12.2	12.1	12.8	11.7	12.7	
Analysis, dry:												
CO_2--vol.-pct.	22.1	22.6	24.5	23.5	21.8	22.3	22.5	23.4	22.2	22.1	20.3	
Ill. 7/--do.	1.0	1.2	1.9	1.3	1.7	1.2	1.3	1.0	0.8	0.2	1.4	
O_2--do.	0.0	0.0	0.0	0.0	0.0	0.5	0.3	0.0	0.6	0.0	0.1	
CO--do.	4.2	4.3	3.2	4.8	4.9	5.1	5.6	6.1	5.2	5.2	5.2	
H_2--do.	5.1	5.7	6.1	4.0	4.7	5.2	4.9	6.4	6.0	3.8	5.8	
Hydrocarbons 8/--do.	3.0	2.4	7.1	2.2	3.9	2.9	3.3	3.6	2.0	2.3	2.8	
N_2--do.	64.6	63.8	57.2	64.2	63.0	62.8	62.1	59.5	63.2	66.4	64.4	
Heating value, gross (calc.) B.t.u./std.c.f.	85	90	131	81	99	89	96	108	84	66	95	
Spent shale properties:												
Fischer assay--gal./ton	3.4	2.9	3.7	5.0	6.8	2.4	2.6	1.6	1.9	0.8	0.8	
Organic residue 9/--wt.-pct.	--	--	--	--	--	--	--	--	--	--	--	
Mineral CO_2--do.	--	--	--	--	--	--	--	--	--	--	--	
Operating data:												
Press. drop/ft. bed height--in. H_2O	0.5	0.5	0.5	0.4	0.3	0.4	0.4	0.5	0.7	0.7	0.9	
Retort gas outlet temp.--°F.	130	130	130	120	120	120	120	120	160	160	200	
Recycle gas temp. 10/--do.	118	121	119	117	116	116	115	115	117	114	117	
Air inlet temp.--do.	106	111	106	100	99	106	102	103	105	100	104	
Bed temps., thermocouple Nos.: 11/												
1--°F.	200	210	130	120	120	120	110	120	170	160	170	
2--do.	290	300	210	130	120	200	150	230	470	530	570	
3--do.	--	--	--	--	--	--	--	--	--	--	--	
4--do.	--	--	--	--	--	--	--	--	--	--	--	
5--do.	520	570	540	440	420	540	510	560	630	620	630	
6--do.	670	670	660	600	610	660	630	640	610	760	730	
7--do.	680	680	650	520	520	650	610	670	870	880	890	
8--do.	--	--	--	--	--	--	--	--	--	--	--	
9--do.	830	840	840	740	730	830	790	870	850	860	850	
10--do.	820	830	870	780	780	840	790	900	880	860	870	
11--do.	--	--	--	--	--	--	--	--	--	--	--	
12--do.	660	700	730	720	730	740	770	810	680	620	600	
13--do.	--	--	--	--	--	--	--	--	--	--	--	
14--do.	460	450	510	660	600	490	590	540	450	470	520	
15--do.	460	450	510	650	600	500	590	540	460	480	530	
16--do.	--	--	--	--	--	--	--	--	--	--	--	
17--do.	300	300	400	510	440	330	420	370	330	270	270	
18, spent shale temp.--do.	190	190	210	230	210	180	200	190	170	150	150	
Operating characteristics:												
Degree of clinkering or coking 12/	Mod.	Negl.	Mod.	Negl.	Negl.	Mod.	Mod.	Mod.	Mod.	Severe	Severe	
Degree of refluxing of oil 13/	do.	Mod.	do.	do.	do.	do.	Negl.	Severe	do.	do.	do.	
Other troubles--see note No.	--	--	--	--	--	--	--	--	--	--	--	26
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	

