

## Characterization and pyrolysis of Mongolian Uvdug Khooloin Gashuun oil shale

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**Abstract.** *The oil shale of the Uvdug Khooloin Gashuun deposit, located in Mongolia, has a relatively high content of volatiles (28.40%), but its caloric value is low (1780.0 kJ/kg). Furthermore, it was found to have a relatively high content of organic carbons and a low content of heteroatomic compounds containing elements N, S, O, halogens (X), etc. The ash of oil shale, dominated by aluminosilicates ( $\text{SiO}_2 + \text{Al}_2\text{O}_3/\text{CaO} + \text{MgO} = 10$ ), is acidic and contains more than 40 heavy and toxic elements. The pyrolysis carried out under nitrogen at 500–550 °C produced shale oil (11.21%), pyrogenetic water (11.09%), gases including losses (8.10%), and semi-coke (69.50%). By gas chromatographic-mass spectrometric (GC-MS) analyses, 279 (mainly  $\text{C}_7$ – $\text{C}_{17}$  n-alkanes and n-alkenes, 36.69%) and 323 (mainly  $\text{C}_{12}$ – $\text{C}_{19}$  n-alkanes and n-alkenes, 43.08%) individual organic compounds were identified in both light and middle shale oil distillates, respectively. Also, the neutral sub-fraction (93.1%) of the middle distillate is composed of a large amount of  $\text{C}_{10}$ – $\text{C}_{24}$  aliphatic hydrocarbons (70.1%) and a negligible amount of acidic and basic organic compounds (6.9%). The study results suggest that the Uvdug Khooloin Gashuun oil shale could be used as a raw material for liquid fuels.*

**Keywords:** *Uvdug Khooloin Gashuun deposit, shale oil, pyrolysis, Mongolia.*

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## 1. Introduction

Oil shale occurs naturally as a sedimentary rock composed of solid inorganic and organic matters. Its organic mass kerogen is a valuable energy source because, when hydrocracked, forms useful products such as gasoline, kerosene and diesel [1, 2]. In addition, the kerogen can also be converted into a large number of hydrocarbon-based precursors for chemical industries by various chemical technologies [3]. Currently, the United States of America (USA) and China are implementing strategic plans for utilizing oil shale as a raw material of gas, oil and chemical industries. For example, the USA plans to produce 49% of total gaseous fuel from oil shale by 2030, whereas China has been conducting more intensive experiments and industrial investigations on shale gas production in order to replace the imported gaseous fuels with its own products within 20 years [4, 5]. These strategic plans highlight that oil shale is a promising energy source.

World reserves of fuel shales (fuel tar and gas) significantly exceed those of oil and natural gas. In Russia, Britain, China, Estonia and other countries that possess large reserves of oil shale, research works have been extensively performed with the purpose of producing energy for power plants and solid carbon products from both oil shale on its own and mixtures of oil shale and coal, biomass or other solid fuels by coking, semi-coking, gasification and hydrogenation processes [6–10].

Mongolia has abundant oil shale resources. Since the mid-1980s, exploration of oil shale has been conducted in Tugrug, Bayanjargalan, Bayan-Erkhet, Sumiin Nuur, Eedemt and Shavart Ovoo deposits located in Nyalga, Choibalsan and Dundgobi basins in Mongolia. The identified deposits are classified into 13 oil shale basins. Furthermore, the total geological reserves of oil shale (788.0 billion tonnes) and its kerogen (36.7 billion tonnes) have been estimated for 9 basins, 3 major and other minor deposits, based on the qualitative oil shale characteristics of more than 40 deposits in Mongolia [11, 12]. The characteristics, hydrocarbons' composition and calorific value of Mongolian oil shale have been extensively studied together with its gaseous pyrolysis products [13–18]. However, little research to date has focused on the elemental, fractional and compositional analyses of the pyrolysis liquid product (shale oil) of this oil shale. So far, the hydrocarbons' composition of the pyrolytic shale oil has not been studied in detail by a chromatographic analysis.

The current study presents the elemental, chemical and structural compositions of distillates and sub-fractions obtained from the oil shale of the Uvdug Khooloin Gashuun deposit in Mongolia. In addition to its pyrolysis conditions, the oil shale's technical and chemical characteristics are also described in the study.

## 2. Experimental

The oil shale samples used in this study were received from the Uvdug Khooloin Gashuun deposit in Mongolia. The given deposit is located about 25 km east of Tsagaan-Ovoo sum of Dundgobi Province, 250–270 km south of Ulaanbaatar.

The oil shale samples were crushed in a mortar and then divided into three fractions by particle size. A sample with a particle size of 0.2–0.3 mm was selected as an analytical sample [19].

The analytical sample was dried overnight at 85 °C in a drying oven and then technical analyses were performed by using standard methods for determination of the moisture and ash contents, the volatile matter, and elemental compositions of oil shale [17, 20, 21]. The sample moisture content was determined in a SNOL-320 drying chamber in accordance with the GOST 11014-200 standard method [17]. The elemental compositions of the oil shale and pyrolytic shale oil were determined using the Thermo Scientific FLASH 2000 CHNS analyzer and the oxygen content was obtained by difference. The results of proximate and ultimate analyses of the oil shale sample are given in Table 1. In addition, minerals and microelements in the sample were determined by X-ray fluorescence (XRF) analysis and Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) methods, respectively, after calcination at 850 °C.

