parts when less than 500 gallons per hour (g.p.h.) is handled has been under 48 hours. Modifications of design and changes in materials are being made to attempt to increase their life. Two 1-inch high-pressure elbows, which followed a restricting orifice in the lines handling this material, were cut completely in less than 3 weeks' operation. These 1-inch elbows were replaced with 2-1/2-inch high-pressure tees having solid-shaped plug target which deflected the material in the same manner as an elbow. Three weeks' operation of these units resulted in fairly severe erosion of the plugs and tees. The wear plate in the vessel was also deeply eroded. A replaceable plug having a spherical cup, hard-faced with abrasion resistant metal, then was tried. This change virtually eliminated the wear on the tees and has reduced erosion of the wear plate in the vessel considerably.

Evaluation of Hydrogenation Fuel Products

Motor Gasoline

Extensive fleet tests in Army ordnance transport and engineer equipment have shown that the synthetic gasoline (see fig. 11) will give fully satisfactory performance under sustained 100-percent-overload conditions. Use of the gasoline in all Bureau of Mines equipment at the Louisiana, Mo., Station also has been successful. To evaluate the products further and extend the military test program, samples of finished vapor-phase gasoline made from Rock Springs and Western Kentucky No. 11-bed coals, an aviation base stock, and a blended jet fuel from Western Kentucky No. 11-bed coal were submitted to a commercial testing laboratory for evaluation. The tests are summarized in the following tables:

Finished gasoline	Western Kentucky No. 11 bed	Rock Springs, Wyo.1/
Gravity, °A.P.I.	54.1	54.3
10 percent evaporation .... °F.	125	135
50 percent evaporation .... do.	220	224
90 percent evaporation .... do.	327	320
Residue .... percent	1.0	1.0
Vapor pressure .... p.s.i.	9.9	8.4
Octane number:		
Motor method	77.3	75.3
Research method	83.7	81.5
Existent gum content .... mg./100 ml.	1.6	4.0
Sulfur content .... percent	0.023	0.016
Corrosion copper strip	Negative	Positive
Oxygen stability .... minutes	480+	480+
Composition after removal of phenols and bases, percent		
Aromatics	29.5	25.2
Olefins	2.5	1.8
Naphthenes	26.2	28.1
Paraffin content	41.8	44.9
Aniline point .... °C.	26.4	28.0

1/ The gasoline from Rock Springs coal had been stored in a 55-gallon drum for 1 year.