Run No.	192A	192B	193A	193B	194A	194B	195A	195B	196A	196B	197A
Date	9-23	9-24	9-25	9-26	9-28	9-29	10-1	10-2	10-5	10-6	10-7
Duration--hr.	24	24	24	24	17	24	24	24	24	24	24
Retort type No.	K	K	K	K	K	K	K	K	K	K	K
Oil recovery system type No.	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
Raw material flows:											
Raw shale--lb./hr. x sq. ft. bed area	232	229	233	243	262	234	232	225	234	227	230
Recycle gas 1/-std.c.f./ton raw shale	18,800	18,700	18,400	17,500	15,300	17,200	17,400	17,900	17,400	17,800	18,100
Air 2/--do.	3,810	3,870	3,800	3,660	3,840	4,280	4,340	4,470	4,300	4,400	4,200
Products recovered:											
Shale oil--vol.-pct. Fischer assay	84	79	80	78	82	90	86	90	88	102	91
Shale oil--gal./ton raw shale	20.2	19.6	19.4	19.4	19.4	23.1	20.4	22.3	21.7	22.9	22.4
Gas vented 3/-std. c.f./ton raw shale	5,210	5,580	5,430	5,130	5,240	6,130	6,540	6,500	6,400	6,430	5,900
Spent shale--lb./ton raw shale	1,680	1,680	1,700	1,700	1,600	1,540	1,620	1,640	1,620	1,620	1,620
Water condensed 4/--do.	11	12	8	11	16	21	21	23	20	11	16
Material output--wt.-pct. of input	97	98	99	99	95	95	98	99	98	98	98
Raw shale properties:											
Fischer assay--gal./ton	24.0	24.7	24.2	25.0	23.6	25.7	23.7	24.8	24.6	22.4	24.7
Mineral CO_2--wt.-pct.	--	--	--	--	--	--	--	--	--	--	--
Particle size range--inch	1/4-1	1/4-1	3/8-1	3/8-1	1/2-1	1/2-1	1/4-1	1/4-1	3/8-1	3/8-1	3/8-1
Shale oil properties:											
Gravity--°API	22.0	22.1	21.9	21.6	19.3	19.5	19.7	19.0	19.1	20.4	19.7
Viscosity--S.S.U. at 130° F.	92	90	95	88	135	129	126	140	131	140	129
S.S.U. at 210° F.	45	45	47	48	53	52	52	54	53	54	56
Ramsbottom carbon 5/--wt.-pct.	1.6	2.2	1.7	1.7	3.3	2.9	2.5	3.2	3.3	2.8	2.6
Gas properties:											
Moisture 6/--vol.-pct.	11.5	12.2	13.0	13.1	12.9	12.6	14.0	14.0	15.1	14.3	13.5
Analysis, dry:											
CO_2--vol.-pct.	21.1	24.5	22.6	23.8	--	24.4	27.1	23.5	25.7	26.4	25.0
Ill. 7/--do.	1.0	1.0	1.0	1.4	--	1.2	1.1	1.7	0.9	0.7	0.7
O_2--do.	0.4	0.1	0.3	0.0	--	0.4	0.1	0.9	0.4	0.5	1.0
CO--do.	3.9	2.8	2.8	3.0	--	4.2	3.2	3.5	3.1	3.4	2.8
H_2--do.	6.1	4.5	5.1	4.3	--	4.7	5.1	4.7	5.1	4.0	4.4
Hydrocarbons 8/--do.	2.2	4.7	4.5	2.8	--	2.1	2.3	2.3	2.1	1.8	2.1
N_2--do.	65.3	62.4	63.7	64.7	--	63.0	61.1	63.4	62.7	63.2	64.0
Heating value, gross (calc.) B.t.u./std.c.f.	80	98	107	86	--	84	73	83	76	68	68
Spent shale properties:											
Fischer assay--gal./ton	1.1	2.1	1.1	1.6	3.1	0.3	1.1	1.3	2.9	0.3	0.5
Organic residue 9/--wt.-pct.	--	--	--	--	--	--	--	--	--	--	--
Mineral CO_2--do.	--	--	--	--	--	--	--	--	--	--	--
Operating data:											
Press. drop/ft. bed height--in. H_2O	0.4	0.5	0.4	0.4	0.3	0.3	0.5	0.4	0.3	0.3	0.3
Retort gas outlet temp.--°F.	140	140	140	150	120	130	130	130	130	130	130
Recycle gas temp. 10/--do.	113	115	119	118	119	118	122	122	124	122	120
Air inlet temp.--do.	78	81	83	83	78	77	78	79	80	75	72
Bed temps., thermocouple Nos.: 11/											
1--°F.	140	140	140	160	120	140	130	130	130	130	130
2--do.	410	270	340	390	200	260	200	140	130	170	190
3--do.	--	--	--	--	--	--	--	--	--	--	--
4--do.	--	--	--	--	--	--	--	--	--	--	--
5--do.	600	570	600	580	700	610	620	580	560	600	600
6--do.	740	730	750	720	880	740	720	760	750	780	800
7--do.	840	830	850	890	1,220	840	780	880	720	830	840
8--do.	--	--	--	--	--	--	--	--	--	--	--
9--do.	940	910	970	900	1,030	950	800	980	1,120	1,130	1,110
10--do.	880	810	870	820	910	850	840	850	970	1,020	950
11--do.	--	--	--	--	--	--	--	--	--	--	--
12--do.	630	660	670	660	720	550	730	690	690	700	670
13--do.	--	--	--	--	--	--	--	--	--	--	--
14--do.	360	430	400	400	500	370	420	540	350	370	370
15--do.	380	440	420	410	510	370	440	540	380	400	390
16--do.	--	--	--	--	--	--	--	--	--	--	--
17--do.	320	350	340	320	440	270	460	410	320	300	280
18, spent shale temp.--do.	150	170	160	170	210	150	200	190	170	170	170
Operating characteristics:											
Degree of clinkering or coking 12/	Negl.	Negl.	Mod.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/	Mod.	Mod.	do.	Mod.	Negl.	do.	do.	do.	do.	do.	Do.
Other troubles--see note No.	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.

