A STUDY ON THE COMPOSITION OF SHALE OIL FROM FUSHUN AND MAOMING IN CHINA (I)

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ABSTRACT

Due to the complexity of the shale oils, solvent extraction technique has often been used for their separation,which,however, requires much time and consumption. Fushun and Maoming shale oils have higher contents of aliphatic hydrocarbons[1], so the shale oils were cut into five fractions by using a highly efficient fractionating column. The principal component for each fraction was identified by using the combination of a gas chromatography and a mass spectrometry. Qualitative identification of 145 components for Fushun shale oil, as well as 124 components for Maoming shale oil, was obtained. The results of the analysis show that the components for the two shale oils are very similar.

INTRODUCTION

China is rich in oil shale resources and has a long history of shale oil production. At present, the exploitable reserves are equivalent to about 1.6 billion tons of shale oils[2]. Shale oils have been produced in Fushun and Maoming(the yield is about 200,000 tons per year). It is of great importance to know the compositions of shale oils in order to improve the economic benefits and to apply to chemical industry. Hence, an analysis and determination for Fushun and Maoming shale oils have been doing and the preliminary results have been obtained. Further investigation is still in progress.

EXPERIMENTAL

1. Cutting for the shale oils

By using a highly efficient fractionating column with filling, Fushun and Maoming shale oils were cut into five fractions: 180-250°C; 250-300°C; 300-350°C; 350-400°C and 400-450°C. The fraction before 180°C for Fushun shale oil was collected and determined.

2. Instruments

(1) SIGMA 2000 gas chromatograph (FID) made by P-E Co. (USA).

(2) 339DA integrator, made by H.D. Co.(USA).

(3) Hitachi M-80 mass spectrograph (Japan). The principal technical indices are: resolution(R), 20000; sensitivity(S);0.1ng (methyl stearate);mass range: 1-1500 (accelerating voltage 3KV);2-3000 (accelerating voltage 1.5KV).

(4) Hitachi M-003 computer (Japan).

3. Chromatographic column

Shimadzu OV-1 quartz capillary column (Japan).

High polymer liquid crystal capillary column (China).

4. Experimental conditions

Table 1. Conditions for gas chromatography and mass spectrography

(1) Condition for gas chromatography	
temperature of column	see note in the chromatographic fig.
temperature in gasification room	300 °C
temperature in detector	300 °C
pressure of carrier gas (high purity nitrogen)	0.7 kg/cm^2
pressure of burning gas(hydrogen)	1.4 kg/cm^2
pressure of combustion-supporting gas (air)	1.4 kg/cm^2
speed of recording chart	0.5 cm/min
amount of sample	0.1 µl
(2) Condition for mass spectrography	
ion source	EI
temperature of ion source	180 °C
ionization voltage	20 eV
ionization current	3.4 A
EJ emission current	100 µA
multiplier voltage	1.3 KV
resolution	low
mass range	0-400
sampling mode	GC
scanning mode	linear
scanning speed	8 x 1

Experimental process, results and discussions

1. Choice of columns

The separation for the shale oils was done by using a highly efficient high polymer

column.

2. Determination

With a GC (Hitachi M-80 gas chromatography)/MS (double-focussing mass-spectrometer)/computer, Fushun and Maoming fractions were determined, and the detention time for the normal paraffins was determined. For some isomers, each composition was also determined from the peaks,occurring sequentially with various boiling points.

3. Results

The results for Fushun and Maoming shale oils are shown in Table 2 to 12, from which, it can be seen that the compositions for Fushun and Maoming shale oils (China) are similar, both containing a number of alkanes and alkenes, as well as a portion of aromatics, naphthalenes, phenols, polycyclic compounds and hydroaromatics.

CONCLUSION

1. As the principal components for Fushun and Maoming shale oils are non-polar, straight-chain, aliphatic hydrocarbons, It is available to separate, using OV-1 capillary column for gas chromatograph, and to determine the hydrocarbons and non-hydrocarbons for both shale oils, with the combination of GC/MS. For Fushun and Maoming shale oils, 145 and 124 components were recognized, respectively.

