

TABLE 13. - Recycle cracking of mixture of light and heavy gas oil

OPERATING CONDITIONS		
Charging rate: Mixed gas oils	bbl. per stream-day	102.6
Recycle	do.	309.0

	Heater		Flash chamber	Fractionator	
	Inlet	Outlet	Top	Top	Btm.
Temperature °F.	462	985	796	377	627
Pressure p.s.i.g.	530	250	32		

PRODUCT YIELDS AND PROPERTIES						
	Raw charge	Naphtha	Residuum	Gas	Loss	Recycle stock
Yields vol. percent	100.0	33.5	62.2	-	-	-
Yields wt. percent	100.0	27.6	65.9	7.8	-1.3	-
Gravity °A.P.I.	22.6	55.6	12.2			13.7
Pour point °F.	75		30			55
Viscosity sec.						
S.U.S. at 100° F.	80.7					92.6
S.U.S. at 130° F.	55.0		159.2			67.9
S.U.S. at 210° F.			97.8			
S.F.S. at 122° F.			21.7			
Sulfur wt. percent	0.65	0.60	0.62			0.61
Nitrogen do.	1.98	0.89	2.84			2.67
Tar acids vol. percent		0.8				
Tar bases do.		4.9				
Octane No., M.M. clear		65.6				
+3 cc. tetraethyllead		72.4				
Octane No., R.M. clear		74.1				
+3 cc. tetraethyllead		82.9				
Hydrocarbon analysis:						
Olefins vol. percent		59.6				
Aromaticsdo.		15.8				
Paraffins and naphthenes..do.		24.6				
A.S.T.M. distillation (corrected to 760 mm. Hg)						
I.b.p. °F.	399	110	1/394			419
10 percent at do.	484	174	519			488
20 percent at do.	515	210	579			513
50 percent at do.	621	298	751			603
90 percent at do.	-	382	-			
E.P. do.	699	398	937			699
Recovery vol. percent	72.0	94.0	73.0			80.0

1/ Norwood vacuum distillation corrected to 760 mm. Hg.

Viscosity Breaking

If shale oil is to be piped to refineries on the west coast or other points a great distance from the oil-shale deposits, either viscosity breaking or coking might be used to reduce the viscosity of the crude to limits suitable for pipeline service. Of these two, viscosity breaking probably would be more desirable, for it requires a minimum of equipment and gives a high liquid yield and little gas. Furthermore, it produces no residue, such as coke, which, for reasons of economy, must be marketed at or near the point of production. Finally, the viscosity-broken crude may be recycle-cracked to produce naphtha and fuel oil, with approximately the same yields as are obtained by recycle cracking

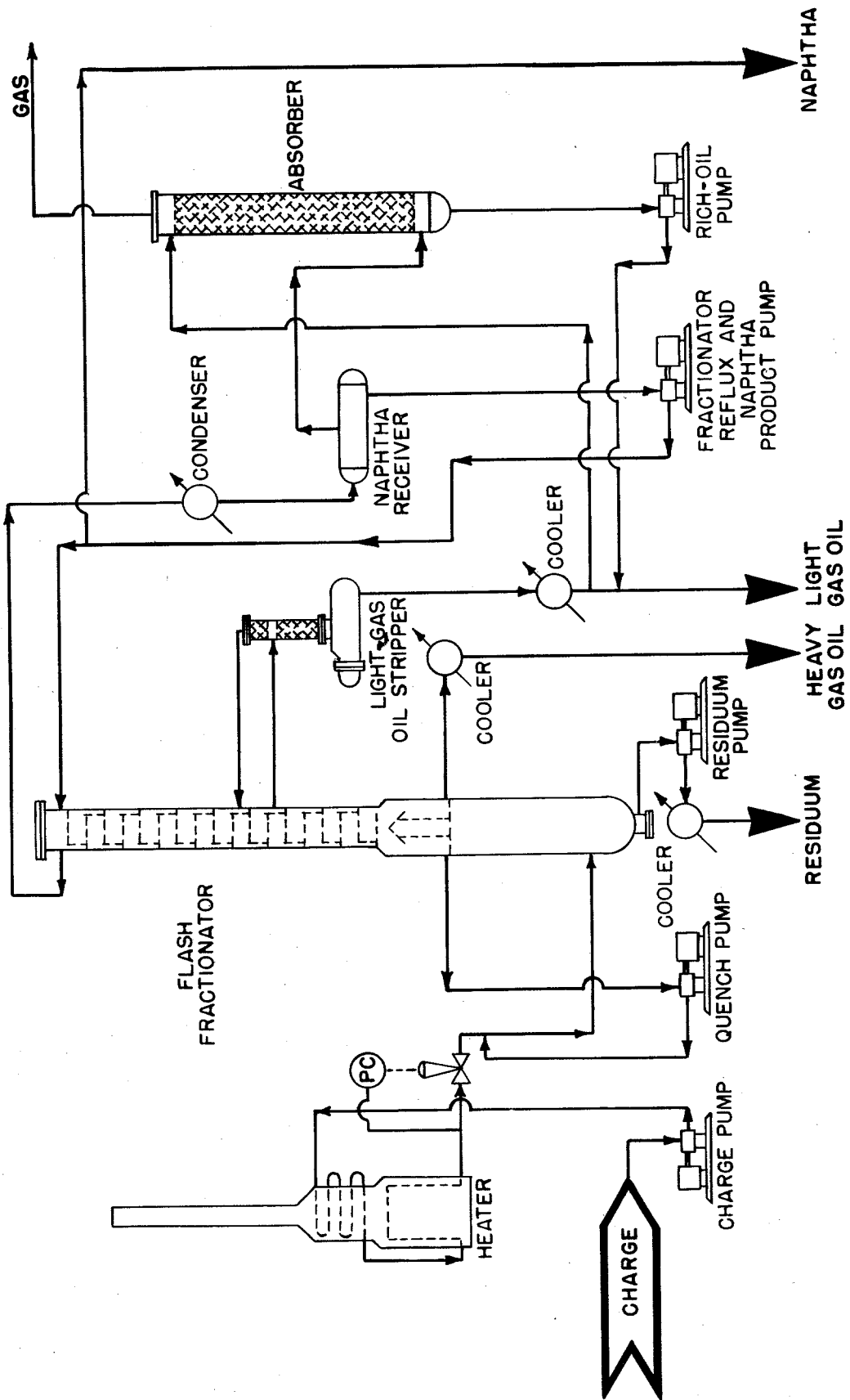


Figure 37. - Viscosity breaking of crude shale oil.

