

PRODUCTION OF PIPELINE GAS BY BATCH
HYDROGENOLYSIS OF OIL SHALE

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ABSTRACT

The conversion of oil shale to high heating value gases by direct hydrogenation was investigated to determine if the production of pipeline gas by this method was feasible and if it offered potential advantages over alternate methods for utilization of the large reserves of this fossil fuel. Data on the batch hydrogenolysis of a 22.9 gal. per ton Fischer assay Colorado oil shale were obtained at a maximum reactor temperature of 1300°F., maximum pressures of 1200 to 5700 p.s.i.g., hydrogen-shale ratios equivalent to 50 to 200 per cent of stoichiometric requirements for complete conversion of the organic carbon plus hydrogen content to methane, and for three particle size ranges. Nearly complete conversion of organic carbon and hydrogen to a fuel gas with a heating value of over 800 B.t.u. per standard cubic foot was obtained in relatively short residence times at temperatures of 1200° to 1300°F., with only little formation of carbon oxides from mineral carbonate decomposition. In view of the relatively low material costs, these results indicate that serious consideration can be given to supplementing the future supply of natural gas with synthetic high heating value gas from oil shale, particularly in areas served by long-distance transmission lines passing in the vicinity of the Colorado deposits.

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An exploratory investigation has been made of the dry, high-pressure hydrogenolysis (hydrogasification) of oil shale as part of a continuing program concerned with the production of natural gas supplements and substitutes from liquid and solid fossil fuels.

Previous publications in this series have dealt with the high-pressure hydrogasification of petroleum oil, bituminous coal and lignites, and pure compounds related to petroleum oils.^{4,13,14} The purpose of the present work was to determine if the recovery of the organic constituents of oil shale in the form of high heating value gas would provide an attractive alternative to the conventional approach of maximizing liquid products recovery. Results indicated that rapid, and nearly complete conversion of the organic carbon plus hydrogen content of oil shale to a high methane and ethane content gas of over 800 B.t.u./SCF (standard cubic foot at 60°F., 30 inches of mercury pressure, saturated with water vapor) heating value can be obtained at relatively moderate temperatures and pressures.

A Colorado oil shale of 22.9 gal. per ton Fischer assay was used throughout the study, since this material appeared representative of the Green River formation deposit of Northwestern Colorado estimated to contain about 1260 billion barrels of oil.⁶

An indication of the need for development of economical methods for the production of pipeline gas from the large reserves of solid fossil fuels can be obtained from a recent study of factors influencing United States crude oil and natural gas production.⁵ The results of this study show that on the basis of an estimate of average drilling return (ratio of established reserves to footage drilled), domestic crude oil prices would have to reach \$6 per barrel to achieve an ultimate recovery of 160 billion barrels, and that at a maximum price of \$4 per barrel only 140 billion barrels would be ultimately recovered. These crude oil prices were computed after allowing for natural gas revenues ranging from 50 cents per barrel at present, to over \$1 per barrel at the time ultimate crude oil recovery reaches 160 billion barrels. Since 88 billion barrels of domestic crude oil had already been discovered at the end of 1957, this would correspond to additional discoveries of only 52 billion barrels at a maximum price of \$4 per barrel, or 72 billion barrels at a maximum price of \$6 per barrel, assuming average drilling return. At an expected average future recovery of 6000 cubic feet of natural gas per barrel of crude oil,^{5,18} the total additional gas supply, including present reserves of 247 trillion cubic feet,¹ would then be about 560 and 680 trillion cubic feet, respectively. This is substantially less than a recent estimate of 1200 trillion cubic feet (corresponding to an ultimate crude oil recovery of 250 billion barrels), based on geological factors without consideration of economic limitations on exploration and drilling.^{7,18}

Thus, if increased importation of relatively low-cost foreign crude is permitted, lack of economic incentives may retard development of a major portion of potential domestic crude oil reserves. Oil shale would correspondingly gain in importance as an alternate source

of pipeline gas in view of the large and well-known proved reserves, approaching in magnitude the thermal value of economically recoverable coal reserves.^{11,12}