2. The results on the compositions indicate that both of shale oils have similar compositions, whose principal components are non-polar, straight-chain aliphatic hydrocarbons. The contents of paraffins increase with the boiling point increasing, and the principal hydrocarbons are n-paraffins. The contents of olefins in the fraction below 350°C also increase with the boiling point increasing. Almost all the compounds in the fraction above 350°C are paraffins and olefins. In the light fraction, there exist a portion of aromatics, naphthalenes, phenols, polycyclic compounds and hydroaromatics. The compounds, such as petroleum acids (fatty and naphthenic acids), pyridines, quinolines, pyrroles and thiophenes, will be analyzed and determined in more detail.

Reference

[1] Hou Xianglin, et al., Shale Oil Industry in China, the Hydrocarbon Processing Press, 1986.

Table 2. Analytical result for Fushun shale oil fraction before 180°C

No	Formula	Compound	Content %
1	C_6H_{14}	C_6-branched alkane	0.06
2	C_6H_{14}	n-hexane	0.47
3	C_7H_{16}	n-heptane	1.63
4	C_7H_{14}	C_7-alkene	0.47
5	---	unknown	---
6	C_8H_{18}	C_8-branched alkane	1.05
7	C_8H_{18}	n-octane	7.41
8	C_8H_{16}	C_8-alkene	0.76
9	---	nknown	---
10	C_8H_{10}	p-xylene	---
11	C_8H_{10}	xylene	---
12	C_9H_{20}	C_9-branched alkane	2.73
13	---	unknown	---
14	C_9H_{18}	n-C_9-alkene	1.63
15	C_9H_{20}	n-nonane	18.3
16	$C_7H_{10}S$	propyl thiophene	---
17	C_7H_9N	dimethyl pyridine	---
18	C_9H_{12}	1,2,3-trimethyl-benzene	1.63
19	C_9H_{12}	1-ethyl-2-methyl benzene	4.3
20	$C_{10}H_{22}$	C_{10}-branched alkane	1.60
21	$C_{10}H_{22}$	iso-C_{10}-branched alkane	1.24
22	C_9H_{12}	1-ethyl-3-trimethylbenzene	1.38
23	C_6H_6O	phenol	0.73
24	C_9H_{12}	1,2,4-trimethyl benzene	1.33
25	$C_{10}H_{20}$	n-C_{10}-alkene	2.53
26	$C_{10}H_{22}$	n-decane	16.85
27	C_9H_{12}	1,3,5-trimethyl benzene	1.28
28	$C_{11}H_{24}$	C_{11}-branched alkane	0.89
29	$C_{11}H_{22}$	C_{11}-alkene	1.67
30	C_7H_8O	2-methyl phenol	0.50
31	$C_{10}H_{14}$	methyl propyl benzene	1.56
32	C_7H_8O	3-methyl phenol	4.00
33	$C_{11}H_{24}$	iso-C_{11}-branched alkane	0.56
34	$C_{10}H_{14}$	tetramethylbenzene	---
35	$C_{11}H_{22}$	n-C_{11}-alkene	1.03
36	$C_{11}H_{24}$	n-undecane	5.89
37	$C_8H_{10}O$	2,5-dimethyl phenol	---
38	$C_8H_{10}O$	3-ethyl phenol	---
39	$C_{10}H_8$	naphthalene	---
40	$C_{12}H_{24}$	C_{12}-alkene	---
41	$C_{12}H_{26}$	n-dodecane	---