of crude shale oil. This combination of processes permits use of available thermal equipment at existing refineries, which are remote from the shale deposits.

Crude shale oil was viscosity-broken in the demonstration refinery, using a conventional flow scheme, as shown in figure 37. To evaluate viscosity breaking as a method of preparing a pipeline crude, the fractions from the distillation column were recombined. Table 14 outlines the operating conditions for a typical run, as well as the characteristics of the raw charge, the individual fractions, and the combined liquid product.

TABLE 14. - Viscosity breaking of crude shale oil

OPERATING CONDITIONS									
Charging rate: Raw crude bbl. per stream-day 263.4									
		Heater		Flash chamber		Fractionator			
		Inlet	Outlet	Top	Top	Btm.			
Temperature	°F.	156	925	785	374	677			
Pressure	p.s.i.g.	530	200	52					
PRODUCT YIELDS AND PROPERTIES									
		Raw charge	Naphtha	Light gas oil	Heavy gas oil	Residuum	Gas	Loss	Product blend
Yields	vol. percent	100.0	1/22.7		29.6	45.7			
Yields	wt. percent	100.0	1/19.8		29.2	48.2	0.6	2.2	
Gravity	°A.P.I.	19.8	52.8	32.6	21.8	11.7			20
Pour point	°F.	85		-40	65				20
Viscosity	sec.								
S.U.S. at 100° F.				33.0	83.8				180
S.U.S. at 130° F.		128.1		30.9	55.4				88
S.U.S. at 210° F.		51.6				49.8			
S.F.S. at 122° F.						274			
Sulfur	wt. percent	0.80	1.06	0.76	0.72	0.65			0.77
Nitrogen	do.	2.09	1.01	1.57	6.92	2.43			2.03
Tar acids....	vol. percent		1.0	4.2					
Tar bases	do.		5.3	11.0					
Cetane No.				29.7					
Octane No., M.M....	clear		68.7						
+3 cc. tetraethyllead .			72.4						
Octane No., R.M....	clear		79.0						
+3 cc. tetraethyllead .			84.2						
Hydrocarbon analysis:									
Olefins....	vol. percent		51.7						
Aromatics	do.		25.9						
Paraffins and naphthenes	do.		22.4						
A.S.T.M. distillation (corrected to 760 mm. Hg)									
I.b.p.	°F.	359	98	334	379	2/376			1.98
10 percent at	do.	489	179	406	525	704			390
20 percent at	do.	557	231	417	555	817			512
50 percent at	do.	-	308	438	633	-			675
90 percent at	do.	-	361	495	-	-			
E.P.	do.	699	383	595	699	940			699
Recovery....	vol. percent	48.0	95.5	99.0	74.5	45.0			62.0

1/ Combined yields of naphtha and light gas oil.

2/ Norwood vacuum distillation corrected to 760 mm. Hg.

Reforming

Thermal reforming has been used for a number of years as a means of improving octane values of straight-run petroleum naphthas. The adaptability of the process to the refining of shale naphtha had not been investigated before 1951. Four exploratory runs were made in an attempt to establish suitable working ranges of temperature, time, and pressure for shale gasoline. The first three runs were very brief because of operating difficulties. These difficulties were overcome in the last run. More runs are necessary to determine the optimum relationship between yield and improvement in antiknock value.

The flow path used in the latest reforming operation (see fig. 38) is conventional. Results of operating with a heater-outlet temperature of 1,010° F. and a pressure of 400 p.s.i.g. are given in table 15. The clear research octane number of the reformed naphtha was approximately four units better than that of the charge stock, and the A.S.T.M. gum and induction periods were improved. No serious operating difficulties were encountered under the conditions shown.

Treatment of Products

The cold acid-treating plant (fig. 39) is capable of processing either shale naphtha or a gas-oil fraction intended for use as Diesel fuel. The sequence of operations is: (a) Removal of tar acids by washing with dilute aqueous caustic soda solution, (b) removal of tar bases by contacting with dilute sulfuric acid, (c) a three-stage countercurrent treatment with concentrated sulfuric acid at controlled temperatures down to 10° F., followed by a water wash and neutralization with caustic soda solution, and (d) redistillation (when required) for end-point correction and polymer removal. Figure 40 is a flow diagram of the treating plant in which the first three stages of the treating operation are carried out.

Shale naphtha and Diesel fuel are treated primarily for removal of sulfur and nitrogen compounds and other unstable materials. The treatment results in an improved storage stability, color, tetraethyllead susceptibility, or cetane number of the product. It is desirable to extract the tar acids and tar bases before the concentrated acid treatment, and these compounds are removed continuously in the two towers shown on the left in figure 40. The sodium cresylate formed by the reaction with dilute caustic soda solution in the first tower and the tar-base sulfate formed in the second tower are pumped to storage. Following extraction of tar acids and tar bases, the naphtha or gas oil may pass either via a chiller to the first concentrated-acid contactor or to storage after receiving a light neutralizing wash with dilute caustic soda. Usually the latter procedure is followed, as the break in the operation between the dilute and concentrated-acid contactors permits better measurement of quantities and provides more accurate data.