APPARATUS AND PROCEDURE

The one-liter Autoclave Engineers high-temperature, high-pressure reactor used in previous batch hydrogenolysis studies was used in this work.^{13,14} The procedure was essentially the same as described in the pure compound study.¹⁴ The reactor was charged at room temperatures and placed in the rocking furnace, which was also at room temperature. Heating at full input (4.5 kw.) was maintained throughout the rising temperature portion of the run, with temperature rising at about 9°F. per minute. Simultaneous temperature and pressure measurements were taken, and gas samples were obtained at intervals throughout the course of each run which consisted of a 128 to 152 minute period required to reach the nominal temperature of 1300°F., and an additional 30 minute period at 1300°F. In all cases reaction was initiated well below 1300°F.; the initiation of rapid gasification appeared to correlate with the appearance of a well-developed temperature dip at 1025°F. In accordance with previous practice, this was designated the initial gasification temperature for oil shale and was arbitrarily used as a zero time base for the space-time yield calculations. Feed and residue shale samples were subjected to sieve analysis, and to ultimate analysis for total carbon and hydrogen. Mineral carbon was determined gravimetrically from the carbon dioxide evolved with acid, in a technique employed by the Bureau of Mines Experiment Station, Laramie, Wyoming; organic carbon was obtained by difference.¹⁷ Carbon dioxide liberation values determined from residue shale analyses were found to be uniformly greater than values obtained from gas analysis data, because of continued evolution of carbon dioxide after runs were terminated; conclusions concerning carbon oxides formation were drawn from product gas yields and compositions.

Product gas samples were analyzed with a Consolidated Engineering Co. Model 21-103 mass spectrometer; heating values and specific gravities were calculated from the analyses. Product gas volumes and heating values were calculated at 60°F., 30 inches of mercury absolute pressure, and saturation with water vapor, assuming the ideal gas law. Specific gravities were calculated on a dry basis from the average molecular weight of the gas referred to air of molecular weight 28.972. Initial hydrogen volumes were obtained by direct measurement; the reactor was charged with shale and hydrogen to the desired pressure, and the hydrogen was slowly vented through a wet test meter. Use of compressibility data at room temperature permitted the calculation of reactor free space when charged with shale. Product gas volumes during the course of the run at temperatures of 950°F. and above were calculated from observed temperatures and pressures and the initial reactor free space, assuming ideal gas behavior. Previous work with coal has shown that gas volumes calculated by this method agree with values measured by wet test meter, with a deviation of about 3 per cent.¹³ Further, the reasonably close agreement of reported organic carbon and hydrogen conversions based on computed product gas volumes, and organic carbon conversions based on residue ultimate analyses, supports the use of pressure-temperature-reactor volume measurements with assumption of ideal gas behavior. The feed shale analysis is given in Table 1, and the effects of process variables are shown in Tables 2, 3, and 4, and Figures 1 and 2.

Table 1.-ASSAY AND ANALYSIS OF U.S. BUREAU
OF MINES OIL SHALE SBR58-40X

Fischer Assay ^a	
Oil, wt. %	8.8
Water, wt. %	1.2
Spent shale, wt. %	88.0
Gas + loss, wt. %	2.0
Total	100.0
Oil, gal./ton	22.9
Water, gal./ton	3.0
Sp. gravity of oil, 60°/60°F.	0.917-0.918

Carbon-Hydrogen Analysis ^b	
Carbon, wt. %	
Mineral	4.88
Organic	10.52
Total	15.40
Hydrogen, wt. %	1.59
Ash, wt. %	68.98
Mineral CO ₂ , wt. %	17.88

Sieve Analysis ^c	
40-100 Mesh Sample	
Runs 3, 4, 5, 10, 11	
U.S.S. Sieve	Wt. %
+40	0.8
40-50	25.3
50-60	20.0
60-70	19.1
70-80	16.7
80-100	13.6
-100	4.5
Total	100.0

Sieve Analysis ^d	
5-20 Mesh Sample	
Run 8	
U.S.S. Sieve	Wt. %
+5	4.6
5-8	41.3
8-10	4.7
10-12	8.4
12-14	8.1
14-16	13.4
16-18	0.6
18-20	13.2
-20	5.7
Total	100.0

Sieve Analysis ^e	
140-325 Mesh Sample	
Run 9	
U.S.S. Sieve	Wt. %
+140	3.2
140-170	24.5
170-200	0.4
200-230	32.8
230-270	11.2
270-325	0.2
-325	27.7
Total	100.0