Table 3. Analytical result for Fushun shale oil fraction in 180-250°C

No	Formula	Compound	Content %
1	C_9H_{20}	n-nonane	---
2	C_9H_{12}	1,2,4-trimethyl benzene	---
3	$C_{10}H_{20}$	n-C_{10}-alkene	---
4	$C_{10}H_{22}$	n-decane	2.20
5	C_9H_{12}	1,3,5-trimethy benzene	0.21
6	$C_{11}H_{24}$	C_{11}-branched alkane	0.19
7	C_7H_8O	2-methylphenol	0.43
8	$C_{10}H_{14}$	methyl propyl-benzene	0.31
9	$C_{10}H_{14}$	n-butyl benzene	1.48
10	C_7H_8O	3-methyl phenol	0.22
11	$C_{11}H_{24}$	iso-C_{11}-branched alkane	0.34
12	$C_{10}H_{14}$	1,2,4,5-tetra-methyl benzene	---
13	$C_{10}H_{12}$	1-ethylene-4-ethyl benzene	0.63
14	$C_{11}H_{22}$	n-C_{11}-alkene	1.38
15	$C_{11}H_{24}$	n-undecane	6.49
16	$C_{11}H_{22}$	C_{11}-alkene	0.77
17	$C_{10}H_{14}$	1,2,3,5-tetra-methyl benzen	1.06
18	$C_{12}H_{26}$	C_{12}-branched alkane	---
19	$C_8H_{10}O$	2-ethyl phenol	1.20
20	$C_8H_{10}O$	2,5-dimethyl phenol	0.77
21	$C_{10}H_{12}$	2,3-dihydro-2-methyl indene	1.58
22	$C_{11}H_{16}$	diethyl methyl benzene	0.38
23	$C_8H_{10}O$	3-ethyl phenol	0.40
24	$C_{10}H_8$	naphthalene	3.85
25	$C_{12}h_{24}$	n-C_{12}-alkene	2.40
26	$C_{12}H_{26}$	n-dodecane	7.39
27	$C_9H_{12}O$	2,4,6-trimethyl phenol	1.49
28	$C_{13}H_{28}$	C_{13}-branched alkane	0.46
29	$C_9H_{12}O$	2,3,4-trimethylphenol	0.72
30	$C_{10}H_{10}$	ethyl-benzene & thiophene	1.25
31	$C_{11}H_{14}$	2,3-dihydro-dimethyl indene	1.46
32	$C_{13}H_{28}$	C_{13}-branched alkane	0.92
33	$C_{11}H_{10}$	2-methyl naphthalene	3.51
34	$C_{13}H_{26}$	n-C_{13}-alkene	2.09
35	$C_{13}H_{28}$	n-tridecane	8.79
36	$C_{13}H_{26}$	C_{13}-alkene	1.07
37	$C_{12}H_{16}$	1,2,3,4-tetrahydro-6,7-dimethyl naphthalene	0.68
38	$C_{14}H_{30}$	C_{14}-branched alkane	0.54
39	$C_{13}H_{18}$	tetrahydro-trimethyl naphthalene	0.37
40	$C_{13}H_{20}$	heptyl benzene	1.01
41	$C_{14}H_{30}$	C_{14}-branched alkane	0.52
42	$C_{14}H_{28}$	C_{14}-alkene	0.38
43	$C_{14}H_{30}$	iso-C_{14}-branched alkane	0.68
44	$C_{14}H_{28}$	n-C_{14}-alkene	2.73
45	$C_{14}H_{30}$	n-tetradecane	8.88
46	$C_{12}H_{12}$	1,2-dimethyl naphthalene	0.64
47	$C_{15}H_{32}$	C_{15}-branched alkane	0.89
48	$C_{15}H_{30}$	n-C_{15}-alkene	1.18
49	$C_{15}H_{32}$	n-pentadecane	3.99
50	$C_{13}H_{14}$	2,3,6-trimethyl naphthalene	---
51	$C_{15}H_{30}$	C_{15}-alkene	---
52	$C_{16}H_{32}$	n-C_{16}-alkene	---
53	$C_{16}H_{34}$	n-hexadecane	1.05