In 1951 the experimental program was designed to establish optimum operating conditions and reagent quantities and was supplemented by laboratory and large-scale investigations of the quality and performance of shale gasoline and Diesel fuel.

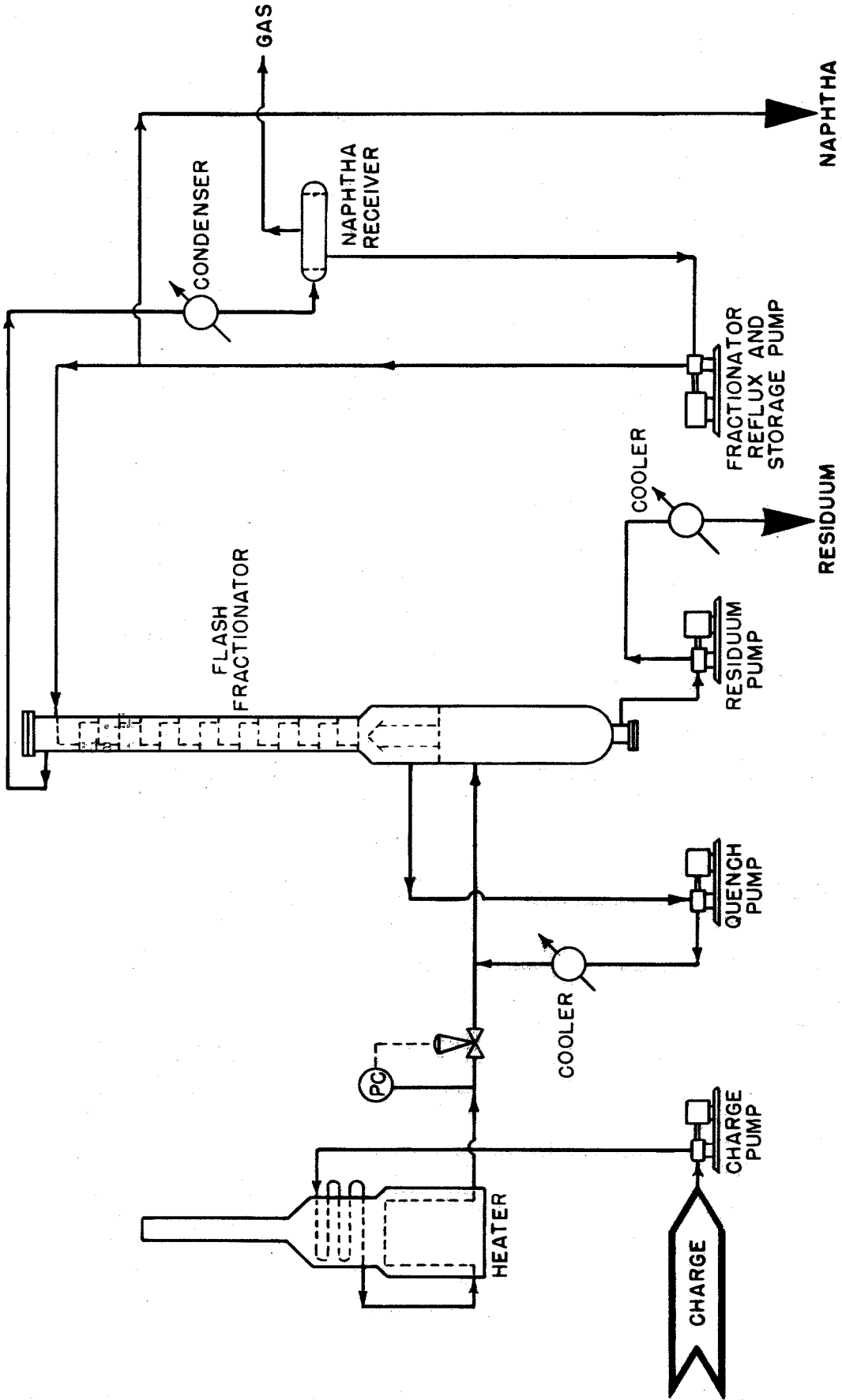


Figure 38. - Thermal reforming of shale-oil naphtha.

