REACTOR-COMBUSTOR FLUIDIZED BED RETORTING OF MAOMING OIL SHALE

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ABSTRACT

Fluidized bed retorting of shale fines of average size 0.2 mm in a reactor-combustor testing equipment of 24 t/day capacity was carried out with shale ash as heat carrier. For each ton of oil shale 51-60 kg of shale oil was produced, with oil yield 68-78% against Fischer assay. Less than 0.3% mechanical impurities was present. Gasoline and diesel fuel accounted for 65-71% of whole shale oil. Gas yield 53-58 m^3/ton, with calorific value 4,000-4,100 kcal/m^3(16,750-17,150 kJ/m^3). More than 60 runs were made, the longest one being 15-20 days.

INTRODUCTION

In the process of exploitation and crushing of Maoming oil shale, about 23% of the shale is particulate shale of <15 mm, which cannot be utilized in the present retorts for lump shale and is discarded. However, particulate shale can be used as boiler fuel or processed in new types of retort. Processing of particulate shale with shale ash as heat carrier is known for its fast reaction rate, larger capacity, higher oil yield, higher gas calorific value and smaller recovery equipment. Various types of retorts, such as solid heat carrier multi-stage ebullated bed, fluidized bed with heat supply from shale ash have been tested since 1965. Pilot plant scale of 24 ton/day was tested for each type and considerable advance was achieved in fluidized bed retort. Process flow scheme, testing results and discussion are presented in this paper.

TESTING FLOW SCHEME

A pilot plant of 24 t/day was built up in 1968 based on hydraulics modeling. Reactor-combustor equipment similar to FCC unit was used with some modification. Testing runs of 67 in total were made from 1969 to 1975.

Shale charge, reaction condition, product recovery, drying by flue gas etc. were studied in testing. In particular, material transport between reactor and combustor, and dust entrainment in shale oil were solved. Continuous operation in more than 15 days was achieved.

Testing flow scheme is shown in Fig. 1.