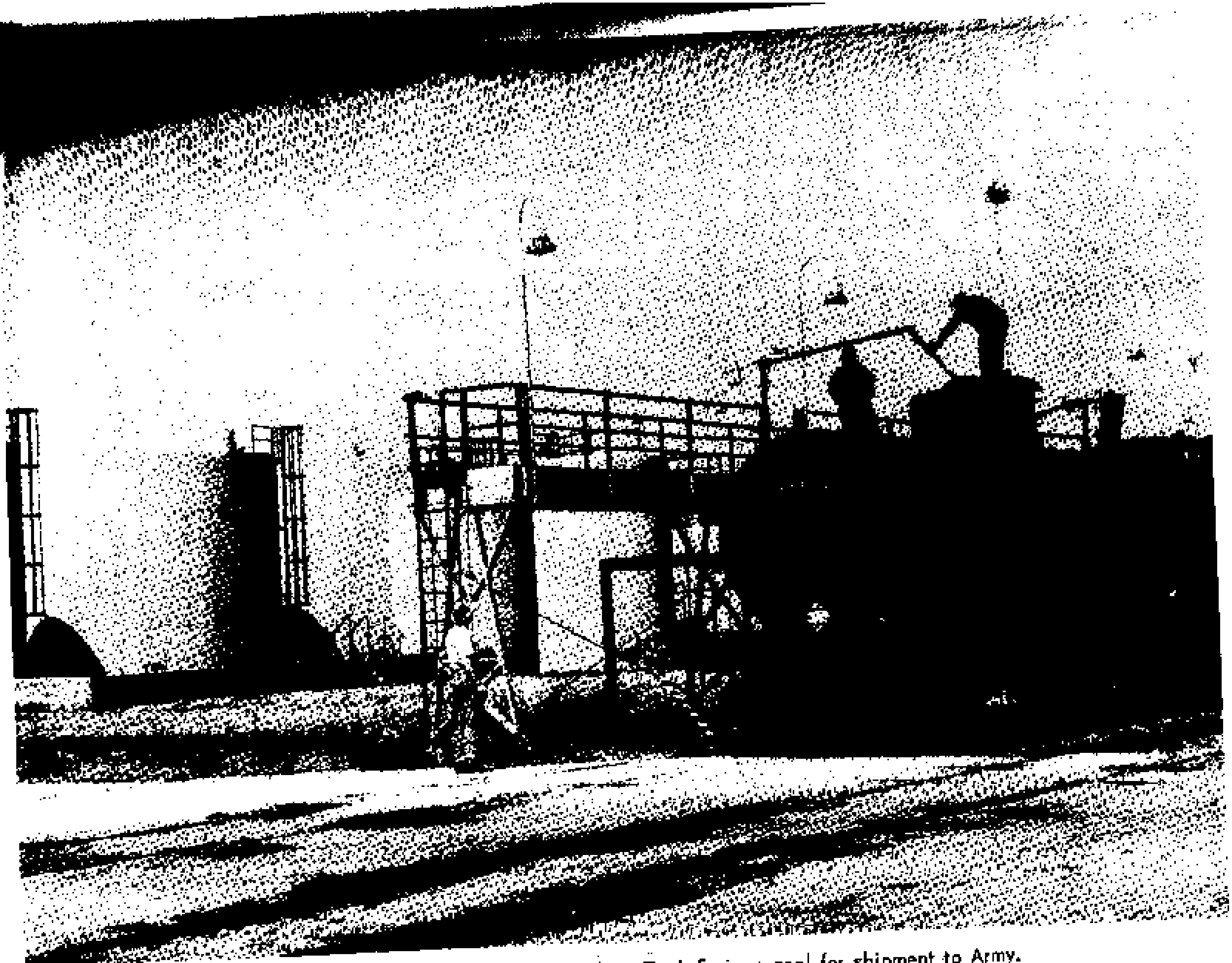