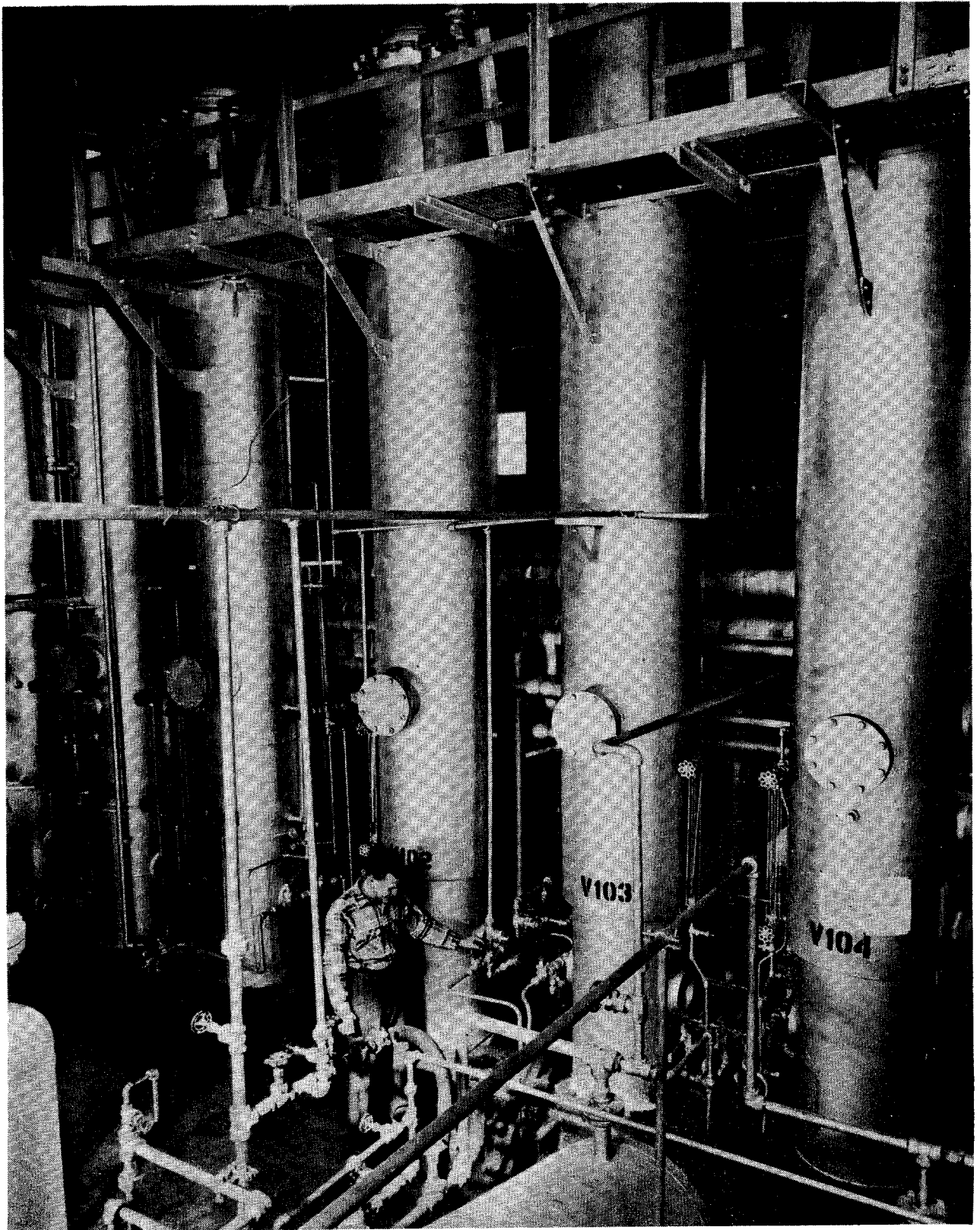


Figure 39. - Settlers in treating plant for separating naphtha or light gas oil from acid and caustic solutions.

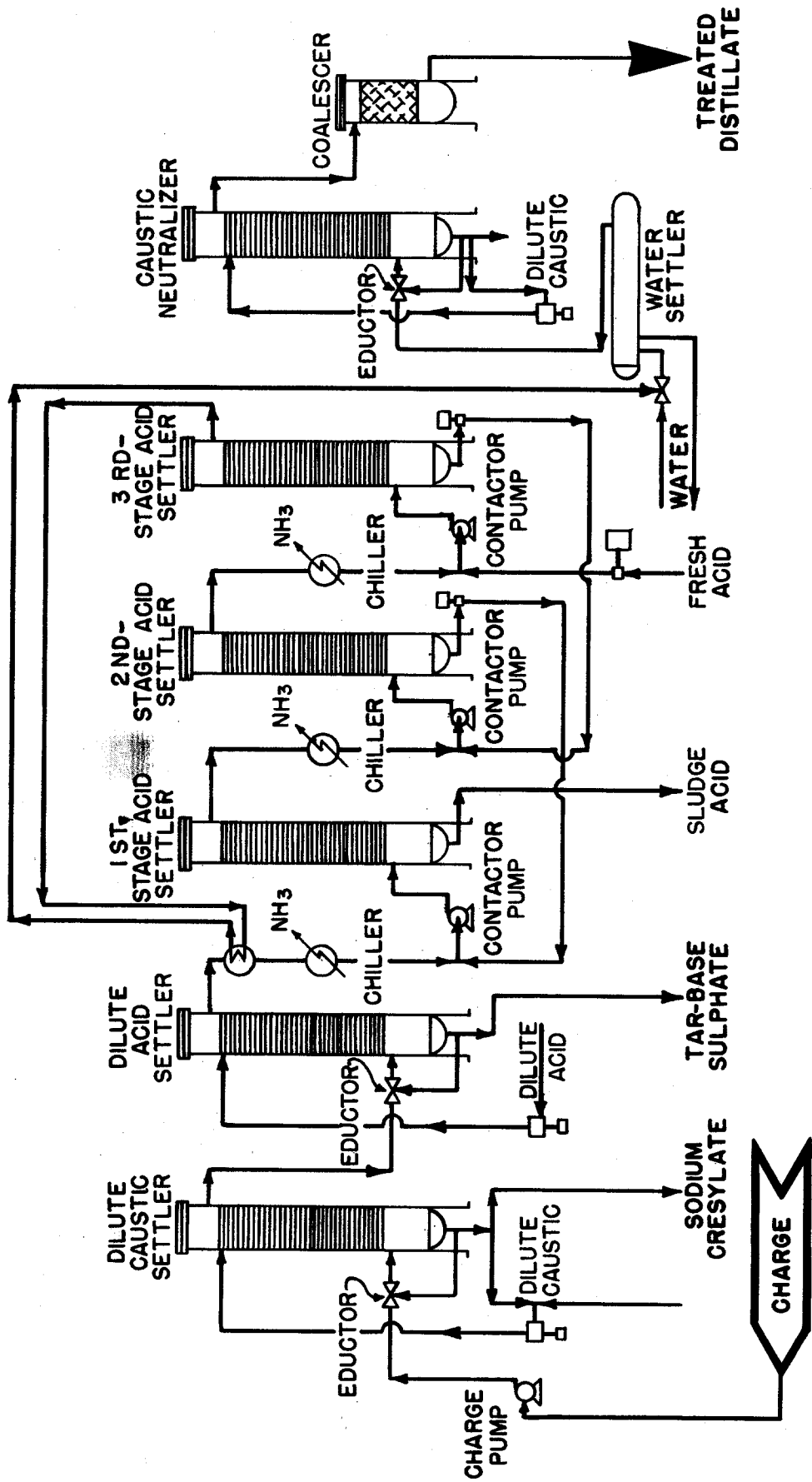


Figure 40. Tar-acid and tar-base removal and acid treating of distillates.