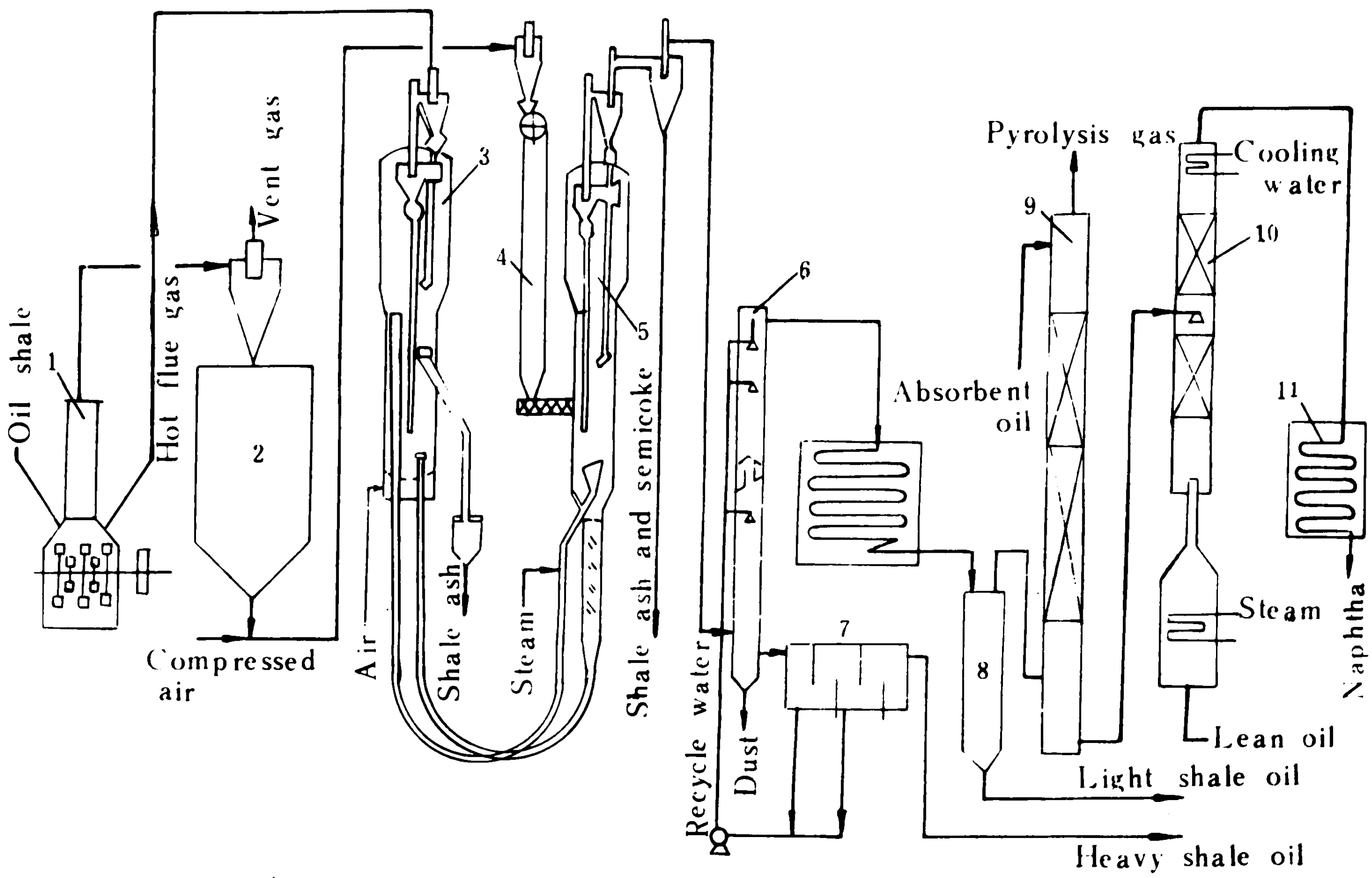

Fig. 1. Flow scheme of fluidized bed retorting of shale fines

1-- crusher; 2-- storage bin; 3-- combustor; 4-- gage tank;
5-- reactor; 6-- scrubber; 7-- oil/water separator;
8-- sedimentation tank; 9-- absorber; 10-- stripper;
11-- cooler.

1. Grinding and transport

Oil shale under 15 mm was transported by belt conveyor to a storage tank, from which it was fed into a shaft grinder. Drying of shale fines was carried out at the same time by 600°C hot gas,which came from an oil burner or from the combustor. Shale fines were entrained by the hot gas, in the size range of 0-3 mm and of moisture content below 4%, then passed through a cyclone separator to a storage bin. Oil shale ready for retorting was transported pneumatically to the top of the retort, passed through a gage tank into an intermediate bin.

2. Fluidized bed retorting

Oil shale was charged by a screw feeder to the middle of the reactor, mixed with the hot shale ash coming from the combustor through a U-tube. Superheated steam was injected as fluidizing agent. Oil shale was heated to about 480°C, oil vapor and pyrolysis gas from decomposition of kerogen passed through a three-stage cyclone together with steam, then to a condensation-recovery system. Shale char and shale ash mixture after stripping was transported through another U-tube to the combustor, where the temperature was as high as 600°C. Most of the shale ash was transferred through a U-tube to the reactor as heat carrier, some surplus ash was discharged through an overflow tube.

3. Product recovery.

The gaseous products after cyclone dedusting was washed by recycle hot water in a scrubber, where heavy oil was condensed with some fine ash. Heavy shale oil was recovered in an oil/water separator. Light shale oil was recovered in an intermediate cooler. Gas naphtha was recovered by absorption with diesel fuel absorbent.

RESULTS AND DISCUSSION

Testing data are listed in Tables 1-9.

Table 1. Raw shale analysis

Fischer assay		Elemental analysis		Proximate analysis	
Shale oil, %	7.51	C, %	13.12	Moisture, %	2.16
Moisture, %	3.48	H, %	2.18	Volatile matter, %	19.88
Shale char, %	86.25	S, %	0.98	Ash, %	74.32
Gas and loss,%	2.76	N, %	0.43	Fixed carbon, %	3.72
Calorific value, kJ/kg		5,325.6		Bulk density, t/m^3	0.713

Table 2. Shale screen analysis

2-1 mm	1-0.823 mm	0.823-0.5 mm	0.5-0.3 mm	0.3-0.1 mm	0.1 mm
0.1%	0.3%	4.6%	3.9%	40.0%	51.1%

Table 3. Operating conditions

Run No.	58-1	58-2
Charge, kg/hr	901	835
Reactor temp., °C	477	478
Combustor temp., °C	605	607
Reactor linear velocity, m/s	0.35	0.33
Average reaction time, minute	3.28	3.50

Table 4. Retorting yields

Run No.	58-1	58-2
Testing period, hr	184	96
Shale charge Fischer assay, %	7.54	7.69
Shale charge moisture, %	0.72	0.64
Products:		
Gas naphtha, kg/ton	4.84	5.45
Light shale oil, kg/ton	7.65	9.19
Heavy shale oil, kg/ton	38.80	45.60
Total, kg/ton	51.29	60.24
Oil yield (against Fischer assay), %	68.10	78.40
Gas yield, Nm^3/ton	53.40	58.40
Gas calorific value, kJ/m^3	16,877	17,178
Overall calorific value, 10^6 KJ/ton	3.159	3.647