Table 4. Analytical result for Fushun shale oil fraction in 250-300°C

No	Formula	Compound	Content %
1	$C_{10}H_{22}$	n-decane	---
2	$C_{11}H_{22}$	n-C_{11}-alkene	---
3	$C_{11}H_{24}$	n-undecane	---
4	$C_{10}H_8$	naphthalene	0.28
5	$C_{12}H_{26}$	n-dodecane	0.24
6	$C_{11}H_{10}$	2-methyl naphthalene	0.25
7	$C_{13}H_{28}$	n-tridecane	1.40
8	$C_{12}H_{10}$	bibenzene	0.37
9	$C_{14}H_{28}$	n-C_{14}-alkene	0.82
10	$C_{14}H_{30}$	n-tetradecane	4.45
11	$C_{14}H_{28}$	C_{14}-alkene	0.36
12	$C_{12}H_{12}$	1,2-dimethyl naphthalene	0.49
13	$C_{15}H_{32}$	C_{15}-branched alkane	1.79
14	$C_{12}H_{10}$	acenaphthene	10.66
15	$C_{15}H_{30}$	n-C_{15}-alkene	3.37
16	$C_{15}H_{32}$	n-C_{15}-alkane	10.77
17	$C_{13}H_{14}$	2,3,6-trimethyl naphthalene	0.42
18	$C_{15}H_{30}$	C_{15}-alkene	1.36
19	$C_{13}H_{14}$	1,3,6-trimethyl naphthalene	0.72
20	$C_{13}H_{10}$	fluorene	1.18
21	$C_{16}H_{32}$	n-C_{16}-alkene	3.47
22	$C_{16}H_{34}$	n-hexadecane	15.07
23	$C_{16}H_{32}$	C_{16}-alkene	0.77
24	$C_{17}H_{36}$	C_{17}-branched alkane	1.06
25	$C_{17}H_{34}$	n-C_{17}-alkene	3.16
26	$C_{17}H_{36}$	n-heptadecane	14.35
27	$C_{18}H_{38}$	C_{18}-branched alkane	1.81
28	$C_{17}H_{34}$	iso-C_{17}-alkene	0.71
29	$C_{14}H_{10}$	phenanthrene	---
30	$C_{14}H_{10}$	anthrocene	---
31	$C_{18}H_{36}$	n-C_{18}-alkene	1.19
32	$C_{18}H_{38}$	n-octadecane	6.06
33	$C_{18}H_{36}$	C_{18}-alkene	0.74
34	$C_{19}H_{38}$	n-C_{19}-alkene	---
35	$C_{19}H_{40}$	n-nonadecane	0.86

Table 5. Analytical result for Fushun shale oil fraction in 300-350°C

No	Formula	Component	Content %
1	$C_{16}H_{32}$	n-C_{16}-alkene	0.18
2	$C_{16}H_{34}$	n-hexadecane	0.73
3	$C_{17}H_{34}$	n-C_{17}-alkene	0.76
4	$C_{17}H_{36}$	n-heptadecane	3.60
5	$C_{18}H_{38}$	C_{18}-branched alkane	0.52
6	$C_{13}H_{12}O$	2-methoxy bibenzene	---
7	$C_{17}H_{34}$	C_{17}-alkene	---
8	$C_{14}H_{10}$	phenanthrene	---
9	$C_{14}H_{10}$	anthrocene	0.76
10	$C_{18}H_{36}$	n-C_{18}-alkene	2.35
11	$C_{18}H_{38}$	n-octadecane	11.42
12	$C_{18}H_{36}$	C_{18}-alkene	2.15
13	$C_{19}H_{40}$	C_{19}-branched alkane	0.67
14	$C_{19}H_{38}$	C_{19}-alkene	1.64
15	$C_{19}H_{38}$	n-C_{19}-alkene	2.77
16	$C_{19}H_{40}$	n-nonadecane	15.74
17	$C_{19}H_{38}$	iso-C_{19}-alkene	1.02
18	$C_{20}H_{42}$	C_{20}-branched alkane	0.70
19	$C_{19}H_{38}$	iso-C_{19}-alkene	0.41
20	$C_{20}H_{40}$	C_{20}-alkene	1.42
21	$C_{20}H_{40}$	n-C_{20}-alkene	2.79
22	$C_{20}H_{42}$	n-eicosane	13.55
23	$C_{20}H_{40}$	iso-C_{20}-alkene	0.50
24	$C_{21}H_{44}$	C_{21}-branched alkane	0.35
25	$C_{21}H_{42}$	C_{21}-alkene	0.47
26	$C_{21}H_{44}$	iso-C_{21}-branched alkane	1.48
27	$C_{21}H_{42}$	n-C_{21}-alkene	1.68
28	$C_{21}H_{44}$	n-heneicosane	16.23
29	$C_{21}H_{42}$	iso-C_{21}-alkene	0.57
30	$C_{21}H_{42}$	iso-C_{21}-alkene	0.32
31	$C_{22}H_{44}$	C_{22}-alkene	0.67
32	$C_{22}H_{44}$	n-C_{22}-alkene	0.90
33	$C_{22}H_{46}$	iso-n-docosane	5.95
34	$C_{22}H_{44}$	C_{22}-alkene	---
35	$C_{23}H_{46}$	n-C_{23}-alkene	---
36	$C_{23}H_{48}$	n-tricosane	2.64