- a) Average of U. S. Bureau of Mines Runs 53456 and 53457.¹⁷
- b) Average of U. S. Bureau of Mines Runs 10291 and 10292.¹⁷
- c) I.G.T. Lab. No. 3910.
- d) I.G.T. Lab. No. 4012.
- e) I.G.T. Lab. No. 4013

Table 3.-EFFECTS OF HYDROGEN FEED RATIO ON HYDROGASIFICATION OF OIL SHALE

	RUN 11 - 0.100 lb. ORGANIC C+H, 50% OF STOICHIOMETRIC				RUN 5 - 0.025 lb. ORGANIC C+H, 200% OF STOICHIOMETRIC			
	1	2	3	4	1	2	3	4
Feed shale weight, lb	1025	1075	1200	1300	1290	1290	1290	1298
Organic C+H, lb.	205	245	320	405	4075	4075	4075	2040
Feed hydrogen	93	103	107	127	157	177	177	165
Initial pressure, p.s.i.g.								
Feed ratio								
% of stoichiometric ^a	51.5							
SCF/lb. of organic C+H	15.78							
SCF/ton of shale	3822							
Operating Results								
Reactor temperature, °F.	950	1025	1075	1200	1300	1290	1290	1295
Reactor pressure, p.s.i.g.	230	245	245	320	405	4075	4075	2040
Time above room temp., min.	93	103	107	127	147	157	177	165
Time to start run temp., (1300°F.) min.								
Product gas yield ^b								
SCF/lb. org. C+H	15.76	17.44	17.52	20.54	24.30	24.42	24.56	55.22
SCF/ton of shale	3817	4224	4244	4974	5886	5915	5949	13372
Net B.t.u. recovery	490	1511	2332	3582	5656	3423	3330	4366
M.B.t.u./ton of shale	11.2	31.7	49.5	72.3	76.7	70.8	68.8	107.8
Gasification of organic C+H in shale, % of total ^b								
Gasification of organic C in shale, % of total ^d								
Gaseous hydrocarbon space- time yield, ^c reactor-hr.								
SCF/cu.ft. reactor-hr.			294.9	120.6	73.0	57.2	40.6	18.5
Thermal space-time yield, ^c			618.8	139.4	77.9	59.9	42.8	23.7
M.B.t.u./cu.ft. reactor-hr.								
Spent shale, wt. % of shale charged								
Material balance, %								
Product Gas Properties								
Composition, mole %								
N ₂ + CO	2.4	3.6	4.4	3.3	4.1	5.4	6.1	8.6
H ₂	5.1	6.1	6.1	10.0	13.8	16.9	16.1	5.4
CH ₄	85.1	67.2	49.6	3.2	3.8	4.7	5.3	4.1
C ₂ H ₆	3.5	10.4	18.3	71.4	75.4	74.0	71.6	31.9
C ₃ H ₈	1.9	5.9	10.4	10.1	2.0	0.6	0.4	50.7
C ₄ H ₁₀	1.6	4.4	7.2	0.5	0.1	0.1	0.1	3.2
Higher paraffins	1.0	2.1	2.8	0.2	0.1	0.1	0.2	0.1
Higher olefins								
Benzene	1.0	1.3	1.1	0.1	0.1	0.1	0.1	0.1
Toluene								
Total	100	100	100	100	100	100	100	100
Heating value, B.t.u./SCF	449.2	646.8	837.1	965.6	835.4	785.2	765.1	692.0
Specific gravity (air = 1)	0.238	0.411	0.565	0.728	0.712	0.708	0.719	0.466

a) Stoichiometric for complete conversion of organic C + H in shale to methane.
 b) Calculated from observed reactor pressure and temperature, and initial reactor free volume, assuming ideal gas law.
 c) Product of gas yield and heating value, less thermal input of feed hydrogen.
 d) Calculated from carbon analysis of residue.
 e) Value doubtful.