TABLE 22. - Results of oil-shale pilot plant tests

Run No.	197B	198	199A	199B	200A	200B	201	202A	202B	202C	202D	202E	203A	203B	204A	204B	205A	205B	205C	206A	206B	207A	207B
Date	10-8	10-9-51	10-9	10-10	10-11	10-12	10-18	10-19	10-22	10-23	10-24	10-25	10-28	10-29	11-1	11-2	11-4	11-6	11-6	11-8	11-10	11-15	11-16
Duration----hr.	24	12	24	24	24	24		24	24	24	24	24	24	24	24	18	24	12	36	24	24	24	24
Retort type No.	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K
Oil recovery system type No.	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
Raw material flows:																							
Raw shale-lb./hr. x sq. ft. bed area	229	217	224	219	227	231		246	230	222	228	235	232	238	224	220	236	209	230	243	225	218	231
Recycle gas 1/-std.c.f./ton raw shale	18,100	18,100	18,600	19,000	18,300	17,300		15,800	17,300	17,300	17,500	16,900	17,900	17,400	18,700	19,200	17,900	19,600	18,300	17,300	17,500	18,200	17,300
Air 2/----do	4,200	4,150	4,350	4,380	3,790	3,910		3,620	3,940	4,010	3,880	3,790	3,580	3,470	3,700	3,850	3,490	4,150	3,690	3,590	3,640	3,170	3,170
Products recovered:																							
Shale oil----vol.-pct. Fischer assay	92	97	89	97	92	90		74	93	100	97	93	94	89	90	97	88	95	86	91	91	81	81
Shale oil----gal./ton raw shale	24.1	24.6	26.6	29.0	26.8	26.4		23.1	27.3	29.5	28.7	27.9	26.4	26.3	26.4	30.1	25.8	30.9	27.6	27.8	29.2	23.9	25.5
Gas vented 3/-std.c.f./ton raw shale	6,000	6,320	6,390	6,550	5,520	5,420		4,830	5,750	5,940	5,680	5,660	5,380	4,610	4,420	4,970	5,110	5,620	5,220	5,050	5,210	4,330	4,360
Spent shale----lb./ton raw shale	1,600	1,600	1,580	1,640	1,600	1,560		1,620	1,640	1,620	1,580	1,500	1,660	1,720	1,600	1,600	1,620	1,680	1,600	1,580	1,640	1,720	1,600
Water condensed 4/----do	14	10	13	9	102	117		145	35	26	19	24	51	48	41	40	46	50	34	32	27	43	31
Material output----wt.-pct. of input	98	99	98	101	101	100		101	102	101	98	95	101	103	96	99	101	105	99	98	101	101	96
Raw shale properties:																							
Fischer assay----gal./ton	26.2	25.4	29.8	29.9	29.2	29.2		31.1	29.4	29.5	29.6	30.1	28.0	29.5	29.5	31.0	29.2	32.5	31.9	30.7	32.0	29.7	31.6
Mineral CO_2----wt.-pct.	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Particle size range----inch	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1		3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	1/4-1	1/4-1	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	3/8-1¼	3/8-1¼
Shale oil properties:																							
Gravity----°API	19.3	19.9	20.6	19.8	20.0	20.0		19.5	19.9	20.0	20.1	20.1	20.1	20.0	20.4	20.6	19.6	19.8	20.0	20.2	20.2	20.6	20.1
Viscosity----S.S.U. at 130° F.	122	131	124	127	118	118		118	135	138	129	138	114	115	128	121	135	127	112	129	120	127	126
S.S.U. at 210° F.	48	49	50	50	49	49		46	50	52	50	50	47	52	49	47	50	48	47	50	47	48	48
Ramsbottom carbon 5/----wt.-pct.	2.5	2.7	2.7	2.8	2.8	2.8		2.2	2.5	2.5	2.2	2.8	2.6	2.1	2.2	2.1	3.9	2.2	2.1	2.2	2.0	2.5	2.5
Gas properties:																							
Moisture 6/----vol.-pct.	13.2	13.4	13.9	13.8	11.7	10.8		13.8	11.9	12.1	12.8	12.7	12.1	12.5	10.2	11.0	13.7	12.7	13.1	13.0	13.4	12.0	11.8
Analysis, dry:																							
CO_2----vol.-pct.	25.0	27.1	24.1	24.2	21.4	21.0		17.6	25.1	24.3	24.5	25.0	19.8	18.4	19.6	16.1	23.7	21.0	21.4	21.7	20.0	20.3	20.3
Ill. 7/----do	1.0	0.9	1.1	1.4	1.0	1.1		1.7	1.4	1.1	1.2	1.3	1.5	1.0	1.4	1.2	1.7	1.2	1.0	1.1	1.3	1.7	2.1
O_2----do	1.0	0.7	0.7	0.2	1.0	0.5		0.2	0.3	0.9	0.5	0.0	0.6	1.8	1.0	1.9	0.5	1.6	0.9	0.8	2.5	0.5	0.4
CO----do	3.7	4.1	3.9	5.1	4.6	4.7		6.1	4.9	4.9	4.3	5.1	5.0	3.5	5.0	4.6	4.1	3.8	4.1	4.0	4.5	3.8	3.6
H_2----do	4.0	4.7	5.1	5.8	4.1	4.9	No data taken	6.4	4.1	5.8	5.2	5.6	5.7	4.7	4.2	3.2	3.3	2.8	5.0	5.3	4.5	4.8	4.7
Hydrocarbons 8/----do	1.9	2.2	2.6	2.4	3.3	4.1		3.3	2.7	2.3	2.7	2.4	3.2	2.7	2.8	4.2	4.5	2.7	3.2	2.6	3.2	2.9	3.2
N_2----do	63.4	60.2	62.5	60.9	64.6	63.7		64.7	61.5	60.7	61.6	60.6	64.2	67.9	66.0	68.8	62.2	66.9	64.4	64.5	64.0	65.9	65.7
Heating value, gross (calc.) B.t.u./std.c.f.	72	75	90	90	74	104		113	88	84	86	82	104	75	89	105	113	82	88	84	88	98	100
Spent shale properties:																							
Fischer assay----gal./ton	0.3	0.5	0.3	0.5	0.5	0.8		4.5	0.3	0.3	0.3	0.3	0.5	1.3	0.7	2.9	2.2	0.5	1.5	1.2	2.6	5.2	2.6
Organic residue 9/----wt.-pct.	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mineral CO_2----do	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Operating data:																							
Press. drop/ft. bed height---in. H_2O	0.3	0.41	0.42	0.42	0.29	0.28		0.35	--	--	--	--	--	--	0.36	0.45	0.32	0.12	0.20	0.60	0.60	0.27	0.28
Retort gas outlet temp.----°F.	140	130	130	150	120	120		130	120	120	120	120	130	130	120	120	130	130	130	120	120	120	120
Recycle gas temp. 10/----do	119	150	121	121	115	112		120	116	117	118	118	117	118	111	116	124	120	121	120	121	118	117
Air inlet temp.----do	75	77	75	77	70	70		84	81	83	86	81	80	82	66	70	74	74	78	82	82	77	75
Bed temps., thermocouple Nos.: 11/																							
1----°F.	130	140	140	160	130	120		130	120	120	120	130	130	130	120	120	130	130	130	130	130	130	130
2----do	260	280	320	370	280	180		240	180	210	240	210	190	230	200	250	220	220	220	190	150	140	140
3----do	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4----do	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5----do	630	640	690	720	750	620		730	570	580	600	600	550	640	560	610	630	590	690	590	530	480	500
6----do	880	910	960	1,040	640	790		900	740	740	750	770	730	870	710	760	740	770	1,000	750	760	770	720
7----do	880	900	950	980	850	800		870	760	780	820	820	810	850	740	790	710	820	930	810	740	670	760
8----do	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9----do	1,120	1,140	1,110	1,030	1,050	1,040		980	970	970	940	950	930	990	910	920	900	910	950	940	750	870	960
10----do	850	880	830	750	850	900		700	850	840	820	840	680	810	770	730	720	670	690	750	660	750	780
11----do	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12----do	660	660	660	640	--	710		800	760	760	700	750	660	720	640	500	650	640	560	660	580	570	530
13----do	--	--	--	--	660	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14----do	300	290	290	300	380	500		350	590	590	580	600	540	480	530	540	540	600	580	510	590	460	510
15----do	320	300	310	320	390	500		630	570	560	500	520	400	520	390	350	500	440	460	440	450	460	420
16----do	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17----do	240	230	220	240	270	300		270	360	350	340	350	330	320	310	340	410	400	440	310	380	360	400
18, spent shale temp.----do	150	150	150	150	150	160		300	220	210	220	200	210	230	170	180	220	190	220	190	200	230	220
Operating characteristics:																							
Degree of clinkering or coking 12/	Negl.	Negl.	Mod.	Mod.	Negl.	Negl.		Mod.	Negl.	Negl.	Mod.	Negl.	Mod.	Mod.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Mod.	Negl.	Negl.
Degree of refluxing of oil 13/	do.	do.	Negl.	Negl.	do.	do.		Negl.	do.	do.	Negl.	do.	Negl.	Negl.	do.	Negl.	do.	do.	do.	do.	Negl.	do.	Do.
Other troubles----see note No.	--	--	--	--	--	--	27	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.		Sat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Sat.	Sat.	Sat.	Unsat.	Sat.	Sat.	Sat.	Sat.	Sat.