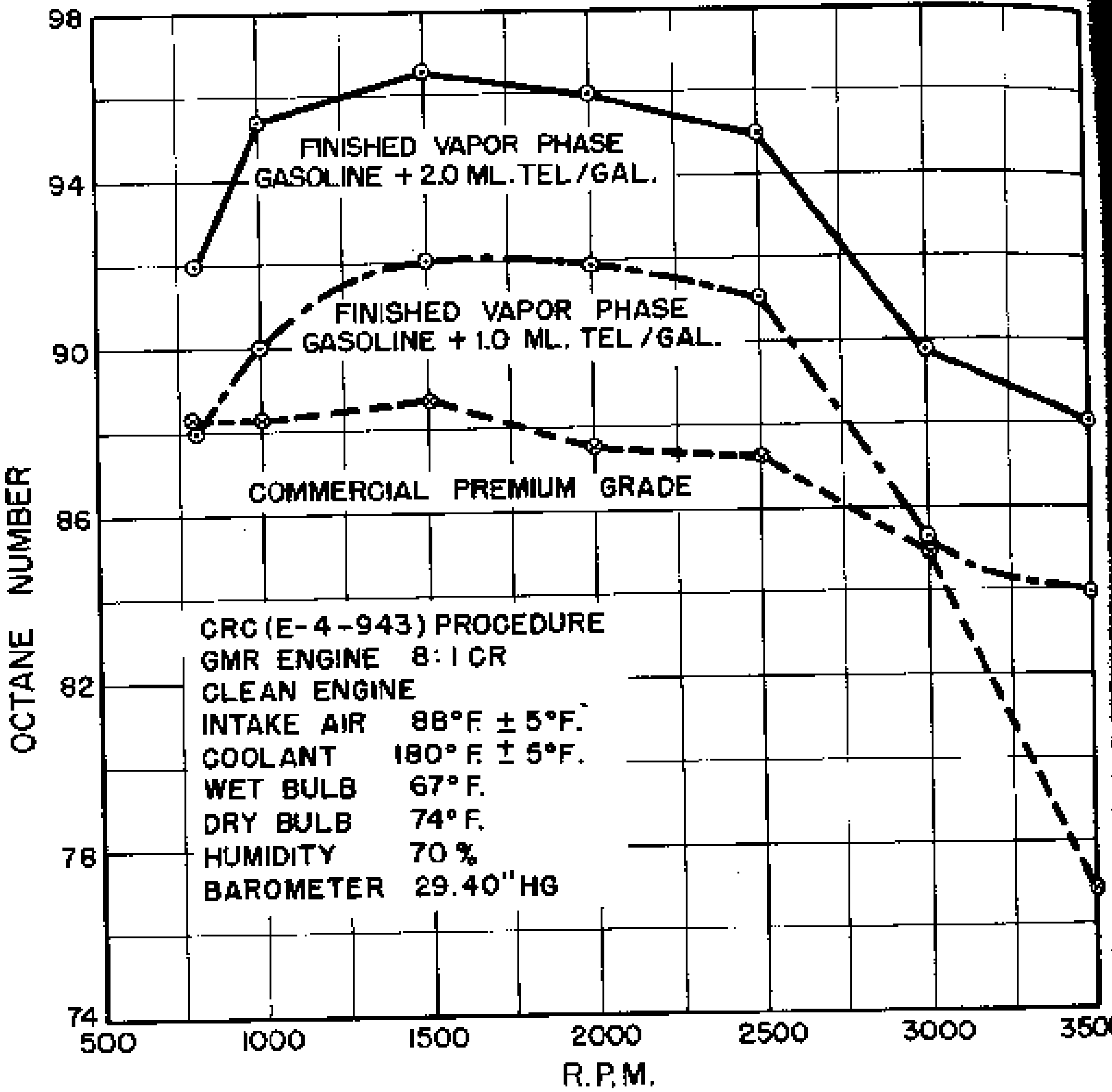