Table 6. Analytical result for Fushun shale oil fraction in 350-400°C

No	Formula	Component	Content %
1	$C_{19}H_{40}$	n-nonadecane	0.32
2	$C_{20}H_{40}$	n-C_{20}-alkene	0.22
3	$C_{20}H_{42}$	n-eicosane	1.35
4	$C_{21}H_{42}$	C_{21}-alkene	0.27
5	$C_{21}H_{42}$	n-C_{21}-alkene	0.53
6	$C_{21}H_{44}$	n-heneicosane	3.54
7	$C_{21}H_{42}$	iso-C_{21}-alkene	0.21
8	$C_{22}H_{44}$	C_{22}-alkene	1.17
9	$C_{22}H_{44}$	n-C_{22}-alkene	1.31
10	$C_{22}H_{46}$	n-docosane	6.90
11	$C_{22}H_{44}$	iso-C_{22}-alkene	0.26
12	$C_{17}H_{16}$	2,3,5-trimethyl phenanthrene	0.41
13	$C_{17}H_{16}$	2,3,5-trimethyl anthrocene	0.56
14	$C_{17}H_{12}$	1-methyl pyrene	0.61
15	$C_{23}H_{48}$	C_{23}-branched alkane	1.49
16	$C_{23}H_{46}$	n-C_{23}-alkene	1.34
17	$C_{23}H_{48}$	n-tricosane	10.76
18	$C_{23}H_{46}$	C_{23}-alkene	0.57
19	$C_{24}H_{50}$	C_{24}-branched allkane	0.33
20	$C_{24}H_{48}$	C_{24}-alkene	0.70
21	$C_{24}H_{50}$	iso-C_{24}-branched alkane	0.93
22	$C_{24}H_{48}$	n-C_{24}-alkene	3.00
23	$C_{24}H_{50}$	n-tetracosane	13.33
24	$C_{24}H_{48}$	iso-C_{24}-alkene	0.44
25	$C_{25}H_{50}$	C_{25}-alkene	0.39
26	$C_{25}H_{50}$	n-C_{25}-alkene	2.18
27	$C_{25}H_{52}$	n-pentacosane	12.48
28	$C_{25}H_{50}$	iso-C_{25}-alkene	0.39
29	$C_{26}H_{54}$	C_{26}-branched alkane	0.35
30	$C_{26}H_{52}$	n-C_{26}-alkene	0.65
31	$C_{26}H_{54}$	n-hexacosane	10.82
32	$C_{26}H_{52}$	C_{26}-alkene	0.38
33	$C_{27}H_{54}$	n-C_{27}-alkene	0.47
34	$C_{27}H_{56}$	n-heptacosane	6.13

Table 7. Analytical result for Fushun shale oil fraction in 400-450°C

No	Formula	Component	Content %
1	$C_{21}H_{44}$	n-heneicosane	0.20
2	$C_{22}H_{46}$	n-docosane	0.32
3	$C_{23}H_{48}$	n-tricosane	0.36
4	$C_{24}H_{50}$	n-tetracosane	0.63
5	$C_{25}H_{52}$	n-pentacosane	1.38
6	$C_{26}H_{54}$	n-hexacosane	3.98
7	$C_{27}H_{56}$	C_{27}-branched alkane	0.43
8	$C_{27}H_{56}$	n-heptacosane	6.80
9	$C_{28}H_{58}$	C_{28}-branched alkane	0.74
10	$C_{28}H_{56}$	n-octacosene	0.37
11	$C_{28}H_{58}$	n-octacosane	10.46
12	$C_{29}H_{60}$	C_{29}-branched alkane	1.00
13	$C_{29}H_{60}$	n-nonacosane	14.09
14	$C_{30}H_{62}$	C_{30}-branched alkane	2.20
15	$C_{30}H_{62}$	n-triacontane	7.78
16	$C_{31}H_{64}$	C_{31}-branched alkane	1.21
17	$C_{31}H_{64}$	n-hentriacontane	7.30
18	$C_{32}H_{66}$	branched dotriacontane	1.37

