AN OVERVIEW OF SHALE OIL UTILIZATION

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The contribution of shale oil as raw material to the mineral oil processing industry has been increased due to the worldwide energy demand. This review article discusses the principles of shale oil processing using rotary dry distillation boilers and the practical applicability of shale oil. The complete utilization of oil shale sources results in good economic and social benefits.

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Introduction

Oil shale is a solid-state organic-rich sedimentary and combustible rock with high ash content.[1] Shale oil recovered from oil shale contains not only a lot of unsaturated hydrocarbons but numerous non-hydrocarbon compounds, which cause its bad stability and black colour.[2]

Oil shale comprises a host rock and kerogen material, which can be transformed into conventional light oil without elevated temperature and pressure. Oil shale can be found near the surface, which is advantageous in using as source of liquid fuels, compared to mineral oil or coal. There are about 1.5 trillion of barrels of oil shale which is located near the borders of Wyoming, Utah, and Colorado. Shale oil as a supplemental energy source provides economic and social benefits for public.[3]

In this paper, the main properties, processing, and utilization of shale oil are reviewed, including a detailed discussion of processing using a rotary dry distillation boiler.

Discussion

Properties of shale oil

Table 1 shows the properties of different shale oil samples.[4] The composition and properties, such as density, wax content, setting point, and asphaltene content of different shale oils vary between a wide range, but the ratio of carbon to hydrogen generally varies between 7 and 8, which is very close to the relevant value of petroleum. Shale oil as fuel may become an important substitute of petroleum in the near future.

Shale oil contains a lot of unsaturated hydrocarbons and non-hydrocarbon compounds as well. *Fushun* shale oil has higher nitrogen content than that of *Maoming* or *Estonia*, while *Estonia* shale oil has higher oxygen content than shale oils from other sources (see Table 1). Mineral oils, however, contains in general smaller amounts of unsaturated hydrocarbons, nitrogen or oxygen compounds than shale oil.

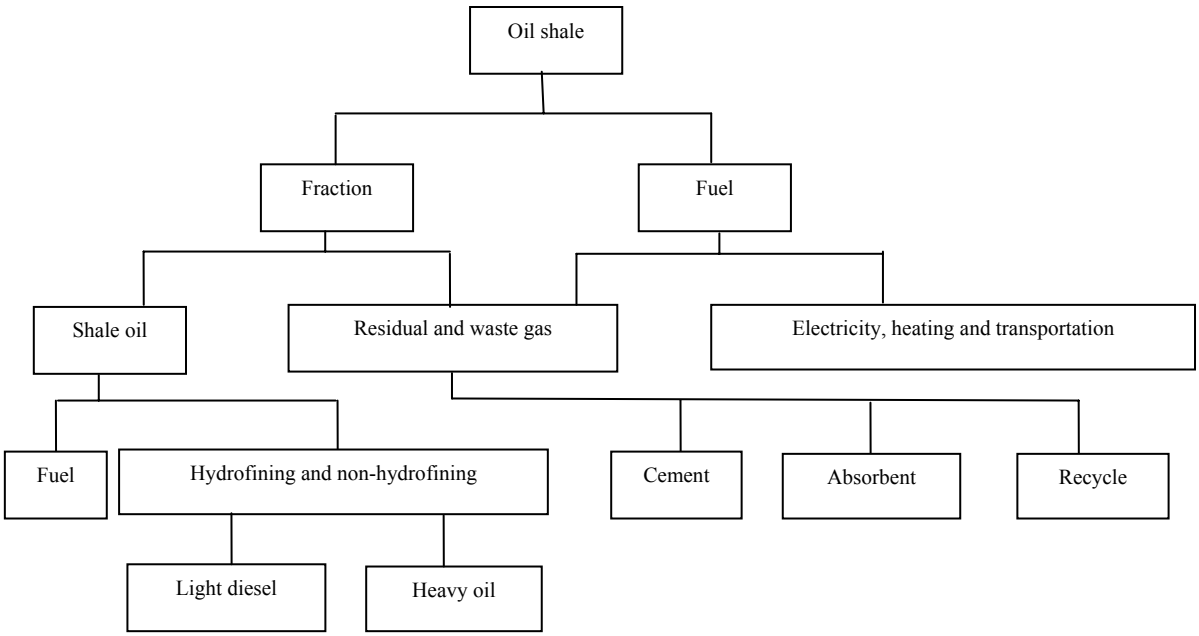

Figure 1. Flow chart of oil shale utilization

Fushun shale oil contains less amount of light fraction, e.g. its gasoline fraction content is varied between 2.5 and 2.7 % and the amount of fraction boils below 360 °C is varied between 40 and 50%. Its wax and residual oil content were between 25 and 30% or 20 and 30%, respectively.[5] *Fushun* shale oil belongs to the group of high nitrogen compound containing paraffinic oils with high wax content and setting point, and low asphaltene content.