Table 4.-EFFECTS OF PARTICLE SIZE RANGE ON HYDROGASIFICATION OF OIL SHALE

	RUN 8 - 5 TO 20 MESH PARTICLE RANGE				RUN 9 - 140 TO 325 MESH PARTICLE RANGE			
Feed Shale								
Charge weight, lb.	0.4129				0.4129			
Organic C-H, lb.	0.0500				0.0500			
Feed rate, lb./hr.	725				740			
Initial pressure, p.s.i.g.	103.2				103.0			
Feed ratio	31.64				31.54			
% of stoichiometric C-H	7663				7639			
SCF/lb. of organic C-H								
SCF/ton of shale	850	1085	1075	1200	1308	1298	1300	1305
Operating Results	1860	1705	2105	2385	2425	2400	2480	2520
Reactor temperature, °F.	68	100	107	125	140	150	140	150
Reactor pressure, p.s.i.g.	--	--	--	--	--	--	--	--
Reactor run time, min.	--	--	--	--	--	--	--	--
Time at normal run temp., (1300°F.), min.	--	--	--	--	--	--	--	--
Product gas yield, ^b								
SCF/ton of shale	31.44	32.34	31.60	31.68	32.58	33.16	34.02	32.38
SCF/ton of shale	7614	7832	7653	7672	7891	8031	8239	7944
Net B.t.u. recovery, ^c	425	1948	2725	4062	4191	4017	3739	398
M B.t.u./ton of shale	10.6	42.4	60.0	87.4	95.5	93.4	88.4	6.7
Gasification of organic C-H in shale, % ideal	--	--	--	--	--	--	--	--
C in shale, % of total	--	--	--	--	--	--	--	--
Gasous hydrocarbon space-time yield,								
SCF/cu.ft. reactor-hr.	--	--	--	--	--	--	--	--
Thermal space-time yield,								
M B.t.u./cu.ft. reactor-hr.	--	--	--	--	--	--	--	--
Spent shale, wt. % of shale charged	--	--	--	--	--	--	--	--
Water balance, %	--	--	--	--	--	--	--	--
Proct Gas Properties								
Composition, mole %								
N ₂ + CO	1.1	2.9	3.8	6.4	8.1	7.0	6.3	1.5
CO ₂	1.6	2.0	2.6	5.3	10.9	13.9	17.3	1.9
H ₂	93.8	77.2	66.1	33.4	15.2	9.1	5.9	93.9
CH ₄	1.3	7.9	12.6	33.5	52.0	62.8	68.7	1.2
C ₂ H ₆	0.5	4.6	7.4	19.8	12.8	6.4	1.4	0.6
C ₃ H ₈	0.4	3.0	5.0	0.7	0.2	0.2	--	0.5
Higher paraffins	0.3	0.2	0.3	0.1	--	--	--	0.2
Alkynes	0.3	0.5	0.5	0.2	--	--	--	0.2
Higher olefins	0.7	0.6	0.3	0.4	0.8	0.6	0.4	0.2
Benzene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total	377.2	561.5	676.0	848.5	841.4	805.0	750.9	349.7
Heating value, B.t.u./SCF	0.147	0.296	0.393	0.585	0.698	0.717	0.733	0.136
Specific gravity (air = 1)								

a) Stoichiometric for complete conversion of organic C + H in shale to methane.
 b) Calculated from observed reactor pressure and temperature, and initial reactor free volume, assuming ideal gas law.
 c) Product of gas yield and heating value, less thermal input of feed hydrogen.
 d) Calculated from carbon analysis of residue.