TABLE 23. - Results of oil-shale pilot plant tests

Run No.	208A	208B	209	210A	210B	210C	210D	211A	211B	212A	212B	213A	213B	214A	214B	215A	215B	215C	215D	216A	216B	216C	217A
Date	11-17	11-18	11-20	11-24	11-25	11-28	11-28	11-26	11-27	11-29	12-1	12-1	12-2	12-5	12-6	12-7	12-8	12-9	12-10	12-13-9/	12-14	12-15	12-16
Duration----------hr.--	24	24	24	24	24	24	24	24	24	24	18	24	18	24	24	24	24	24	12	24	24	12	24
Retort type No.	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K	K
Oil recovery system type No.	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
Raw material flows:																							
Raw shale-lb./hr. x sq. ft. bed area--	225	223	244	229	229	225	232	228	230	226	227	223	248	224	235	222	219	216	238	223	225	241	223
Recycle gas 1/-std.c.f./ton raw shale--	17,500	17,600	16,300	17,400	17,500	17,900	17,000	17,600	17,300	17,600	17,300	17,900	16,300	17,700	16,800	17,200	17,800	18,300	16,300	17,800	17,700	16,500	17,700
Air 2/----------do----	3,250	3,530	3,200	3,550	3,580	3,650	3,550	3,700	3,560	3,810	3,830	3,930	3,520	3,940	3,930	3,980	4,030	4,110	3,740	4,150	4,120	3,840	4,140
Products recovered:																							
Shale oil----vol.-pct. Fischer assay--	73	86	84	79	92	92	91	87	82	89	86	82	81	89	92	90	88	99	80	92	96	90	98
Shale oil---------gal./ton raw shale--	20.8	25.8	24.7	22.2	28.2	25.9	25.3	26.2	23.3	24.8	23.5	23.1	23.4	24.0	27.0	24.9	25.6	30.3	24.5	28.0	28.4	26.2	29.1
Gas vented 3/-std.c.f./ton raw shale--	4,300	4,790	4,400	5,160	5,100	5,020	5,450	5,130	5,140	5,130	5,240	5,360	4,980	5,840	5,460	5,730	5,730	5,620	5,240	5,780	5,780	5,370	6,050
Spent shale--------lb./ton raw shale--	1,740	1,620	1,680	1,680	1,600	1,580	1,500	1,600	1,620	1,620	1,580	1,620	1,620	1,620	1,580	1,640	1,640	1,620	1,560	1,620	1,580	1,460	1,640
Water condensed 4/----------do----	41	37	32	31	30	31	31	36	37	26	31	24	18	23	22	22	24	17	12	33	25	22	27
Material output----wt.-pct. of input--	101	98	99	100	99	97	95	97	98	97	96	97	95	99	96	100	99	99	94	100	98	92	102
Raw shale properties:																							
Fischer assay----------gal./ton--	28.6	30.1	29.5	27.9	30.6	28.0	27.9	30.2	28.6	27.9	27.2	28.1	29.0	27.1	29.4	27.6	29.0	30.6	30.6	30.5	29.6	29.1	29.7
Mineral CO_2----------wt.-pct.--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Particle size range---------inch--	3/8-1¼	3/8-1¼	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	3/8-1	1/4-1	1/4-1	1/4-1¼	1/4-1¼	1/4-1	1/4-1	1/4-1	1/4-1	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼
Shale oil properties:																							
Gravity----------°API--	19.5	19.4	20.1	20.5	20.3	20.0	20.0	20.7	20.3	19.9	20.7	19.9	20.0	19.5	19.6	20.1	20.0	20.3	19.8	19.9	20.1	20.0	20.0
Viscosity--------S.S.U. at 130° F.--	131	128	121	125	125	136	135	118	129	148	130	132	159	174	138	138	133	130	129	130	121	123	127
S.S.U. at 210° F.--	49	48	48	49	52	51	50	48	48	50	49	50	48	50	54	50	64	52	49	50	47	49	56
Ramsbottom carbon 5/--------wt.-pct.--	2.7	2.6	2.6	2.3	2.3	2.4	2.4	2.0	2.2	2.6	1.9	2.0	2.5	2.5	2.4	2.5	2.4	2.2	2.4	2.4	2.4	2.3	2.6
Gas properties:																							
Moisture 6/----------vol.-pct.--	13.1	12.7	14.0	12.3	11.7	11.7	12.3	12.0	12.3	12.5	12.7	12.9	12.5	12.3	11.9	11.2	10.4	10.2	10.6	10.2	10.0	10.0	11.0
Analysis, dry:																							
CO_2----------vol.-pct.--	19.3	19.5	17.6	25.1	22.8	21.9	27.9	22.6	24.2	21.1	21.2	22.1	22.0	24.6	22.2	24.6	23.9	22.2	19.8	23.6	23.2	23.7	24.9
Ill. 7/----------do----	1.9	1.7	2.2	1.1	1.4	1.2	1.4	1.4	1.4	1.5	1.0	1.0	1.4	1.2	1.3	1.2	1.2	1.1	2.4	1.0	1.1	1.2	1.3
O_2----------do----	0.5	0.6	0.4	1.1	0.2	0.8	0.0	0.2	0.4	0.7	0.5	0.3	0.8	0.0	0.0	0.0	0.0	0.3	0.1	1.3	0.9	0.2	0.0
CO----------do----	3.7	3.7	3.8	3.9	4.9	4.0	4.3	4.8	4.4	2.7	3.7	3.2	3.8	4.0	4.7	4.3	4.8	4.7	5.5	4.5	4.6	4.3	4.6