Figure 11. - Loading gasoline made from Rock Springs coal for shipment to Army.



FUEL RATINGS

SAMPLE	800	1000	1500	2000	2500	3000	3500
FIN. VAPOR PH. GASO. +2.0 ML. TEL/GAL.	92.0	95.5	96.5	96.0	95.0	89.7	88.0
COMMERCIAL PREMIUM GRADE	88.2	88.2	88.7	87.5	87.2	85.0	76.7
FIN. VAPOR PH. GASO. +1.0 ML. TEL/GAL.	88.0	90.0	92.0	92.0	91.0	85.2	84.0

Figure 12. - Dynamometer fuel ratings of gasoline from Western Kentucky coal.

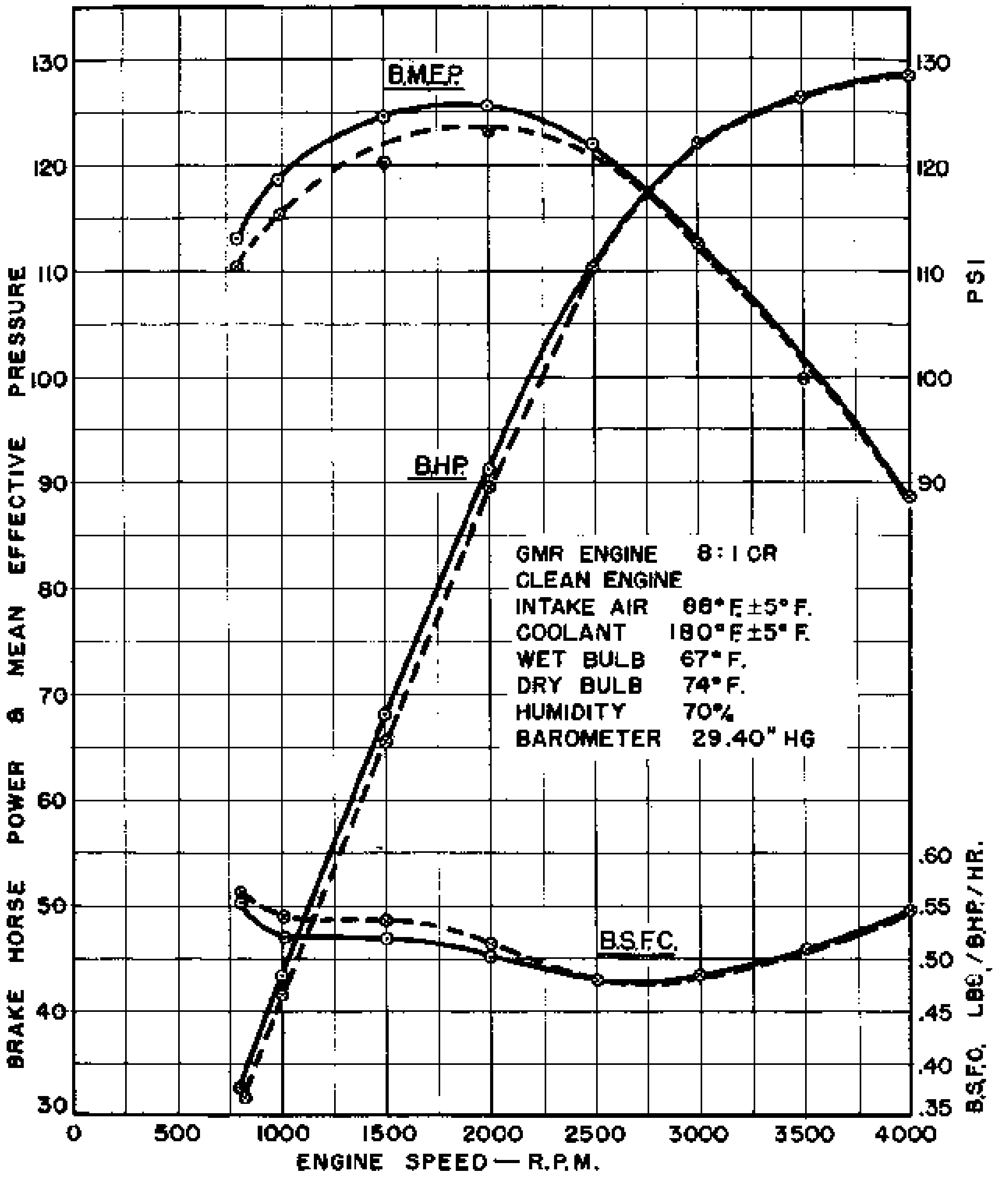


Figure 13. - Maximum performance curves, knock limited, for gasoline from Western Kentucky coal. B.M.E.P. is brake-mean effective pressure, B.H.P. to brake horsepower, and B.S.F.C. to best-setting fuel consumption.

Lead susceptibility

	Octane No.			
	Western Kentucky		Rock Springs	
	Motor	Research	Motor	Research
Gasoline + 1 ml. TEL/gal.	84.2	90.8	82.6	88.6
Gasoline + 2 ml. TEL/gal.	86.8	93.7	85.7	92.5
Gasoline + 3 ml. TEL/gal.	88.9	96.2	88.4	94.3

It is evident that both of these fuels have good lead-susceptibility characteristics and meet the requirements for a high-quality gasoline.

The finished vapor-phase gasoline from Western Kentucky No. 11-bed coal was subjected to dynamometer tests made on a General Motors research engine at 8:1 compression ratio to determine its maximum performance characteristics and octane ratings A conventional commercial-type premium-grade gasoline was run for comparative purposes. The CRC designation E-4-943 test procedure was used to determine the fuel ratings. The maximum performance characteristics were developed at full throttle, and the spark timing was adjusted for trace knock or peak power, depending upon the detonation tendency of the fuel. The results are summarized in figures 12 and 13.

Examination of the curves indicates that the vapor-phase gasoline has a higher octane rating than a commercial-type premium fuel. The brake horsepower and mean effective pressures developed by the vapor-phase gasoline with 2 cc. per gallon TEL added were higher than the premium fuel at engine speeds below 2,500 r.p.m. and the same at 2,500 r.p.m. and higher. The fuel consumption was likewise lower at the lower speeds and the same at 2,500 r.p.m. and higher. This can be attributed to the fact that both fuels satisfied the maximum power octane-number requirement at the higher engine speeds.