Shale oil processing in the world

Two kinds of oil shale processing exist, the so-called underground and the above-ground retorting.[6] In the underground retorting method the oil shale is not mined out, but treated locally at its occurrence site in the deepness, then the oil is pumped out to the ground. This processing can cause environmental pollution, thus it is not a widely used method. The above-ground retorting means that oil shale is mined and processed into oil at the ground.

Table 2 shows the parameters of main oil shale processing plants. There are low outputs (100 t per day) in *Fushun* and *Kivioli*, due to sites are wide-spread. Shale oils in *Fushun* and Kivioli ensure about 65 % output yields, but only low heating value shale ash is obtained. Higher output yields (between 1500 and 6000 tons/day) are found in *Sao Mateus*, *Narva*, and *Stuart*. Yield of oils varies between 80 and 90 % and shale ash residues have high heating value.

Shale oil utilization

Due to improving processing technologies and environmental protection requirements, over using as simple energy source new utilization possibilities of shale oil have been appeared.[7]

They improve utilization efficiencies of shale oil resources, decrease specific investment costs and decrease environment pollution.

Figure 1 shows the flow chart of oil shale utilization. Oil shale can directly be used as fuel or can be fractionated. Shale oil, one of the main fractions which can be separated into components by distillation, is used as fuel. Light diesel and heavy oil fractions obtained by hydrofining or non-hydrofining methods increase the value of shale oil. On the other hand, oil shale can directly be used as fuel to generate electricity or steam, e.g. *Estonia* uses oil shale to generate electricity and heat in power plants. The ratio of produced electricity and heat from shale oil based on tax in Estonia is 76% to 14%, respectively. The combustion residues can be used to fill wells, generate cement or brick. Waste gases can also be burnt to provide energy.

Processing in a rotary dry distillation boiler

Combustion Resources Company developed a new shale oil treatment technology and designed a new rotary dry distillation boiler which is shown in Figure 2.[8] The boiler has indirect heating, simple construction, and good performance, and the shale and the shale oil can be easily separated without environmental pollution. Figure 3 shows the flow chart of the rotary dry distillation boiler. It consists of a unit for the generation of hydrogen, a unit to produce shale oil, and a unit for fining of shale oil. Coal is used as raw material for low price hydrogen production. Oil shale was grounded (<10mm) and transported into the rotary dry distillation boiler, which was heated up to 500 °C indirectly with the produced hydrogen. Shale oil gas was separated and recycled. Shale oil and heavy carbon were cracked and fined to obtain different motor fuels.

Table 1. Properties of different shale oils

Name	Fushun	Maoming	Estonia	USA
Density (20°C)/kg·m^{-3}	903.3	912.2	1010	934.0
Setting point °C	33	30	-15	24
ω (Wax), %	20.2	13.2	-	-
ω (Asphaltenes), %	0.85	1.54	-	-
ω (Gum), %	42	43	-	-
Distillation range °C				
IBP	216	214	190	66
30%	318	306	320	326
50%	362	350	370	410
ω Element analysis %				
C	85.39	84.82	83.30	84.69
H	12.09	11.40	10.00	10.71
S	0.54	0.48	0.70	0.84
N	1.27	1.10	0.30	1.85
O	0.71	2.20	5.70	1.90
C/H	7.06	7.44	8.33	7.90

Table 2. The main oil shale processing plants in the world

Country	Place	Oil shale (t/d)	Shale (m/m)	Yield (%)	Production
China	Fushun	100	10-75	65	Fuel, low heating value gas, shale ash
Estonia	Kivioli	100	10-100	68	Fuel, chemicals, low heating value gas, shale ash
Brazil	Sao Mateus	1500 and 6000	6-50	85-90	Light oil, sulfur, high heating value gas, shale semi-coke
Estonia	Narva	3000	0-25	85-90	Fuel, chemicals, high heating value gas, shale ash
Australia	Stuart	6000	0-16	85-90	Light fuel, light oil with low S content, high heating value gas, shale ash