H_2----------do----	3.0	4.9	5.9	4.5	4.9	4.4	4.7	4.7	4.6	3.7	4.3	3.9	4.8	5.3	5.0	4.9	5.1	5.0	5.8	3.7	4.3	4.6	5.1
Hydrocarbons 8/----------do----	2.8	3.0	3.3	2.3	2.9	2.4	2.6	3.4	2.5	3.1	2.9	2.7	3.3	3.9	2.4	3.1	2.8	2.7	3.5	2.9	3.4	3.2	3.4
N_2----------do----	68.8	66.6	66.8	62.0	62.9	65.3	59.1	62.9	62.5	67.2	66.4	66.8	63.9	61.0	64.4	61.9	62.2	64.0	63.0	63.0	62.5	62.7	60.7
Heating value, gross (calc.) B.t.u./std.c.f.--	91	93	117	75	98	84	90	98	100	88	81	80	92	93	95	91	92	89	125	77	84	85	89
Spent shale properties:																							
Fischer assay----------gal./ton--	6.7	2.9	2.1	6.8	1.9	2.1	1.6	3.2	5.2	2.5	4.9	4.1	2.9	1.7	0.8	2.3	3.7	0.6	5.8	0.8	0.3	0.3	0.7
Organic residue----------wt.-pct.--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mineral CO_2----------do----	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Operating data:																							
Press. drop/ft. bed height---in. H_2O--	0.26	0.29	0.41	0.25	0.26	0.29	0.28	0.24	0.26	0.29	0.38	0.39	0.34	0.26	0.29	0.33	0.30	0.30	0.34	0.25	0.25	0.37	0.31
Retort gas outlet temp.----------°F.--	130	130	130	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Recycle gas temp. 10/----------do----	121	120	123	118	116	117	120	117	118	121	121	122	121	119	118	114	112	112	112	113	112	112	115
Air inlet temp.----------do----	78	78	86	81	79	79	81	78	80	80	78	75	75	80	77	74	73	70	71	75	71	73	77
Bed temps., thermocouple Nos.: 11/																							
1----------°F.--	130	130	130	120	120	120	130	130	120	130	120	130	130	120	120	120	130	120	130	120	120	120	120
2----------do----	140	140	140	130	130	130	140	140	130	100	180	200	160	140	140	130	140	180	140	140	160	160	180
3----------do----	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4----------do----	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5----------do----	470	540	560	220	510	500	520	510	450	520	630	530	600	520	530	490	550	610	520	540	580	630	630
6----------do----	670	760	790	680	690	700	710	700	690	740	800	870	790	700	690	700	780	770	790	.730	750	770	870
7----------do----	930	850	770	690	710	710	720	720	700	720	640	700	830	770	770	770	760	800	760	810	750	770	850
8----------do----	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9----------do----	840	1,150	1,130	960	990	1,040	990	950	940	990	800	940	830	960	930	920	900	940	880	1,030	1,010	970	990
10----------do----	720	730	790	780	810	860	850	790	790	810	710	770	730	790	810	790	780	760	790	800	830	800	800
11----------do----	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12----------do----	490	430	570	440	550	540	610	510	560	630	480	620	570	510	490	630	580	600	670	570	600	640	690
13----------do----	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14----------do----	55C	440	480	550	510	500	500	500	540	510	620	600	530	550	570	560	530	540	560	520	510	530	540
15----------do----	440	430	560	550	510	500	500	500	540	510	620	600	540	550	570	560	530	540	560	370	380	400	440
16----------do----	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17----------do----	410	340	380	430	420	400	400	420	430	390	470	460	390	400	410	410	350	360	370	370	390	390	380
18, spent shale temp.----------do----	260	210	250	230	200	190	200	210	220	200	340	210	250	210	200	200	180	180	210	180	180	190	190
Operating characteristics:																							
Degree of clinkering or coking 12/-----	Mod.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Mod.	Mod.	Mod.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/-------	Negl.	do.	do.	do.	do.	do.	do.	do.	do.	do.	do.	do.	Negl.	do.	do.	do.	do.	Negl.	Negl.	Negl.	do.	do.	Do.
Other troubles----------see note No.--																							
Evaluation of results 14/----------	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Unsat.	Unsat.