Table 8. Analytical result for Maoming shale oil fraction in 180-250°C

No	Formula	Compound	Content %
1	C_6H_6O	phenol	0.53
2	C_9H_{12}	1,2,4-trimethyl benzene	0.29
3	$C_{10}H_{22}$	n-decane	0.38
4	C_9H_{18}	1,3,5-trimethyl benzene	---
5	C_8H_7N	indole	---
6	C_9H_8	indene	0.56
7	C_7H_8O	2-methyl phenol	0.17
8	C_7H_8O	3-methyl phenol	2.02
9	$C_{10}H_{14}$	1,2,4,5-tetramethyl phenol	---
10	$C_{10}H_{14}$	tetramethyl benzene	---
11	$C_{11}H_{22}$	n-C_{11}-alkene	0.77
12	$C_{11}H_{24}$	n-undecane	1.74
13	$C_{10}H_{14}$	1,2,3,5-tetramethyl benzene	0.44
14	$C_8H_{10}O$	2-ethyl phenol	0.86
15	$C_8H_{10}O$	2,5-dimethyl phenol	1.65
16	$C_{10}H_{10}$	3-methyl indene	0.97
17	$C_{11}H_{16}$	diethyl methyl benzene	0.92
18	$C_8H_{10}O$	2,3-dimethyl phenol	0.66
19	$C_{10}H_8$	naphthalene	4.18
20	$C_{12}H_{24}$	n-C_{12}-alkene	1.94
21	$C_{12}H_{26}$	n-dodecane	4.45
22	$C_9H_{12}O$	2,4,6-trimethyl phenol	1.64
23	$C_{13}H_{28}$	C_{13}-branched alkane	0.40
24	$C_8H_{10}O$	3-ethyl-5-methyl phenol	0.45
25	$C_8H_{10}O$	2,3,4-trimethyl phenol	1.04
26	$C_8H_{10}O$	3,4,5-trimethyl phenol	1.37
27	$C_8H_{10}O$	4-ethyl-3-methyl phenol	0.97
28	$C_{13}H_{28}$	iso-C_{13}-branched alkane	0.62
29	$C_{11}H_{10}$	2-methyl naphthalene	3.65
30	$C_{13}H_{26}$	n-C_{13}-alkene	2.47
31	$C_{13}H_{28}$	n-tridecane	7.18
32	$C_{13}H_{26}$	C_{13}-alkene	1.38
33	$C_9H_{11}N$	1,2,3,4-tetrahydro quinoline	1.29
34	$C_{13}H_{18}$	tetrahydro-trimethyl naphthalene	0.84
35	C_9H_9N	6-methyl-nitrogen indene	1.28
36	$C_{14}H_{30}$	C_{14}-branched alkane	0.78
37	$C_{14}H_{30}$	iso-C_{14}-branched alkane	0.89
38	$C_{14}H_{28}$	n-C_{14}-alkene	2.77
39	$C_{14}H_{30}$	n-tetradecane	8.68
40	$C_{12}H_{12}$	1,3-dimethyl naphthalene	0.74
41	$C_{12}H_{12}$	1,2-dimethyl naphthalene	0.45
42	$C_{15}H_{32}$	iso-C_{15}-branched alkane	0.53
43	$C_{15}H_{32}$	C_{15}-branched alkane	1.54
44	$C_{15}H_{30}$	n-C_{15}-alkene	1.29
45	$C_{15}H_{32}$	n-pentadecane	4.94
46	$C_{15}H_{30}$	C_{15}-alkene or cycloparaffin	0.40
47	$C_{13}H_{14}$	2,3,6-trimethyl naphthalene	0.27
48	$C_{16}H_{32}$	n-C_{16}-alkene	0.19
49	$C_{16}H_{34}$	n-hexadecane	0.96