TABLE 15. - Thermal reforming of shale-oil naphtha

OPERATING CONDITIONS

Charging rate	bbl. per stream-day					244.8
	Heater		Flash chamber	Fractionator		
	Inlet	Outlet	Top	Top	Btm.	
Temperature °F.	103	1,030	695	430	577	
Pressure p.s.i.g.	622	400	57			

PRODUCT YIELDS AND PROPERTIES

	Naphtha charge	Reformed naphtha	Residuum	Gas	Loss
Yields vol. percent	100.0	96.4	3.1	-	-
Yields wt. percent	100.0	95.6	3.8	1.4	-0.8
Gravity °A.P.I.	50.0	51.5	15.7		
Pour point °F.	-	-	0		
Gum, A.S.T.M. mg./100 ml.	240	82			
Viscosity sec. S.U.S. at 130° F.	-	-	99.1		
Sulfur wt. percent	0.81	0.85	0.76		
Nitrogen do.	0.63	0.63	1.26		
Tar acids vol. percent	1.0	0.8			
Tar bases do.	4.1	3.9			
Octane No., M.M. clear	62.8	66.2			
+3 cc. tetraethyllead	71.2	73.6			
Octane No., R.M. clear	70.3	74.6			
+3 cc. tetraethyllead	78.3	82.3			
Hydrocarbon analysis:					
Olefins vol. percent	49.0	44.0			
Aromatics do.	17.0	18.0			
Paraffins and naphthanes do.	34.0	38.0			
A.S.T.M. distillation					
(corrected to 760 mm. Hg)					
I.b.p. °F.	139	121	243		
10 percent at do.	218	199	452		
20 percent at do.	250	237	579		
50 percent at do.	309	304	679		
90 percent at do.	373	366	-		
E.P. do.	407	401	699		
Recovery vol. percent	98.0	96.5	60.0		

Gasoline

Two types of naphtha treatment have been studied. In the first, the total 400° F. end-point naphtha is contacted with the desired quantity of concentrated sulfuric acid. In the second, the naphtha is fractionated into two cuts, the light one requiring only a mild treatment and the heavy naphtha a more-severe one.

Numerous test treatments have been applied to 400° F. end-point shale naphtha. The quantity of 66° B. acid per barrel of charge and the operating temperature were varied widely to permit comparisons between quality of product

and reagent requirements. Table 16 gives a typical example of the treatment of a cracked shale naphtha in which the charge stock was contacted with 15.4 pounds of 66° B. sulfuric acid per barrel of charge at 50° F. Before the concentrated-acid treatment, aqueous caustic soda and dilute sulfuric acid exceeding stoichiometric quantities were employed to insure as thorough extraction of tar acids and tar bases as possible.

It is particularly interesting that the sulfur was reduced from 0.62 to 0.22 percent and that the reduction in gum content was good. Nitrogen was almost completely removed. The clear motor-method octane number was reduced, but lead sensitivity was increased.

Finished gasolines of similar characteristics have been produced with different concentrated-acid rates and temperatures. Further experimentation should establish the minimum quantity of reagent required to achieve desired results.

The prime objective of any naphtha-treating procedure is to produce, with a minimum of reagents, a fuel that will have the desired stability and sulfur content. One approach to this objective is to apply a severe treatment to the portion of total naphtha that requires it and a lighter application to the other portions. An investigation of this procedure was started and shows considerable promise.

For the initial demonstration-scale run of this type, recycle cracked naphtha was fractionated into two portions with end points of 273° F. and 450° F., respectively. The light fraction was washed with caustic soda solution for tar-acid removal and then treated with 5 pounds of 66° B. sulfuric acid per barrel of charge. The heavy fraction was processed in the usual manner for tar-acid and tar-base removal and then given a concentrated-acid treatment of approximately 25 pounds per barrel. Following acid treatment, each naphtha was redistilled. Table 17 shows the results of the treatment and includes physical properties of the two fractions as charged, at various stages of treating, and after treatment, as well as the properties of a proportionate blend of the two redistilled fractions.

Diesel Fuel

To determine the suitability of shale oil as a source of Diesel-engine fuel, several light-gas-oil treating runs have been made. Two were on a rather large scale to produce enough Diesel fuel for extended test runs in Denver and Rio Grande Railroad equipment.

Table 18 shows the results of a typical light-gas-oil treatment to produce Diesel fuel. The raw material used as charge stock for this run was produced by delayed coking of crude shale oil. Treatment was conducted in the same manner as that described for gasoline. Tar acids and tar bases first were removed with dilute reagents. Then, after measuring and sampling, the oil was contacted with 66° B. sulfuric acid in three countercurrent stages, using 10 pounds of concentrated acid per barrel of charge. The operation was conducted at 69° F. Since the treatment used did not appreciably change the distillation range or pour point, the product oil was not redistilled. However, it was stabilized by adding 0.05 volume percent of a stabilizer produced by the National Aluminate Co.