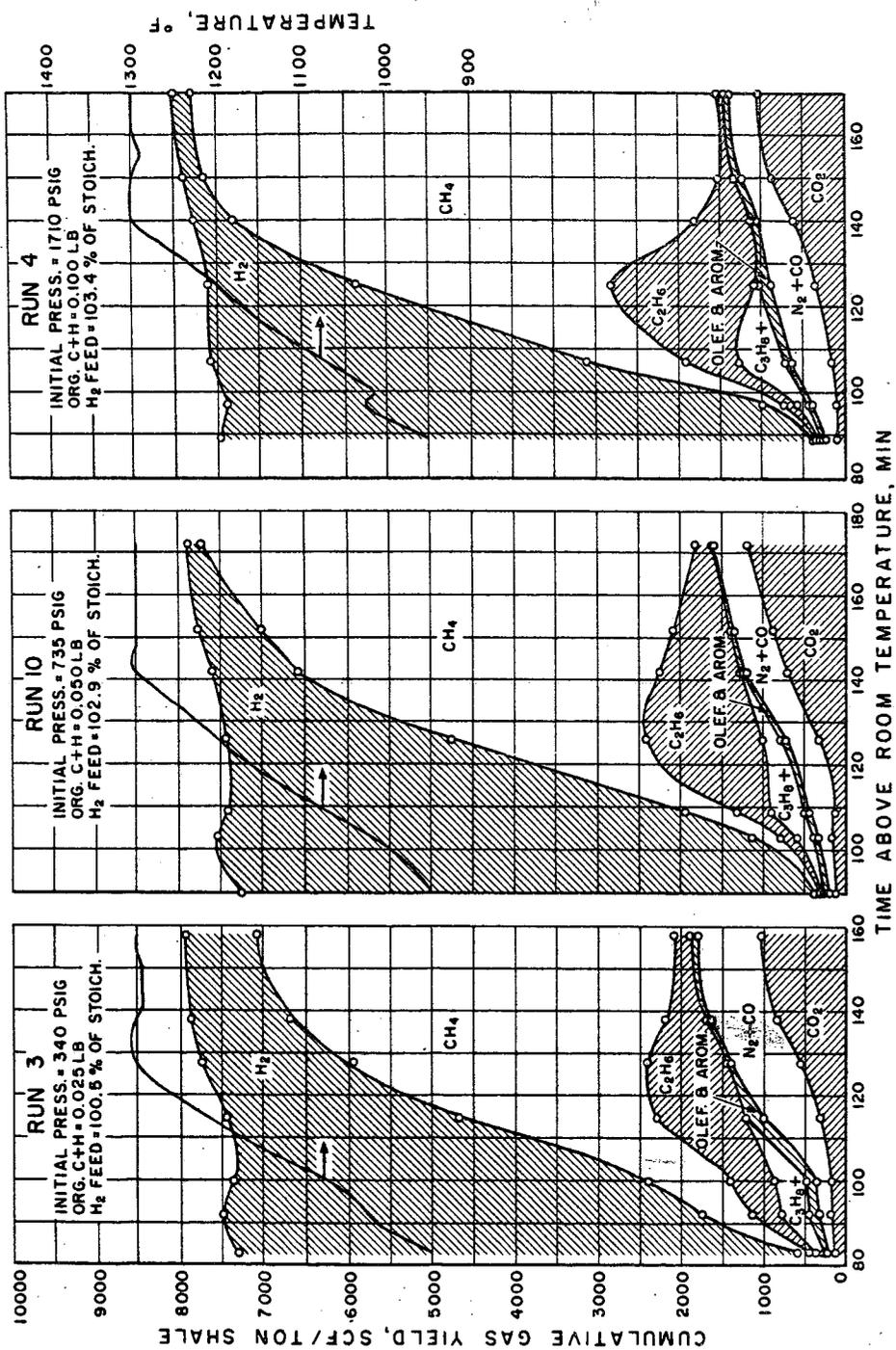


FIG. 1.-EFFECTS OF PRESSURE ON HYDROGASIFICATION YIELDS OF 22.9 GAL./TON FISCHER ASSAY OIL SHALE

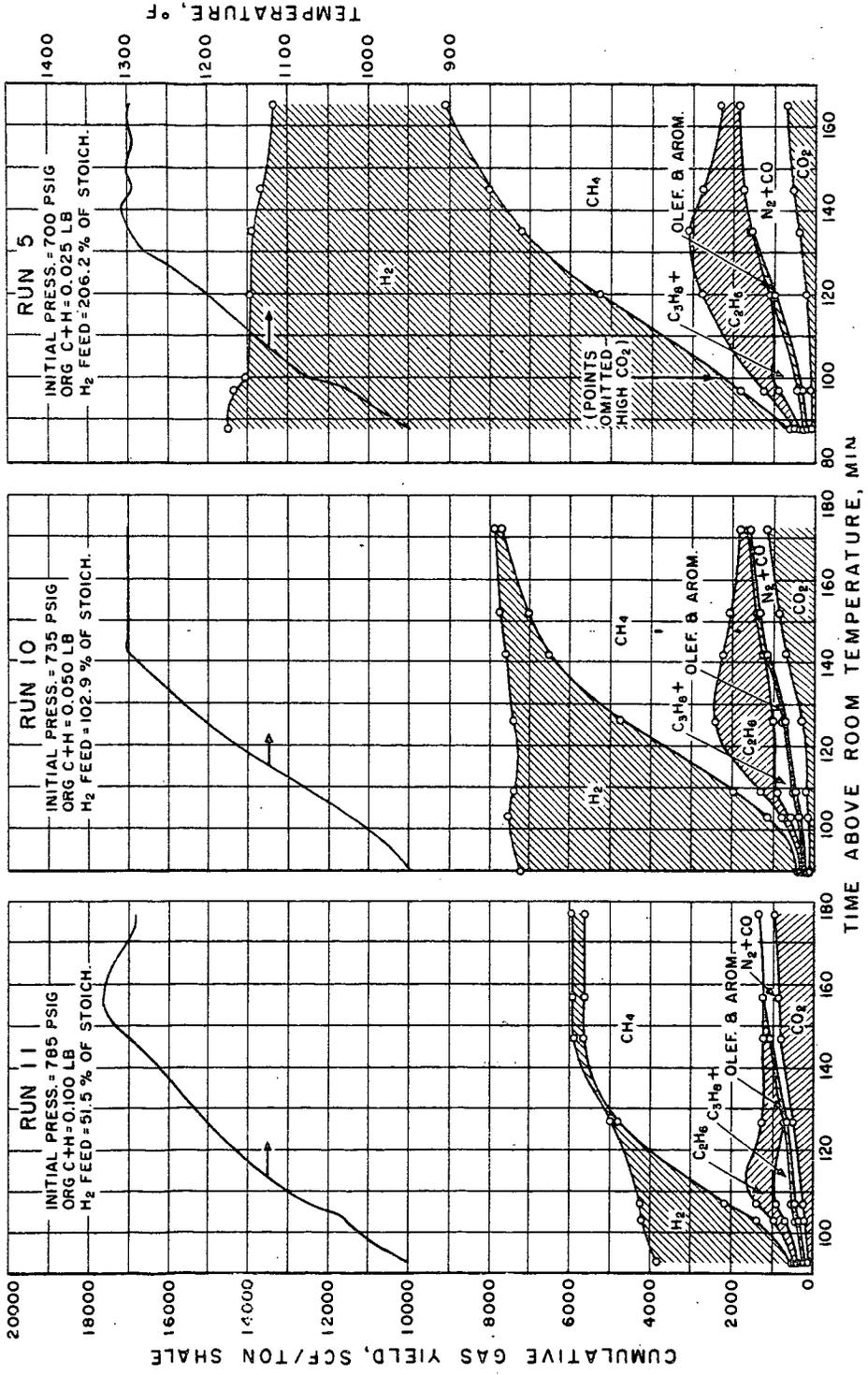


Fig. 2.-EFFECTS OF FEED RATIO ON HYDROGASIFICATION YIELDS OF 22.9 GAS./TON FISCHER ASSAY OIL SHALE

EFFECTS OF PRESSURE

At all three pressure levels studied, 340, 735 and 1710 p.s.i.g. initial pressure (1215, 2430 and 5540 p.s.i.g., respectively, upon attainment of 1300°F.), the results showed that high heating value product gases were obtained at high organic carbon-plus-hydrogen conversions as the nominal run temperature of 1300°F. was approached; product gas dilution with carbon oxides was not excessive and practically no liquid products were formed (Table 2). The spent shale was free flowing and had virtually the same sieve analysis as the charge.

Rapid attainment of high conversions of the organic matter to gas (primarily methane, ethane and propane) at temperatures of only 1200° to 1300°F. was primarily responsible for the low evolution of mineral carbon oxides⁹; this differs significantly from the results obtained in high-temperature retorting at low pressures and in the absence of hydrogen.^{2,18} Although higher pressure would be expected to suppress carbon dioxide evolution, the apparent yield and mole per cent of carbon dioxide was not affected significantly by pressure level (Figure 1). However, total yields of carbon oxides were decreased at the higher pressures, reflecting the decrease in carbon dioxide conversion to carbon monoxide by the reaction $\text{CO}_2 + \text{H}_2 \rightarrow \text{CO} + \text{H}_2\text{O}$, as the hydrogen content of the product gas decreased. Even at the lowest pressure level, total carbon oxides content was only 22.4 mole %. (The reported $\text{N}_2 + \text{CO}$ contents were primarily carbon monoxide.)