Table 9. Analytical result for Maoming shale oil fraction in 250-300°C

No	Formula	Compound	Content %
1	$C_{14}H_{28}$	n-C_{14}-alkene	0.56
2	$C_{14}H_{30}$	n-tetradecane	1.86
3	$C_{12}H_{12}$	1,3-dimethyl naphthalene	0.45
4	$C_{12}H_{12}$	1,2-dimethyl naphthalene	0.67
5	$C_{15}H_{32}$	C_{15}-branched alkane	1.98
6	$C_{12}H_{10}$	acenaphthene	0.86
7	$C_{15}H_{30}$	n-C_{15}-alkene	3.96
8	$C_{15}H_{32}$	n-pentadecane	9.88
9	---	unknown	0.38
10	$C_{13}H_{14}$	2,3,6-trimethyl naphthalene	2.00
11	$C_{15}H_{30}$	C_{15}-alkene	0.91
12	$C_{13}H_{14}$	1,3,6-trimethyl naphthalene	1.14
13	$C_{13}H_{10}$	fluorene	1.86
14	$C_{16}H_{32}$	n-C_{16}-alkene	3.89
15	$C_{16}H_{34}$	n-hexadecane	16.13
16	$C_{16}H_{32}$	C_{16}-alkene	0.78
17	---	unknown	0.93
18	$C_{17}H_{36}$	C_{17}-branched alkane	2.46
19	$C_{17}H_{34}$	n-C_{17}-alkene	3.19
20	$C_{17}H_{36}$	n-heptadecane	15.15
21	$C_{18}H_{38}$	C_{18}-branched alkane	2.44
22	$C_{17}H_{34}$	C_{17}-alkene	0.64
23	$C_{18}H_{36}$	C_{18}-alkene	0.92
24	$C_{14}H_{10}$	phenanthrene	1.32
25	$C_{14}H_{10}$	anthracene	0.43
26	$C_{18}H_{36}$	n-C_{18}-alkene	0.69
27	$C_{18}H_{38}$	n-octadecane	4.73
28	$C_{18}H_{36}$	iso-C_{18}-alkene	0.38
29	$C_{19}H_{40}$	n-nonadecane	0.48

Table 10. Analytical result for Maoming shale oil fraction in 300-350°C

No	Formula	Compound	Content %
1	$C_{15}H_{32}$	n-pentadecane	---
2	$C_{36}H_{32}$	n-C_{16}-alkene	---
3	$C_{16}H_{34}$	n-hexadecane	---
4	$C_{17}H_{34}$	n-C_{17}-alkene	1.12
5	$C_{17}H_{36}$	n-heptadecane	4.18
6	$C_{18}H_{38}$	C_{18}-branched alkane	0.86
7	$C_{17}H_{34}$	C_{17}-alkene	1.59
8	$C_{14}H_{10}$	phenanthrene	---
9	$C_{14}H_{10}$	anthracene	---
10	$C_{18}H_{36}$	n-C_{18}-alkene	3.58

11	$C_{18}H_{38}$	n-octadecane	14.85
12	$C_{18}H_{36}$	C_{18}-alkene	3.79
13	---	unknown	---
14	$C_{19}H_{40}$	C_{19}-branched alkane	1.36
15	---	unknown	---
16	$C_{19}H_{38}$	n-C_{19}-alkene	3.74
17	$C_{19}H_{40}$	n-nonadecane	19.13
18	$C_{19}H_{38}$	C_{19}-alkene	2.10
19	$C_{20}H_{42}$	C_{20}-branched alkane	0.75
20	$C_{20}H_{42}$	iso-C_{20}-branched alkane	1.23
21	$C_{20}H_{40}$	C_{20}-alkene	1.05
22	$C_{20}H_{40}$	n-C_{20}-alkene	3.30
23	$C_{20}H_{42}$	n-eicosane	10.57
24	$C_{20}H_{40}$	iso-C_{20}-alkene	0.39
25	$C_{21}H_{42}$	n-C_{21}-alkene	---
26	$C_{21}H_{44}$	n-heneicosane	2.26
27	$C_{22}H_{44}$	n-C_{22}-alkene	---
28	$C_{22}H_{46}$	n-docosane	---