TABLE 16. - Cold sulfuric acid treatment of recycle cracked naphtha

Stage	Raw charge	Tar-acid removal 2.9 vol. percent of 15 percent NaOH	Tar-base removal 16.2 vol. percent of 14.4 percent H ₂ SO ₄	Sulfuric acid sludge Acid sludge from following step. Naphtha at 45° F.	Fresh 660 B. sulfuric acid 15.4 lb. acid per bbl. Naphtha at 55° F.	Treated gasoline 1.5 vol. percent of 15 percent NaOH	Redistillation to desired end point									
Recovered	100					87.7	80.7									
Tests after each step:																
Gravity	54.8	54.6	56.6	55.7 56.8	55.3	55.1	59.9									
Reid vapor pressure	6.6					7.8	5.0									
Color						2	1									
Corrosion						Neg.	Neg.									
Gum, A.S.T.M. ... mg./100 ml.	351					412	2.0									
Doctor test	Sour					Sweet	Sour									
Sulfur	0.62	0.63		0.63 0.57	0.60	0.51	0.22									
Mercaptan sulfur	0.030						0.004									
Tar acids	1.1	0.40		Nil												
Tar bases	5.1		0.9	0.2												
Nitrogen	0.93		0.35	0.06 0.08	0.01	0.01	Nil									
Octane number, M.M. ... clear	68.8					64.7	65.4									
+1 cc. tetraethyllead	71.7					64.6	70.4									
+3 cc. tetraethyllead	75.4					63.2	74.8									
Octane number, R.M. ... clear	76.7					70.9	73.0									
+1 cc. tetraethyllead	80.0					70.3	78.7									
+3 cc. tetraethyllead	84.3					70.0	82.0									
Induction period	420+					420+	420+									
A.S.T.M. distillation (corrected to 760 mm. Hg), °F.																
Volume percent recovered	I.B.P.	2	5	10	20	30	40	50	60	70	80	90	E.P.	Rec.	Res.	Loss
Raw gasoline	94	106	125	143	184	249	257	287	314	338	360	393	403	92	1	7
Treated gasoline	107	123	143	165	204	237	266	291	315	338	365	424	494	92.5	3	4.5
Rerun gasoline	111	-	-	149	160	208	235	255	273	291	310	338	393	99	1	0

TABLE 17. - Cold sulfuric acid treatment of light and heavy naphthas from recycle cracking of viscosity-broken crude shale oil

	Raw charge		Tar-acid removal		Sulfuric acid sludge		Fresh 66° B. sulfuric acid		Treated gasoline								
	Heavy naph.	Light naph.	Heavy naphtha 4.5 vol. percent of 12 percent NaOH	Heavy naphtha 35.5 vol. percent of 16 percent H ₂ SO ₄	Heavy naphtha Acid sludge from following steps at 40° F.	Light naphtha Acid sludge from following steps at 20° F.	Heavy acid 26.5 lb. per bbl. gasoline 400° F.	Light acid 4.3 lb. per bbl. gasoline 20° F.	Heavy 4.3 vol. percent of 12 percent NaOH	Re-distilled	Light 6.2 vol. percent of 12 percent NaOH	Re-distilled	Blend of light and heavy fractions				
Recovery	100	100							80.8	98.2	86.4						
Gravity	40.5	72.9	40.9	43.5	44.5	71.3	44.3	69.5	44.7	67.7	70.1	55.9					
Reid vapor pressure	-	12.1							11.1	10.4	9.0						
Color	-	1 NFA							1-1/2 NFA	1 NFA	1-1/2 NFA	> 1 NFA					
Corrosion, cu. strip at 122° F.	Neg.	Neg.							Neg.	Neg.	Neg.	Neg.					
Gum, A.S.T.M. mg./100 ml.	550	10							380	5	1	1					
Doctor test	Sour	Sour							Sweet	Sour	Sweet	Sweet					
Induction period	20	50							435+	460+	45	445+					
Sulfur	0.78	0.22			0.77	0.23	0.25	0.24	0.72	0.36	0.31	0.15					
Mercaptan sulfur	0.006	0.016							0.007	0.008	0.006	0.02					
Nitrogen	1.56	0.07	0.3	0.50	.13	.07	.01		-	-	-						
Tar acids	1.4	0.2							-	-	-						
Tar bases	11.7	0.4		1.6					-	-	-						
Olefins	38.0	55.4							32.8	33.9	41.5	46.4					
Aromatics	24.0	8.8							31.0	23.7	7.6	17.9					
Paraffins and naphthenes ..	38.0	35.7							36.2	42.4	36.1	35.7					
Octane No., M.M. clear	69.5	69.0	65.3	60.3					52.9	54.8	67.0	60.9					
+1 cc. tetraethyllead	72.8	72.0	69.2	63.3					54.4	59.9	71.1	71.1					
+3 cc. tetraethyllead	74.6	74.3	72.2	67.4					59.4	65.3	75.5	71.1					
Octane No., R.M. clear	76.2	77.8	75.3	69.4					60.3	59.7	78.0	68.2					
+1 cc. tetraethyllead	80.0	83.6	78.1	73.3					61.8	66.0	79.8	84.5					
+3 cc. tetraethyllead	84.6	88.3	81.8	77.6					67.5	72.8	83.9	79.3					
Volume percent recovered	A.S.T.M. distillation (corrected to 760 mm. Hg), %																
Raw gasoline	heavy fraction	224	253	275	286	302	314	324	336	347	357	373	380	390	406	451	Rec. Res. 1.0
Treated gasoline	light fraction	86	96	106	119	135	151	163	177	189	202	219	275	275	297	297	96.5
Re-run gasoline	heavy fraction	222	253	273	284	300	310	320	331	343	356	373	403	403	463	550	97.5
Blend of light and heavy fractions	light fraction	94	104	116	128	145	161	178	193	209	226	250	303	303	387	391	95.0
1/ Saybolt.	heavy fraction	221	262	274	285	297	307	317	325	334	345	357	374	374	409	409	98.5
	light fraction	97	107	118	127	141	156	170	183	196	209	222	243	243	277	277	97.0
	heavy fraction	121	121	121	166	197	262	262	262	262	262	262	262	262	262	262	98