Table 5. Shale char and shale ash mixture

	Mixture	Shale ash		Mixture	Shale ash
Proximate analysis			Elemental analysis		
Moisture, %	1.02	1.15	C, %	3.35	2.73
Volatile matter, %	3.00	3.14	H, %	0.40	0.34
Ash, %	93.46	94.33	S, %	1.17	0.14
Fixed carbon, %	2.52	1.38	N, %	0.21	0.18
Calorific value, kJ/kg	1,038.3	736.9			

Table 6. Evaluation of whole shale oil

Specific gravity d_4^{20}	0.8868	Asphaltene, %	0.64
Wax, %	3.33	Gum (silica gel), %	10.08
Moisture, %	trace	Conradson carbon, %	0.883
Ash, %	0.02	Pour point, °C	-7
Mechanical impurities,%	0.015	Flash point (open cup),°C	<19
Sulfur, %	0.45	Engler viscosity 50°C	1.17
Nitrogen, %	0.85	Acid value, mg KOH/g	0.18

Table 7. TBP distillation of whole shale oil

IBP	°C	30.5	IBP--140°C,	%	17.15
140--200°C,	%	15.50	200--280°C,	%	23.63
280--340°C,	%	15.00	>340°C+loss,	%	28.72

Table 8. Shale oil fractions analysis

Gas naphtha sp. gr. d_4^{20}	0.7270	Pyridines	
Light shale oil		<201°C, %	1.96
Sp. gr. d_4^{20}	0.8110	201-280°C, %	4.02
205°C distil off, %	89.8	Phenols	
Heavy shale oil		<201°C, %	3.83
Sp. gr. d_4^{20}	0.9160	201-280°C, %	--
Moisture, %	0.197	Aromatics, <140°C,%	29.12
Octane number of gasoline fraction	71.3 (motor method)		
Cetane number of diesel fuel fraction	32.3		

Table 9. Gas chromatographic analysis and calorific value

CH_4	12.90%	CO_2	25.60%
C_2H_6	3.34%	H_2	35.00%
C_2H_4	1.96%	O_2	0.51%
C_3H_8	1.46%	CO	4.35%
C_3H_6	1.88%	N_2	11.57%
C_4	1.43%	Calorific value (calculated)	16,877 kJ/m³

A comparison of the products yield and properties with laboratory modified Fischer assay shows lower oil yield but smaller specific gravity and marked increase in gas yield (Table 10), which can be ascribed to secondary cracking of shale oil in fluidized bed retorting.

Table 10. Comparison of fluidized bed retorting and modified Fischer assay

	Fluidized bed retorting	Modified Fischer assay
Shale oil yield, kg/ton	50-50	65-75
Shale oil specific gravity	0.87-0.88	0.93-0.95
Gas yield, m^3/ton	50-55	30-35

Some catalytic cracking effect can be inferred from the analysis of shale oil fractions. Light fractions yield reaches 71%, much higher than the 44% light fractions yield produced from thermal cracking of whole shale oil. The gasoline octane number of fluidized bed retorting is 71.4, higher than 57 of thermal cracking gasoline produced from whole shale oil. The aromatics content in <140°C fraction is 30-50%, while those in thermal cracking fraction produced from shale oil is only 10-20%.

This catalytic cracking effect may be caused by the catalytic activity of Maoming shale ash. Firstly, the composition of shale ash is similar to that of aluminosilicate catalyst. It is porous and contains 26.8 % of alumina. Secondly, shale ash can be activated by superheated steam in the reactor.

CONCLUSION

1. Normal operation can be achieved in a 24 t/day reactor-combustor fluidized bed unit processing shale fines of average size 0.2 mm, with a record of continuous operation of 15-20 days. From each ton dried shale 51-60 kg shale oil can be produced (oil yield 68-78% against Fisher assay). Gasoline-diesel fuel fraction accounts for 65-71%, with gasoline octane number 71.2. Mechanical impurities in shale oil <0.3%. Yield of pyrolysis gas 53-58 m^3/ton with calorific value 4,000-4,100 kcal/m^3.

2. Fluidized bed retorting is noted for its advantages over the conventional moving bed retorting of lump shale, such as higher shale utilization, higher retorting yield, higher light fractions yield, higher gas calorific value, better shale oil quality, higher retort intensity, smaller recovery system, less waste water, ease in utilizing shale ash, possibility of mechanization and automation. It is also superior to

other particulate shale retorting technology in matured fluidization technology and readiness of scaling up. However, its disadvantages are high energy consumption in crushing and fluidization, larger amount of dust and higher dedusting demand, larger investment and operation cost.

3. Fluidized bed retorting of shale fines is a promising advanced technology of producing oil and gas. Shale ash can be used to make building materials. This technology is useful in comprehensive utilization of oil shale as well as coal. Further study on a larger scale is justified to meet the sharp demand on energy and building materials.