Table 11. Analytical Result for Maoming shale oil Fraction in 350-400°C

No	Formula	Compound	Content %
1	$C_{19}H_{40}$	n-nonadecane	0.28
2	$C_{20}H_{40}$	n-C_{20}-alkene	0.34
3	$C_{20}H_{42}$	n-docosane	1.41
4	$C_{21}H_{42}$	C_{21}-alkene	0.74
5	$C_{21}H_{42}$	n-C_{21}-alkene	1.34
6	$C_{21}H_{44}$	n-heneicosane	6.95
7	$C_{21}H_{42}$	iso-C_{21}-alkene	0.98
8	$C_{22}H_{44}$	C_{22}-alkene	1.90
9	$C_{22}H_{44}$	n-C_{22}-alkene	2.40
10	$C_{22}H_{46}$	n-docosane	12.58
11	$C_{22}H_{44}$	iso-C_{22}-alkene	0.77
12	$C_{17}H_{16}$	2.3.5-trimethyl phenanthrene	0.73
13	$C_{17}H_{16}$	2.3.5-trimethyl anthracene	1.06
14	$C_{17}H_{16}$	1-methyl pyrene	---
15	$C_{23}H_{46}$	C_{23}-alkene	0.79
16	$C_{17}H_{12}$	11H-benzofluorene	1.04
17	$C_{18}H_{18}$	2,4,5,7-tetra-methyl phenanthrene or anthracene	1.11
18	$C_{23}H_{48}$	C_{23}-branched alkane	1.43
19	$C_{23}H_{46}$	n-C_{23}-alkene	1.27
20	$C_{23}H_{48}$	n-tricosane	13.17
21	$C_{23}H_{46}$	C_{23}-alkene	0.41
22	$C_{24}H_{50}$	C_{24}-branched alkane	0.73
23	$C_{24}H_{48}$	C_{24}-alkene	0.85
24	$C_{24}H_{48}$	n-C_{24}-alkene	1.89
25	$C_{24}H_{50}$	n-tetracosane	11.81
26	$C_{25}H_{52}$	C_{15}-branched alkane	0.25
27	$C_{25}H_{50}$	n-C_{25}-alkene	0.99
28	$C_{25}H_{52}$	n-pentacosane	9.73
29	$C_{25}H_{50}$	C_{25}-alkene	0.29
30	$C_{26}H_{52}$	n-C_{26}-alkene	0.24
31	$C_{26}H_{54}$	n-hexacosane	7.14
32	$C_{27}H_{56}$	n-heptacosane	2.92

Table 12. Analytical result for Maoming shale oil Fraction in 400-450°C

No	Formula	Compound	Content %
1	$C_{21}H_{44}$	n-heneicosane	0.23
2	$C_{22}H_{44}$	n-docosene	0.19
3	$C_{22}H_{46}$	n-docosane	0.39
4	$C_{23}H_{46}$	n-tricosene	0.29
5	$C_{23}H_{48}$	n-tricosane	0.96
6	$C_{24}H_{48}$	n-tetracosene	0.17
7	$C_{24}H_{50}$	n-tetracosane	2.35
8	$C_{25}H_{50}$	n-pentacosene	0.35
9	$C_{25}H_{52}$	n-pentacosane	5.60
10	$C_{26}H_{52}$	n-hexacosene	0.62
11	$C_{26}H_{54}$	n-hexacosane	9.41
12	$C_{26}H_{52}$	C_{26}-alkene	0.28
13	$C_{27}H_{56}$	C_{27}-branched alkane	0.28
14	$C_{27}H_{54}$	n-heptacosene	0.99
15	$C_{27}H_{56}$	n-heptacosane	13.83
16	$C_{28}H_{56}$	C_{28}-alkene	0.45
17	$C_{28}H_{58}$	C_{28}-branched alkane	0.83
18	$C_{28}H_{56}$	n-octacosene	1.36
19	$C_{28}H_{58}$	n-octacosane	11.45
20	$C_{28}H_{56}$	iso-C_{28}-alkene	0.52
21	$C_{29}H_{60}$	C_{29}-branched alkane	0.38
22	$C_{29}H_{60}$	n-nonacosane	11.36
23	$C_{29}H_{60}$	C_{29}-alkene	1.50
24	$C_{30}H_{60}$	n-triacontene	0.64
25	$C_{30}H_{62}$	n-triacontane	7.59
26	$C_{30}H_{60}$	C_{30}-alkene	0.80
27	$C_{31}H_{64}$	C_{31}-alkane	0.51
28	$C_{31}H_{64}$	n-hentriacontane	5.86
29	$C_{31}H_{62}$	C_{31}-alkene	1.92
30	$C_{32}H_{66}$	C_{32}-branched alkane	0.76
31	$C_{32}H_{66}$	n-dotriacontane	3.80
32	$C_{32}H_{64}$	@$_{32}$-alkene	0.59
33	$C_{33}H_{68}$	n-tritriacontane	1.83
34	$C_{33}H_{66}$	C_{33}-alkene	0.41