TABLE 24. - Results of oil-shale pilot plant tests

Run No.	217B	218A	218B	218C	218D	219	220A	220B	220C
Date	12-17	12-19	12-20	12-21	12-22	12-26	12-28	12-29	12-30
Duration, hr.	12	24	24	24	24		24	24	11
Retort type No.	K	K	K	K	K	K	K	K	K
Oil recovery system type No.	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
Raw material flows:									
Raw shale, lb./hr. x sq.ft. bed area	227	226	236	227	241		240	223	222
Recycle gas 1/, std.c.f./ton raw shale	17,500	17,500	16.500	17,400	16,100		16,000	16,900	17,200
Air 2/, do.	4,080	4,040	3,910	4,075	3,810		3,730	3,990	4,000
Products recovered:									
Shale oil, vol.-pct. Fischer assay	96	93	82	89	78		80	85	94
Shale oil, gal./ton raw shale	24.3	25.6	25.8	26.5	23.0		22.2	25.3	27.3
Gas vented 3/, std.c.f./ton raw shale	5,340	5,230	5,180	5,500	5,220		5,310	5,770	5,760
Spent shale, lb./ton raw shale	1,520	1,640	1,620	1,600	1,680		1,640	1,640	1,620
Water condensed 4/, do.	22	49	47	43	30		32	31	35
Material output, wt.-pct. of input	93	100	99	99	100		99	101	101
Raw shale properties:									
Fischer assay, gal./ton	25.4	27.5	31.5	29.8	29.6		27.7	29.7	29.1
Mineral CO_2, wt.-pct.	--	--	--	--	--		--	--	--
Particle size range, inch	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼		3/8-1	3/8-1	3/8-1
Shale oil properties:									
Gravity, °API	19.8	19.9	20.3	20.2	20.0		20.1	20.1	20.1
Viscosity, S.S.U. at 130° F.	133	136	130	116	120		126	132	131
S.S.U. at 210° F.	51	49	49	46	48		51	52	52
Ramsbottom carbon 5/, wt.-pct.	2.5	2.5	2.6	2.4	2.5		4.2	4.3	4.4
Gas properties:									
Moisture 6/, vol.-pct.	10.2	9.6	10.0	10.5	11.6		12.2	12.2	12.2
Analysis, dry:									
CO_2, vol.-pct.	20.1	18.6	19.8	21.8	21.2		24.7	25.2	--
Ill. 7/, do.	1.2	1.2	1.3	1.3	1.7		1.3	1.3	--
O_2, do.	0.5	2.4	0.0	0.0	0.2		0.3	0.1	--
CO, do.	3.4	4.1	4.3	3.6	3.6		3.1	4.0	--
H_2, do.	4.7	4.1	5.6	5.5	5.1		4.3	4.7	--
Hydrocarbons 8/, do.	3.0	2.0	2.8	2.8	3.0		2.8	2.6	--
N_2, do.	67.1	67.6	66.2	65.0	65.2	No data taken	6.5	62.1	--
Heating value, gross (calc.) B.t.u./std.c.f.	84	77	89	86	129		113	115	--
Spent shale properties:									
Fischer assay, gal./ton	1.3	0.4	5.1	1.3	3.3		5.7	4.2	1.9
Organic residue 9/, wt.-pct.	--	--	--	--	--		--	--	--
Mineral CO_2, do.	--	--	--	--	--		--	--	--
Operating data:									
Press. drop/ft. bed height, in. H_2O	0.37	0.26	0.26	0.26	0.29		0.31	0.26	0.28
Retort gas outlet temp., °F.	120	120	120	120	120		120	120	120
Recycle gas temp. 10/, do.	113	109	110	112	116		119	119	120
Air inlet temp., do.	73	74	72	75	78		81	81	81
Bed temps., thermocouple Nos.: 11/									
1, °F.	120	120	120	120	130		120	130	130
2, do.	150	150	140	220	180		140	130	130
3, do.	--	--	--	--	--		--	--	--
4, do.	--	--	--	--	--		--	--	--
5, do.	610	570	630	650	760		570	530	450
6, do.	990	780	910	860	890		1,070	770	750
7, do.	790	790	800	800	900		1,000	810	700
8, do.	--	--	--	--	--		--	--	--
9, do.	1,000	1,000	1,020	1,000	1,000		1,170	970	870
10, do.	780	860	830	830	840		930	910	840
11, do.	--	--	--	--	--		--	--	--
12, do.	750	700	670	690	670		660	590	600
13, do.	--	--	--	--	--		--	--	--
14, do.	510	520	540	500	530		500	530	520
15, do.	570	490	550	540	540		490	440	410
16, do.	--	--	--	--	--		--	--	--
17, do.	330	360	400	360	380		370	340	360
18, spent shale temp., do.	230	200	210	190	230		220	200	200
Operating characteristics:									
Degree of clinkering or coking 12/	Mod.	Mod.	Mod.	Mod.	Negl.		Negl.	Mod.	Mod.
Degree of refluxing of oil 13/	Negl.	Negl.	Negl.	Negl.	do.		do.	Negl.	Negl.
Other troubles, see note No.	--	--	--	--	--	28	--	--	--
Evaluation of results 14/	Unsat.	Sat.	Sat.	Sat.	Sat.		Sat.	Sat.	Sat.