Aviation-Base Gasoline

The sample of aviation-base gasoline produced from Western Kentucky No. 11-bed coal had the following properties:

Gravity	°A.P.I.	54.0
Distillation:		
10 percent evaporated	°F.	155
50 percent evaporated	do.	209
90 percent evaporated	do.	277
E.B.P.	do.	324
Recovery	percent	99.0
Residue	do.	1.0
Sum of 10 percent and 50 percent evaporated	°F.	364
Acidity of distillation residue		Nil
Vapor pressure	p.s.i.	5.6
Corrosion, copper strip		Negative
Copper dish gum	mg./100 ml.	12.5
Potential gum	do.	2.4
Sulfur content	percent	0.03
Freezing point	°F.	2 below 0
Water tolerance		Immiscible
Aniline point	°F.	87.8
Heat of combustion	calculated B.t.u./lb.	18,710
Octane number:		
Lean mixture		75.2
Performance number		53.
Rich mixture		Too low for use of method

This gasoline was blended with isopentane and alkylate and the blends tested for meeting the requirements for 91/98, 100/130, and 115/145 gasolines. The compositions and vapor pressures of the blends were as follows:

Blend	91/98	100/130	115/145
Aviation-base gasoline .... percent	88.9	53.3	19.6
Isopentane .... do.	11.1	6.7	2.4
Alkylate .... do.	-	40.0	78.0
TEL .... ml./gal.	4.6	4.6	4.5
Vapor pressure .... p.s.i.	7.0	6.7	6.7

The results of the tests are as follows:

Blend	Lean mixture (A.S.T.M-D 614-49T.)	Rich mixture (A.S.T.M.-D 909-48T.)
91/98		
Octane rating	92.7	Iso-octane plus 0.37 ml. TEL/gal.
Performance No.	-	112.5
100/130		
Octane rating	99.9	Iso-octane plus 1.55 ml. TEL/gal.
Performance No.	-	133.5
115/130		
Performance No.	Iso-octane plus 0.47 ml. TEL/gal. 115	Iso-octane plus 3.0 ml. TEL/gal. 146.6
Alkylate		
Performance No.	Iso-octane plus 0.98 ml. TEL/gal. 125.4	Iso-octane plus 4.6 ml. TEL/gal. 155.5

Results of these tests indicate that the base stock, after blending, meets the knock-value requirements for all grades of aviation gasolines. Except for the copper-dish gum and freezing points, the fuel meets all inspection tests outlined in A.S.T.M.-D 910-48T. The copper-dish gum is only slightly high, but the freezing point is much too high. The freezing-point specification was easily met in German plants processing bituminous coal. Investigations in the Bureau's laboratory show that our gasoline has a freezing point of -70° F. The cause of the discrepancy between the Bureau and commercial laboratory determinations of freezing point is not yet known but is being investigated.

Jet Fuel

A sample of jet fuel made from vapor-phase products obtained by hydrogenation of Western Kentucky No. 11-bed coal also was tested. The blend contained 25 percent vapor-phase distillation bottoms, 40 percent aviation-base gasoline, and 35 percent finished vapor-phase gasoline.

The results of the laboratory tests were as follows:

Gravity	°A.P.I.	45.4
Distillation:		
10 percent evaporated	°F.	158
50 percent evaporated	do.	255
90 percent evaporated	do.	432
End point	do.	557
Recovery	percent	99.0
Residue	do.	1.0
Reid vapor pressure	p.s.i.	6.1
Freezing point	°F.	2
Corrosion, ("air-well" copper strip)		No evidence
Existent gum	mg./100 ml.	13.8
Accelerated gum	mg./100 ml. (16 hrs.)	15.8
Aromatics	percent	26.6
Sulfur	do.	0.024
Water tolerance		Immiscible
Bromine number		16
Heat of combustion	B.t.u./lb. (calculated)	18,520

The blend meets specification MIL-F-5624A, except the aromatics limitation of 25 percent and the freezing point, -76° F. The earlier comments also apply in this case.