The hydrocarbon hydrogenolysis reactions, and the sequence of appearance of the stable intermediates in methane production from higher molecular weight carbon-containing materials (such as oil shale kerogen), corresponded closely to those observed in hydrogenolysis of petroleum oils¹³ and pure compounds related to petroleum oils.¹⁴ Propane and higher paraffin hydrocarbons formed in earlier portions of each run were soon hydrogenolyzed with increasing appearance of ethane and methane. Ethane yields and concentrations in turn passed through maxima with increases in time and temperature, as methane, the stable final product, continued to increase. Maximum ethane yields were observed at attainment of 1200°F. at all pressures (Figure 1). The effect of pressure increase was to increase the rate of ethane production below 1200°F. and the rate of ethane disappearance to methane above 1200°F. Methane yields were considerably increased above 1200°F. with increases in pressure, accompanied by increases in conversions and space-time yields. Increased hydrogen consumptions at higher pressures, together with lower carbon oxide yields and higher methane yields resulted in considerable increases in product gas heating values. For example, heating values of 792, 871 and 908 B.t.u./SCF were observed at attainment of 1300°F. as pressure was increased from 1215 to 2430 to 5540 p.s.i.g., respectively (Table 2).

At the two higher pressures studied, as well as in other runs carried out at 100% of stoichiometric feed ratio, the gasification of organic carbon-plus-hydrogen decreased slightly at temperatures of 1200° to 1300°F., accompanied by a decline in gas heating value in excess of that corresponding to increased carbon oxide formation. This indicates that insufficient hydrogen may have been present in the later portions of these runs to prevent a small amount of carbon formation from product hydrocarbons. This effect appeared to be greater at higher pressures, due to decreased hydrogen concentrations brought about by the higher hydrogen consumptions characteristic of higher pressure operation.

EFFECTS OF HYDROGEN-SHALE FEED RATIO

Figure 2 presents gas yield data at hydrogen-shale feed ratios of 50% (Run 11), 100% (Run 10) and 200% (Run 5) of stoichiometric requirements for conversion to methane; complete results for Runs 11 and 5 are given in Table 3, and for the key test, Run 10, in Table 2. At temperatures below 1200°F., the extent of gasification at 50% of stoichiometric hydrogen-shale feed ratio was approximately the same as at the higher feed ratios so that, in the absence of excess hydrogen dilution, earlier formation of high heating value product gas occurred. However, at the higher temperatures, conversions were reduced substantially by decreases in hydrogen supply, but not proportionally to reductions in feed ratio. For instance, at 1300°F., gasification of organic carbon and hydrogen was 77 weight % at 50% of stoichiometric, 90 weight % at 100% of stoichiometric, and complete at 200% of stoichiometric feed ratio. Considerable vapor-phase carbon formation was indicated during the later portion of the run at 50% of stoichiometric, and none at 200% of stoichiometric. This compares with evidence of only limited vapor-phase carbon formation, indicated by a gradual decline in conversion and product gas heating value, late in the course of the run at 100% of stoichiometric feed ratio.

Pressure levels for Runs 10 and 5 at 100% and 200% of stoichiometric feed ratio, respectively, were quite comparable, permitting a direct evaluation of the effect of hydrogen concentration on carbon oxides formation. Total carbon oxide yields were about the same for these two runs, but increased hydrogen concentration at 200% of stoichiometric feed ratio caused much greater conversion of evolved carbon dioxide to carbon monoxide.

Ethane yields were increased by increases in feed ratio from 50% to 200% of stoichiometric; however, ethane contents were greatest at 100% of stoichiometric feed ratio. Dilution of the product gas with excess hydrogen reduced the ethane content at 200% of stoichiometric, and pyrolysis reactions favoring methane over ethane formation reduced the ethane content at 50% of stoichiometric.

EFFECTS OF PARTICLE SIZE RANGE

In view of the substantial cost of oil shale size reduction,¹⁰ it would be desirable to utilize relatively large particle sizes if a practical hydrogenolysis process can be developed for moving- or fixed-bed operation. In Table 4, it can be seen that insignificant effects on gas yields and composition resulted from a variation in particle size range from 5-20 mesh to 140-325 mesh.