TABLE 18. - Cold sulfuric acid treatment of light gas oil from coking N-T-U shale oil

	Raw charge	Tar-acid removal	Tar-base removal	Sulfuric acid sludge	Fresh 66° B. acid	Treated Diesel fuel
Specific treatment applied to distillate	None	8.1 vol. percent of 11 percent NaOH	53.6 vol. percent of 14.5 percent H ₂ SO ₄	Acid sludge from following step Temp. - 90° F	18.9 lb. acid per bbl. of dist. Temp. - 92° F.	2.4 vol. percent of 11 percent NaOH
Recovery	100					74.6
Tests after each step:						
Gravity	28.7	29.6	32.2	32.6	35.0	35.0
Flash point, P.M.	150					176
Pour point	+10					+15
Viscosity	40					35.6
Aniline point	91.4			111.56	125.06	126.68
Corrosion, Cu s.	Neg.					Neg.
Conradson carbon residue..wt.percent	-					0.504
Sulfur	0.83					.90
Nitrogen	1.71					.05
Tar acids	2.8	0.3	0.62	.48	.05	.0
Tar bases	13.9	13.5	.5	.4		.10
Color	-		.7	.5		4-1/2
Diesel index	26.2		8 dilute			44.3
Cetane No., M.M.	33.1					45.9
Gum, air jet						791
A.S.T.M. distillation, °F. (corrected to 760 mm. Hg)						
I.b.p.	395			435	412	407
10 percent	458			462	448	454
50 percent	504			498	504	506
90 percent	575			604	596	607
E.P.	658			671	675	665
Recovery	99.0			99.0	99.0	98.0
Residue	1.0			1.0	1.0	2.0
Loss	0.0			.0	.0	-

Through a cooperative agreement with the Denver & Rio Grande Western Railroad, 5,000 gallons was furnished for use in a test run on a standard General Motors EMD switching engine. The engine operated for 751 hours on shale fuel. During this period, the operating crews were unable to detect any difference in performance between the test fuel and the commercial product normally used. Fuel consumption was less than normal, but this may have been due at least in part to variations in work load. Inspection of the engine at the end of the test run revealed no unusual deposits or accumulations on the cylinder heads or cylinders or in the fuel injector or fuel filters. Engine appearance was normal for the period during which it had been operated.

A significant point revealed by the test is that the switch engine performed excellently on a fuel containing 0.90 percent sulfur. The same unit had been sensitive to sulfur in petroleum Diesel fuel and had given trouble with sulfur contents of 0.4 to 0.5 percent. In shale-oil distillates the sulfur compounds are largely thiophenic, and it appears that they permit greater sulfur tolerance in engines of this type.

Byproduct Studies

Road Materials

The need for bituminous road-surfacing work at the station has afforded a practical opportunity to study the adaptability of shale products for this purpose. An 11° A.P.I. gravity cracked residuum was reduced to asphalt of 80 to 100 penetration by charging it to the heater, maintaining a heater outlet temperature of 760° F. at 25 p.s.i.g., and stripping with steam in the flash chamber. Fluxes, prepared by distilling a polymer-gasoline-gas oil mixture, were blended with this asphalt to produce MC-2, RC-4, and RC-1 road materials. They were applied in the standard manner and have been under traffic for 4 months. The road appearance is satisfactory. Earlier applications that have been in service for more than a year have shown good durability. The characteristics of the shale road oils are compared with standard specifications in table 19.

Tar Acids and Tar Bases

The sodium cresylate and tar-base sulfate produced by treating naphtha and light gas oil have received as much additional demonstration-scale processing as possible with equipment currently in use. As yet, there are no facilities for steam stripping or similar purification methods.

Various sodium cresylates were sprung with dilute aqueous sulfuric acid. Crude acids thus prepared were supplied to the Petroleum and Oil-Shale Experiment Station, Laramie, Wyo., where purification and evaluation on a laboratory scale are now in progress. The results obtained thus far indicate that the tar acids from shale naphtha produced by recycle cracking of crude shale oil contain substantial proportions of currently salable tar acids.

Crude sprung bases also are being purified and evaluated in the laboratory, but this work has not progressed far enough to provide data on the types of tar bases extracted from shale-oil distillates and the proportions in which they occur.

TABLE 19. - Characteristics of road oils produced from shale-oil residuum

Type and grade	MC-2		RC-1		RC-4	
	Shale oil	Asphalt specs.	Shale oil	Asphalt specs.	Shale oil	Asphalt specs.
Gravity °A.P.I.	10.3		13.6		8.1	
Flash point, C.O.C. ^{1/} °F.	130	150+			130	80+
Viscosity sec.						
S.F.S. at 122° F.			97	75-150		
S.F.S. at 140° F.	190	100-200				
S.F.S. at 180° F.					141	125-250
Distillation: Percent of total distilled to 680° F.						
To 374° F.			20.9	10+		
To 437° F.	5.9	10-	51.9	50+	20.0	8+
To 500° F.	34.5	15-55	73.3	70+	44.0	40+
To 600° F.	73.8	60-87	89.9	88+	76.0	80+
Residue from distillation (by difference) vol. percent	81.8	67+	71.3	60+	87.5	78+
Penetration at 77° F. (100 gm. 5 sec.) 0.01 cm.	129	120-130	105	80-120	82	80-120
Ductility at 77° F.	113	100+	98	100+	105	100+
Percent soluble in carbon tetrachloride	95.68	99.5+	90.83	99.5+	93.2	95.5+

^{1/} Tag open-cup.