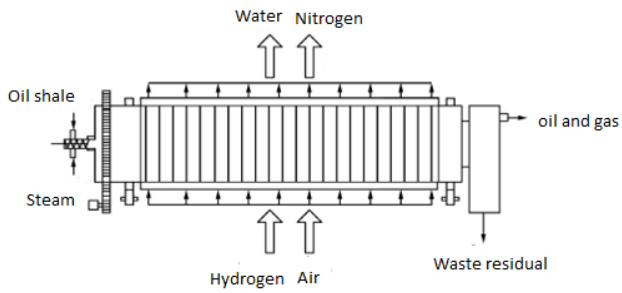

Figure 2. Construction of the rotary dry distillation boiler

The practical appliance of shale oil in China

The Chinese government implemented several policies to save energy and green environment, thus researchers are working to fulfil these requirements, for example, in the field of utilization and processing of shale oil. The main research areas are focusing on the distribution and reserve of shale oil, and on the development of new processing methods and equipments. Industrialization of these methods is in progress; e.g. *Fushun* Shale Oil Plant started its operation in 1989 and by now the output of the plant has already reached 9 million tons/year.[9]

Chinese economy requires large amount of mineral oil, and considerable amount of mineral oil has to be imported from other countries. This situation damages the Chinese petroleum strategy, so introduction of other mineral oil based product sources as shale oil is very important for China. The Chinese petroleum strategy has to be adjusted toward energy safety control and environment protection policies.

Oil shale provides different quality fuel materials, fuel gas and raw material for production of various chemicals. The residues of oil shale separation can be used for manufacturing bricks and cement. For example, heating 1000 kg of grounded oil shale at 500 °C produces shale oil in the amount varied between 38 and 378 L.

Hydrocracking of shale oil produces gasoline, kerosene, diesel oil, wax, and paraffin oils.

Oil shale can be used directly as fuel in power plants to provide electricity. Oil shale can also be separated into shale oil, fuel gas, and shale residue. The shale residue can be used to produce brick and cement, and for the recovery of different rare earth elements, such as La, Ce, Pr, Nd, Sm, Eu, Ho, Er, Tm, Yb, Lu, and Y, and to produce different kinds of manure.[10]

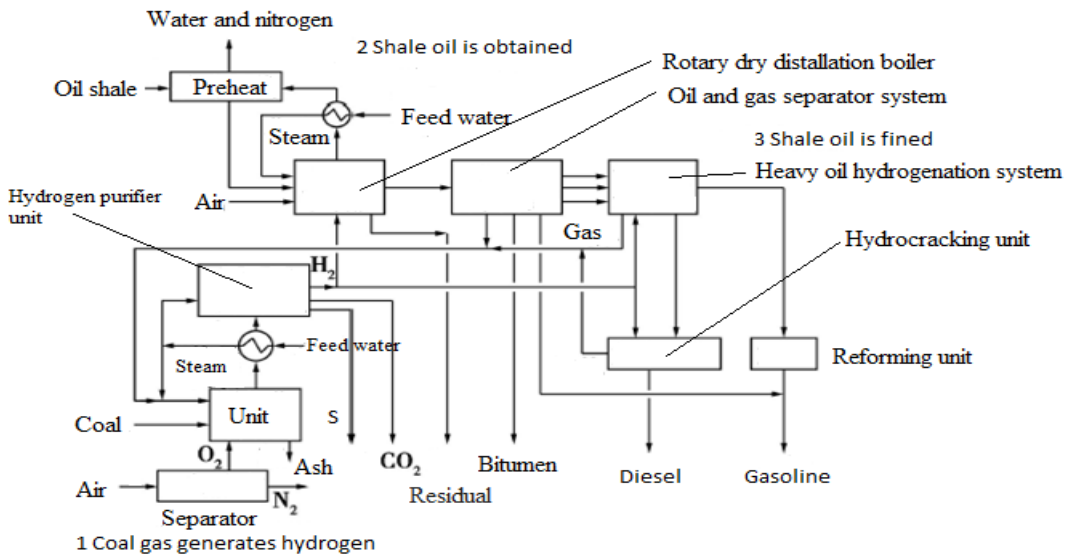

Figure 3. Flow chart of the rotary dry distillation boiler

Conclusion

Shale oil can be used directly as fuel instead of coal, or can be transformed into more valuable products in order to meet Chinese energy requirements. Utilization of shale oil provides less damage to the natural environment and ensures other economic advantages as well. There is a huge demand to find possibilities and opportunities to utilize shale oil in different petrochemical processes, in more rational way than a simple combustion, with introduction of new technologies. These new methods are expected to improve energy efficiency and to reduce pollution and damage toward the ecological environment.

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