COMMERCIAL POSSIBILITIES

Production of pipeline gas from oil shale may be preferable to liquid fuel production because of higher conversion of organic matter (90-100 weight % for hydrogasification, compared to about 80 weight % conversion to liquid and gaseous products in conventional retorting²) and elimination of costly liquid product refining operations. Hydrogasification, in addition to producing a free-flowing residue containing little organic matter, also yields only negligible quantities of liquid products. This differs from oil hydrogasification^{13, 14} and pyrolysis of crude shale oil,⁹ where substantial quantities of liquid byproducts are formed. Absence of agglomeration problems should permit the development of continuous moving- or fluid-bed oil shale hydrogasification processes. Fixed-bed operation would have the advantage of reduced feed preparation costs. Hydrogen requirements could be met with conventional catalytic steam reforming and carbon

oxide removal processes, utilizing a portion of the purified product gas for feed and fuel.

On the basis of the results with 22.9 gal. per ton shale at 50 to 100% of stoichiometric feed ratios, about 4900 to 6600 SCF/ton of 1000 B.t.u./SCF equivalent gas can be produced with 3800 to 7600 SCF/ton of hydrogen feed. Total product gas requirements for hydrogen production, including all fuel requirements, will be about 1900 to 3800 SCF/ton, leaving a net 1000 B.t.u./SCF equivalent gas yield of 2800 to 3000 SCF/ton. Heat requirements for the shale processing step, estimated from gas combustion retort data³, will be about 500,000 B.t.u./ton, so that if product gas is used as a source of heat, a net gas yield of 2300 to 2500 SCF/ton would finally be obtained. At 50 cent/ton mining cost and 25 cent/ton crushing cost,¹⁰ this would result in a raw material cost of 30 to 33 cents/1000 SCF of 1000 B.t.u./SCF gas equivalent for 22.9 gal. per ton shale. Large deposits of shale average 30 gal. per ton or more,⁹ so that raw material cost could be reduced to less than 30 cents/MCF with the richer shale.

Existing pipeline systems and requested extensions could supply the major West Coast and Middle West marketing areas with pipeline gas produced in Colorado. With adequate storage, already under consideration by Congress, the flow of the Colorado river is adequate to provide water for a 2 million barrel per day oil shale industry, which is equivalent to about 8 billion cubic feet per day of net pipeline gas production.¹⁰

CONCLUSIONS

Nearly complete conversion of the organic matter of a typical Colorado oil shale to high methane and ethane content, high heating value fuel gases has been achieved in batch hydrogenolysis at 1200° to 1300°F. in the presence of sufficient hydrogen to convert the organic carbon and hydrogen to methane. Liberation of mineral carbon dioxide was kept at a low level by operation at these relatively low temperatures. Particle size range variations from 5-20 mesh to 140-325 mesh had no significant effect on gasification rates and yields. Increases in pressure to 5500 p.s.i.g. resulted in more rapid formation of high heating value gas, higher gas yields and lower total yields of carbon oxides. However, pressure increases above 2000 to 2500 p.s.i.g. did not appear to afford advantages commensurate with the cost increases that would be involved in a commercial application. Hydrogen feed of twice the stoichiometric requirements for methane formation resulted in complete conversion of organic carbon content, but excess hydrogen diluted the product gas. Hydrogen feed of one-half of the stoichiometric requirements resulted in lower conversions and some vapor-phase carbon deposition, but pyrolysis reactions brought about high yields of high heating value gases at 1200°F. before appreciable carbon deposition appeared to begin. Low hydrogen concentrations in the product gas slowed conversion of carbon dioxide to carbon monoxide, an undesirable reaction which consumes feed hydrogen. Although fuel gases of pipeline quality were produced in this study without further treatment, it would probably be economic to remove carbon dioxide before high-pressure transmission. On the basis of these results, high heating value gas production by hydrogasification of oil shale with hydrogen produced from a portion of the product gas appears both technically and economically feasible. In view of the large reserves of oil shale, vastly exceeding estimated ultimate crude oil reserves and approaching in magnitude the thermal value of economically recoverable coal reserves, serious consideration to this alternate source of pipeline gas should be given in studies of future gas supply.

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