Run No.	221A	221B	221C	221D	222A	222B	222C	222D	222E	222F	222G	222H	222I	222J
Date	1-8-52	1-9	1-10	1-11	1-17	1-18	1-19	1-20	1-21	1-22	1-23	1-24	1-25	1-26
Duration, hr.	24	24	23.2	15.75	24	24	24	24	24	24	24	24	24	24
Retort type No.	K	K	K	K	K	K	K	K	K	K	K	K	K	K
Oil recovery system type No.	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
Raw material flows:														
Raw shale, lb./hr. x sq.ft. bed area	254	229	227	238	229	229	232	233	233	234	233	236	236	238
Recycle gas 1/, std.c.f./ton raw shale	15,400	17,400	17,500	16,600	17,000	17,000	16,700	16,500	16,800	16,600	16,600	16,500	16,300	16,100
Air 2/, do.	3,410	3,820	3,820	3,640	3,870	3,820	3,770	3,750	3,780	3,760	3,750	3,700	3,710	3,680
Products recovered:														
Shale oil, vol.-pct. Fischer assay	89	98	95	92	97	95	96	94	94	93	95	95	94	89
Shale oil, gal./ton raw shale	24.8	29.1	29.5	26.5	26.3	26.6	27.3	27.1	26.7	27.3	28.1	28.3	28.1	27.2
Gas vented 3/, std.c.f./ton raw shale	4,950	5,350	5,440	5,320	5,840	5,910	5,910	5,710	5,830	5,800	5,950	5,820	5,900	5,430
Spent shale, lb./ton raw shale	1,600	1,600	1,580	1,540	1,540	1,580	1,560	1,560	1,580	1,540	1,540	1,540	1,560	1,580
Water condensed 4/, do.	39	42	37	38	.29	28	23	31	27	23	20	25	23	28
Material output, wt.-pct. of input	97	100	99	96	97	99	99	101	99	97	98	98	99	98
Raw shale properties:														
Fischer assay, gal./ton	27.9	29.6	30.9	28.9	27.2	27.9	28.4	29.0	28.5	29.3	29.3	29.9	30.0	30.5
Mineral CO_2, wt.-pct.	--	--	--	--	16.6	17.2	17.0	16.7	17.6	17.4	16.8	16.7	16.9	16.8
Particle size range, inch	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼	1/4-1¼
Shale oil properties:														
Gravity, °API	20.1	20.1	20.3	20.1	20.7	20.4	20.3	20.7	20.4	20.5	20.4	20.2	20.4	19.9
Viscosity, S.S.U. at 130° F.	121	122	124	124	141	140	138	140	131	157	131	134	127	123
S.S.U. at 210° F.	50	48	48	49	51	53	51	54	51	49	49	48	49	49
Ramsbottom carbon 5/, wt.-pct.	3.7	4.7	4.6	2.3	2.2	2.1	2.3	2.2	3.4	2.3	2.5	2.3	2.2	2.6
Gas properties:														
Moisture 6/, vol.-pct.	12.0	11.2	11.2	12.3	12.0	12.3	12.7	12.0	11.4	12.7	13.0	12.9	13.3	13.5
Analysis, dry:														
CO_2, vol.-pct.	22.3	21.9	21.7	21.3	26.9	28.1	27.6	27.4	27.5	26.9	27.3	25.7	21.6	24.8
Ill. 7/, do.	0.9	1.5	1.5	2.0	1.2	1.3	1.3	1.1	1.3	1.3	1.3	1.7	1.4	2.1
O_2, do.	0.4	0.0	0.2	0.1	0.0	0.2	0.1	0.1	0.1	0.4	0.3	0.3	0.1	0.3
CO, do.	5.5	5.1	5.6	5.3	4.7	4.7	5.3	4.8	5.4	4.8	5.2	4.8	4.9	3.4
H_2, do.	6.2	5.3	5.5	6.8	4.8	4.4	4.4	4.2	5.4	5.6	5.6	6.2	5.2	4.3
Hydrocarbons 8/, do.	2.5	2.7	2.9	2.6	3.0	3.0	3.4	3.5	2.5	2.7	2.8	3.2	3.3	3.2
N_2, do.	62.2	63.5	62.6	61.9	59.4	58.3	57.9	58.9	57.8	58.3	57.5	58.1	57.5	61.9
Heating value, gross (calc.) B.t.u./std.c.f.	96	109	106	116	85	85	92	87	84	85	88	99	94	95
Spent shale properties:														
Fischer assay, gal./ton	1.8	0.4	0.9	0.3	0.2	0.3	0.3	0.3	0.4	0.2	0.3	0.3	0.8	0.8
Organic residue 9/, wt.-pct.	--	--	--	--	2.4	2.0	2.4	2.1	2.1	2.5	2.4	2.3	2.2	3.0
Mineral CO_2, do.	--	--	--	--	16.1	16.91	17.49	17.59	19.47	18.88	17.88	18.95	18.99	20.37
Operating data:														
Press. drop/ft. bed height, in. H_2O	0.26	0.27	0.27	0.29	0.37	0.37	0.37	0.37	0.29	0.24	0.32	0.32	0.38	0.34
Retort gas outlet temp., °F.	120	120	120	120	120	120	120	120	120	120	120	120	120	130
Recycle gas temp. 10/, do.	119	117	117	120	120	121	122	120	118	122	123	123	124	124
Air inlet temp., do.	78	75	78	80	84	85	86	83	80	82	84	84	84	84
Bed temps., thermocouple Nos.: 11/														
1, °F.	120	120	120	120	120	120	120	120	120	120	120	120	120	130
2, do.	130	140	170	170	150	160	160	160	150	170	170	170	160	150
3, do.	--	--	--	--	260	280	290	280	270	310	320	300	290	330
4, do.	--	--	--	--	480	520	530	510	510	540	540	520	520	550
5, do.	510	570	610	600	560	540	680	580	580	610	600	590	600	610
6, do.	670	710	750	730	710	740	780	730	730	770	760	740	770	750
7, do.	730	770	820	820	710	760	790	790	820	850	800	790	820	770
8, do.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9, do.	860	910	930	940	840	870	860	810	870	980	910	880	880	830
10, do.	800	850	860	870	850	870	860	840	880	910	880	870	840	860
11, do.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12, do.	530	500	500	500	570	550	540	510	520	510	530	560	610	560
13, do.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14, do.	610	610	550	540	550	560	540	590	560	450	500	530	550	580
15, do.	450	370	370	380	370	360	350	350	350	340	340	360	370	450
16, do.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17, do.	450	410	330	320	360	350	340	400	360	390	330	350	360	370
18, spent shale temp., do.	240	200	180	180	180	180	180	190	190	180	180	190	190	220
Operating characteristics:														
Degree of clinkering or coking 12/	Negl.	Negl.	Mod.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.
Degree of refluxing of oil 13/	do.	do.	Negl.	do.	do.	do.	do.	do.	do.	do.	do.	do.	do.	Do.
Other troubles, see note No.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Evaluation of results 14/	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.