The development of procedures for removing tar acids and tar bases from shale-oil distillates and of methods for their purification and identification has been facilitated by a cooperative agreement with Koppers Co., Inc. Koppers has provided an engineer whose suggestions and assistance on the matter of tar acids and tar bases, as well as on a variety of other refining problems, both technical and economic, have been valuable.

Coke

The work with shale-oil coke and pitch under a cooperative agreement with the Geneva Steel Co. has been outlined. Additional coke and pitch samples have been submitted to various users for testing and evaluation. These studies soon should establish the suitability of shale coke and pitch for such purposes as the manufacture of carbon electrodes.

Future Refining Studies

Additional thermal cracking runs will be made to determine optimum conditions for processes that have been shown to be readily adaptable to shale-oil refining - delayed coking, recycle cracking, viscosity breaking, and reforming. These runs will determine the conditions that give the best-possible yields and quality of product.

The combination of thermal and catalytic processing represented by the Suspensoid catalytic cracking process also will be investigated. Engineering work has been completed, and equipment is being procured for experimenting

with this technique in the Demonstration Refinery. The process is simple, and most conventional thermal cracking plants can be adapted to use it at relatively small expense. Considerable information on the behavior of shale oil and shale-oil distillates toward various catalysts should be obtained from this investigation.

Catalytic treating, an operation similar to hydroforming, has been suggested as a means of reducing the sulfur and nitrogen contents of shale naphtha and has been investigated extensively in the laboratory. In essence, the process consists of passing raw naphtha over a catalyst at elevated temperatures (800° to 1,000° F.) and pressures (300 p.s.i.g. or higher) in the presence of hydrogen. Laboratory results with such catalysts as bauxite and cobalt molybdate have been encouraging, and design work is now in progress on a demonstration-scale unit.

As in the past, studies of hydrogenation processes will be continued. At present, however, no plans have been made for installing hydrogenation equipment other than the catalytic naphtha treating unit. Experimental shale-oil hydrogenation work is being done by industry and by the Bureau at Laramie, Wyo., and Bruceton, Pa. Hydrogenation processes have been proposed recently by the National Petroleum Council and by the Koppers Co. In these, however, as in other hydrogenation processes that have been proposed, thermal steps such as those being studied in the demonstration refinery are essential parts of the over-all refining schemes.

Cooperative Agreements

The Bureau deeply appreciates the efforts of oil companies and other industrial organizations, as well as educational institutions, other Government agencies, and individuals, who have shown interest in the Bureau's program and have been making original investigative studies on oil shale and shale oil. Splendid contributions have been made by cooperating organizations in various fields of oil-shale technology, such as retorting, refining, and byproduct utilization. To provide liaison among related research and development activities and to enable Government and non-Government investigators to be of greater assistance to each other, a form of agreement is being used that resembles a contract, except that it is briefer and simpler and does not involve any monetary exchange. Both the Bureau and the cooperator share the technical information developed, and the agreements have proved beneficial to all concerned.

Three general types of cooperative agreements are in effect between the Bureau and various cooperators. Under one type, the Bureau supplies oil shale, shale oil, or shale-oil products for experimental work in the laboratories and pilot plants of the cooperator. Under another, the cooperator supplies equipment to the Bureau for testing by the Oil-Shale Demonstration Branch to determine the suitability of the equipment for some phase of oil-shale or shale-oil processing. In either case, the organization conducting the tests supplies the other with results of the experimental work; but, of course, engineering and technical data designated by the cooperator as confidential are not disclosed to unauthorized persons. Under the third type of agreement, an engineer or other technical employee of the cooperator is assigned to work as a member of the Bureau's technical staff at Rifle, Colo.

Where cooperative investigations have progressed far enough to warrant description of the nature and scope of the work, they are described in other parts of this report

This year 16 new cooperative agreements and 4 extensions have gone into effect at the Oil-Shale Demonstration Branch. Altogether, about 100 have been negotiated since inception of the cooperative program some 3 years ago, and many of the older ones are still in effect.

In accordance with the provisions of cooperative agreements, reports are furnished by cooperators when an investigation or some part of it has been completed. Ten such reports have been received this year. Conversely, during this same period, the Bureau has sent five reports to cooperators relative to tests on their equipment.

Industry-Scale Oil-Shale Project

Progress on mining, retorting, and refining development has made it possible to present two plans for oil-shale processing that are improvements over those reported previously. Both cases submitted herein are identical in the method of mining the oil shale and producing the crude shale oil but differ in methods of refining the crude to marketable products. Of significant importance in the improved economics of oil-shale utilization illustrated by the two plans is the production of crude oil by the gas-combustion process.

Estimates have been made of the costs for a 250,000-barrel-per-calendar-day oil-shale industry with crude-oil production by the Bureau's gas-combustion process. In case I, refining is by thermal cracking, catalytic reforming and acid treating, and in case II, refining is by coking, mild hydrogenation, and catalytic cracking. The latter refining scheme embodies developments made by the Union Oil Co. of California.

The over-all investment is estimated to be \$872,150,000 or \$4,508 per daily barrel of liquid fuels in case I, and \$1,184,950,000, or \$5,889 per daily barrel of liquid fuels in case II.

The daily production of gasoline is 103,680 barrels for case I and 126,900 barrels for case II. Other fuels produced include Diesel oil, fuel oil, and L.P.G.

Based on a capitalization of 50 percent equity and 50 percent borrowed funds and with all products selling at current bulk prices, the rate of return, after income taxes, on the equity capital is estimated to be 8.4 percent for case I and 11.2 percent for case II.

Steel requirements for the project are 579,000 tons, or about 3 tons per daily barrel of liquid fuels, for case I and 555,000 tons, or about 2.8 tons per daily barrel of liquid fuels, for case II. Case I requires a larger pipeline, hence more steel.