Chemicals

Routine laboratory determinations have been made of the total contents of the chemicals under discussion in the product streams from three coals. These contents, as volume percent of product streams, are given in table 3 for the liquid-phase operations and in table 5 for the vapor-phase. Liquid-phase tar acid and base percentages are given for Rock Springs, Western Kentucky, and Illinois coals and aromatics for the last two coals only, as these determinations were not made during the Rock Springs liquid-phase runs. Vapor-phase percentages for the three types of chemicals are given for Rock Springs and Western Kentucky coals only, as the Illinois liquid-phase product has not yet been processed in vapor-phase.

The difference in content of chemicals in the respective liquid-phase streams of the three coals may be attributed to several factors, such as: (1) Difference in boiling range of the respective streams for each coal; (2) type of catalyst used in processing; (3) severity of processing; and (4) inherent differences in the coals themselves. The Rock Springs coal was processed with tin catalyst and subjected to a severe treatment, as attested in table 2 by the high reaction temperatures and the negative yields in heavy oil. Western Kentucky and Illinois coals were processed under milder conditions - Illinois entirely under $FeSO_4$ as catalyst and Western Kentucky with tin, tin and iron, and finally with iron as $FeSO_4$.

The total content of the three type chemicals in the liquid-phase light oils is given in table 6 in pounds and in gallons per ton of moisture- and ash-free coal processed. It may be significant that the gross contents of tar acids are lower for both coals with which tin catalyst was used. However, the processing severity for the Rock Springs coal must not be overlooked, and it appears that the high temperatures to which this coal was subjected, though bringing about high reduction of tar acids, at the same time may have caused retention of a higher degree of aromaticity.

The gross content of the lower-boiling tar acids (<225° C.), which constitute the bulk of industrial demand, is given in table 7 for the three coals. These values are based on analyses by the Synthetic Liquid Fuels Research Branch at Bruceton, Pa., from liquid-phase light-oil blends derived from these coals. The higher yields of phenol and cresols from Western Kentucky and Illinois coals are evident at once. However, the blends represent yields under processing conditions attained at this plant only and must not be interpreted as the maximum yields possible.

TABLE 6. - Gross contents of tar acids, tar bases, and aromatics in liquid-phase light oils

Based on m.a.f. coal processed	Rock Springs		Western Kentucky		Illinois	
	Gal./ton coal	Lb./ton coal	Gal./ton coal	Lb./ton coal	Gal./ton coal	Lb./ton coal
Tar acids						
Gasoline	2.4	21.2	0.9	7.6	0.1	0.9
Naphtha	(1)	(1)	13.9	117.1	17.4	146.5
Middle oil ...	20.3	175.9	13.4	116.6	18.4	159.2
Total	22.7	197.1	28.2	241.3	35.9	306.6
Tar bases						
Gasoline	1.5		0.6		0.3	
Naphtha	(1)		.3		.2	
Middle oil ...	2.5		.1		Negligible	
Total	4.0		1.0		.5	
Aromatics						
Gasoline	No individual		6.4		4.1	
Naphtha	stream analysis		11.9		17.9	
Middle oil ...	available		27.6		42.4	
Total	65.6		45.9		64.4	

1/ Naphtha included in gasoline and middle oil.

TABLE 7. - Gross content of low-boiling tar acids in liquid-phase light oils

Based on m.a.f. coal	Rock Springs		Western Kentucky		Illinois	
	Gal./ton coal	Lb./ton coal	Gal./ton coal	Lb./ton coal	Gal./ton coal	Lb./ton coal
Phenol	2.5	22.4	3.1	27.4	2.8	24.7
o-Cresol	1.1	9.6	0.7	6.2	1.1	9.4
m-Cresol	2.4	21.2	2.3	20.1	2.8	24.1
p-Cresol	0.7	6.4	1.2	10.3	1.4	11.8
Subtotal	6.7	59.6	7.3	64.0	8.1	70.0
Mixed xylenols	4.6	39.8	-	-	-	-
Total	11.3	99.4	-	-	-	-