Notes on Tables 11 to 24

1/ The volume of recycle gas, saturated with moisture at the orifice-flow temperature, is corrected to 60° F. and 30 inches Hg. The flow temperature is shown under Recycle gas temperature.

2/ The volume of air to the retort is at 60° F. and 30 inches Hg, uncorrected for moisture (negligible at Rifle).

3/ Gas vented is the net retort gas produced in excess of that used for recycling; it is corrected to the same conditions as recycle gas. Its temperature is the same.

4/ Water condensed is water collected at all units in the oil-recovery system, including water in oil.

5/ Ramsbottom carbon is determined in accordance with ASTM Designation: D524. Conradson carbon, determined in the earlier tests, has been converted to Ramsbottom carbon using a conversion chart of ASTM Standards on Petroleum Products and Lubricants, 1952, p. 223.

6/ Moisture in gas is the volume-percent moisture in recycle and vent gas saturated at the orifice-flow temperature shown under Recycle gas temperature.

7/ The illuminants in gas consist principally of ethylene, propylene, and butene. The average heating value of the illuminants has been determined as 1,610 B. t. u. per std. c. f.

8/ The hydrocarbons have been found by spectrographic analyses of selected samples to consist of about 80 percent methane and 20 percent ethane, having a heating value of 1,170 B. t. u. per std. c. f.

9/ The organic residue of spent shale is determined by a wet oxidation method using concentrated sulfuric acid and potassium chromate. The method is a slight modification of that given in Scotts Standard Methods of Chemical Analysis, 5th edition, p. 226.

10/ The recycle gas temperature is measured at a flow meter before the retort. Vent-gas temperature is the same as that of the recycle gas.

11/ The locations of the thermocouples in the retort bed are shown in figures 9 through 14. The couples extended about 2 inches into the bed.

12/ The degree of clinkering or coking was determined by inspecting the spent shale and by the amount of rodding required to keep the bed moving. Clinkering is defined as sintering or fusion of the mineral constituents of the shale; coking, as the fusing or caking or organic constituents. It was often difficult to tell whether an agglomerate was formed by clinkering or coking, especially when the mass was broken up in the retort by rodding the bed. For this reason the two characteristics are listed together. The following designations are used:

Negl. (negligible):	Not enough agglomeration to stop the shale flow through the retort.
Mod. (moderate):	Sufficient agglomeration to require occasional rodding.
Severe:	Requires frequent heavy rodding, sometimes necessitating a shutdown to clear the retort.

13/ The degree of refluxing of oil in the retort was estimated from an examination of the gravity and viscosity of the oil recovered; light oils of low viscosity indicate refluxing in the shale bed and subsequent cracking to lighter fractions.

Negl. (negligible):	Little or no refluxing, as denoted by a heavy viscous oil.
Mod. (moderate):	Enough refluxing to give a medium gravity and viscosity.
Severe:	Much refluxing, as shown by the production of a very light oil of low viscosity.

Notes on Tables 11 to 24 (Con.)

14/ The evaluation of results is based on a general appraisal of all results but principally on the material balance. Moderate or severe clinkering sometimes resulted in known inaccuracies in measurements, in which case the test is designated as unsatisfactory. Only those runs in which the total material output lies between 94 and 101 percent of the total input are designated as satisfactory.

Sat. = satisfactory
Unsat. = unsatisfactory

15/ The condenser (fig. 15) was partly plugged with a carbon deposit at the end of the run.

16/ There was not enough blower capacity to achieve the predetermined air rate set for the run. Also, the condenser became completely plugged, stopping the flow of gas. No data taken.

17/ The gas lines from the retort were partly plugged with a heavy carbon residue and carbon.

18/ Power failures resulted in erratic operation.

19/ Several failures of the blower motors occurred during the run. No data taken.

20/ The shale flow stopped several times owing to failure of the drive of the spent-shale extractor.

21/ Reliable data could not be obtained owing to excessive clinkering and plugging of retort.

22/ The use of rich shale in runs 55 through 59 caused considerable coking and agglomeration of shale particles in the retort.

23/ A loss of retort gas and oil resulted from a leak in the outlet main.

24/ The electrostatic precipitator was out of order.

25/ The run was stopped owing to the failure of an oil pump. No data taken.

26/ The retort clinkered solid due to attempting to run at a high air rate. No data taken.

27/ The retort was shut down owing to breakdown of the spent-shale turntable.

28/ The retort clinkered badly during the startup owing to failure of the distributor supports. No data taken.