The gross chemical contents of vapor-phase gasolines derived by processing the liquid-phase light oil from Rock Springs and Western Kentucky coals are given in table 8. Comparison of this table with table 6 for the liquid-phase streams at once makes evident the reduction in tar acids that takes place during the vapor-phase processing. The aromatic content on a volume basis compares favorably with the quantities in the feed. Furthermore, a molecular reduction takes place during the vapor-phase processing, converting the heavier aromatics into low-boiling aromatic gasoline components that improve the fuel properties of gasoline or may be separated for industrial usage. Conversion of heavier-boiling compounds by vapor-phase processing into industrially usable low-boiling aromatics is illustrated in the first two columns of table 9 that compare the content of the various compounds in the 50° to 150° C. fractions of liquid- and vapor-phase gasolines from Rock Springs coal. These values are given in pounds per ton of moisture- and ash-free coal processed and again are based on analyses furnished by the Synthetic Fuels Research Branch at Bruceton. Not only do the low-boiling aromatic yields increase tremendously on destructive hydrogenation of the liquid-phase light oils, but also there is a comparative increase in aromatic materials that may be converted by industrial catalytic aromatization processes.

To determine the effectiveness of industrial processes in the aromatic enrichment of coal-hydrogenation gasolines, cooperative study agreements have been made with Universal Oil Products and the Standard Oil Co. of Indiana, wherein gasolines from the demonstration plant have been subjected to platforming and hydroforming under various degrees of treatment severity. The results of these cooperative tests will be published as a joint report. Both processes appear quite suitable for processing final coal-hydrogenation gasolines from the vapor phase.

Column 3 of table 9 gives the indicated yields of the various hydrocarbons had the vapor-phase 50° to 150° C. product been subjected to catalytic aromatic enrichment. A study of aromatic enrichment of liquid-phase gasoline by hydroforming is now in progress.

TABLE 8. - Gross contents of tar acids, tar bases and aromatics in vapor-phase raw gasoline

	Rock Springs		Western Kentucky	
	Gal./ton coal	Lb./ton coal	Gal./ton coal	Lb./ton coal
Tar acids	0.7	6.0	1.0	8.7
Tar bases	1.0	-	1.0	-
Aromatics	43.4	-	37.6	-

TABLE 9. - Comparison of contents of various components in 50° - 150° C. cuts of liquid- and vapor-phase gasoline from Rock Springs coal

Components in 50° - 150° cuts	Pounds per ton of coal		
	Liquid phase	Vapor phase	Vapor-phase cat. aromatized 1/
Paraffins, total	27.6	143.5	98.8
Naphthenes, total	71.4	384.0	91.2
Cyclopentane	0.3	2.6	2.1
Methylcyclopentane	3.6	64.6	37.9
Cyclohexane	10.8	26.6	5.1
Dimethylcyclopentanes	4.5	53.2	22.9
Methylcyclohexane	12.7	52.7	6.8
Ethylcyclopentane	4.8	38.9	4.4
C_8 - Naphthenes)	17.5	78.3	12.9
C_9 - Naphthenes)	10.5	67.2	
Aromatic, total	33.5	208.7	412.0
Benzene	2.5	46.1	86.8
Toluene	11.0	83.3	158.3
Ethylbenzene	11.6	23.7	47.4
m-p-Xylene	5.3	46.8	95.8
o-Xylene	2.9	8.8	22.9
Olefins, total	15.2	8.3	13.7
Total	147.7	744.5	614.9
Nonhydrocarbons, total	11.3	10.6	

1/ Probable yields had the vapor-phase cut been subjected to catalytic aromatization. Estimates based by the Bureau on results obtained by the Standard Oil Co. of Indiana upon hydroforming of vapor-phase gasoline through a cooperative agreement. Full results of cooperative work will be published later.

Gas-Synthesis Demonstration Plant

Coal Gasification

Installation of the new Morgantown-type vertical oxygen-coal gasifier (fig. 14), described in the 1950 Annual Report, has been completed. A flow diagram of this system, which employs a new method of feeding preheated steam-coal mixtures, is shown as figure 15. Existing equipment was used as far as possible in the hook-up.

The coal-feeding system consists of accumulator metering tanks for coal and water, which dump periodically into a slurry-mix tank as additional material is required in the latter. This tank is equipped with two high-speed, propeller-type agitators and is of 1,600 gallons capacity, large enough to