Pyrolysis experiments were performed using a Fisher-type retort. Briefly, the analytical sample (50 g, 0.2–0.3 mm) was placed in an aluminum crucible inside a stainless retort. The retort was put into a furnace with a chromel-alumel thermocouple. Then the sample was continuously heated from room temperature to 500–550 °C at a heating rate of 20 °C min<sup>-1</sup> under nitrogen atmosphere and kept at this temperature for 20 min. The steam and gaseous products produced by the pyrolysis were collected into receiver flasks via a water-cooled condenser. The yields of pyrogenetic water, shale oil and solid residue (mineral components) were calculated by using their weight. The yield of the gaseous product was calculated from its weight loss.

The shale oil produced by pyrolysis was separated from pyrogenetic water and dried with anhydrous Na<sub>2</sub>SO<sub>4</sub>. Thereafter it was distilled under the reduced atmospheric pressure into three main distillate fractions: light (IBP 220 °C), middle (220–350 °C) and heavy (≥ 350 °C, residue).

Of the three distillates, the middle one (220–350 °C) was separated into basic, acidic and neutral sub-fractions by a stepwise extraction process. In the first step, the middle fraction (2 g) was dissolved into 20 ml of hexane and extracted with a 25 ml solution of 15% H<sub>2</sub>SO<sub>4</sub>. The water layer was separated and neutralized with a solution of 10% NaOH. After neutralization, the basic components were isolated as oil on the water layer. The oily basic components were recovered with dichloromethane (CH<sub>2</sub>Cl<sub>2</sub>). In the second step, the acidic components were separated from the hexane solution. The hexane solution was

extracted with a solution of 10% NaOH and the water layer was separated and neutralized with a solution of 15% H<sub>2</sub>SO<sub>4</sub> to recover the acidic components. In the third step, the neutral component of the middle fraction was obtained by evaporating hexane from the residual.

The neutral sub-fraction (2 g) of the middle distillate was separated into aliphatic (paraffin-naphthene), aromatic and polar components by using column chromatography (CC). A column with a diameter of 10 mm and a height of 200 mm filled with silica gel (ACK) was used in the CC separation. The aliphatic, aromatic and polar components of the middle fraction were eluted with hexane, benzene and dichloromethane, respectively.

The compositions of individual hydrocarbons and heteroatomic compounds in the light and middle distillates were determined by gas chromatography-mass spectrometry (GC-MS) on an Agilent 6890A (FID) quadrupole instrument using a DB5-MS 30 m × 0.32 mm fused quartz capillary column. The samples were analyzed in the temperature programming mode, beginning from 50 to 290 °C at a rate of 2 °C/min and held at the final temperature for 20 min with helium as the carrier gas. The chromatographic peaks were identified by comparing the retention times of individual compounds.

### 3. Results and discussion

#### 3.1. Physicochemical properties of oil shale

The Mongolian Uvdug Khooloin Gashuun oil shale has a low content of organic matter compared to those of other countries [6, 8]. The technical characteristics of the sample determined by standard methods are summarized in Table 1. In comparison to other Mongolian oil shale deposits, this deposit oil shale has a low calorific value. However, it has a relatively high content of oil tar (28.40%) [14, 16]. Furthermore, the Uvdug Khooloin Gashuun oil shale was found to have a relatively high content of hydrocarbons (16.10%) and a low content of heteroatomic compounds containing S, N, O, halogens (X), etc. Additionally, the studied oil shale was dominated by inorganic compounds as shown by its ash content of 67.30% (Table 1). The mineral matter in the sample was dominated by silicates (SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub>). The content of carbonates (MgO + CaO + BaO) in its mineral part was about ten times lower than that of silicates. The technical analysis showed the oil shale's ash content to be low and that of volatile matter high.

The XRF analysis results indicate that the mineral component of the oil shale sample contains a large amount of silicon-, aluminium-, ferrum-, magnesium-, calcium-, barium- and sulfur-containing compounds as shown in Table 2. The ash sample is considered to be acidic when its ratio of basic to acidic oxides is less than 1  $[(\text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO} + \text{Na}_2\text{O} + \text{K}_2\text{O} + \text{SrO})/(\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2) \leq 1]$ . In addition to the aforementioned macro-elements, more than 40 microelements were detected in the oil shale sample by the

**Table 1. Proximate and ultimate analyses of the Uvdug Khooloin Gashuun oil shale**

No	Proximate analysis, wt%			Ultimate analysis, wt%				Heat of combustion, Q, kJ/kg
	W <sup>ad</sup>	A <sup>ad</sup>	V <sup>ad</sup>	C	H	N	S	
I	3.91	67.45	28.62	16.29	2.78	0.41	0.48	1395.0
II	3.87	66.86	27.98	15.86	2.94	0.33	0.69	2260.0
III	3.92	67.59	28.60	16.15	2.95	0.28	0.54	1685.0
Average	3.90	67.30	28.40	16.10	2.89	0.34	0.57	1780.0

ICP-OES analysis. However, the contents of microelements in the sample were negligible (0.06–113.00 ppm). On the other hand, it contained a total of 2.03–224.44 ppm of heavy (As, Se, U, V, Ni, Pb, Cd, Mn) and toxic (Li, Rb, Ga, Mo, V, Y, Yb, La, Ce, Zr) metals. These results suggest that we must focus our attention on reducing the toxicity of heavy and toxic chemicals when mining, refining and using the Uvdug Khooloin Gashuun oil shale and its pyrolytic liquid products.

**Table 2. Mineral composition of the ash of the studied oil shale sample, wt%**

SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	SO <sub>3</sub>	Na <sub>2</sub> O	BaO	SrO	TiO
40.36	8.12	5.63	1.22	1.95	1.95	1.07	0.54	0.78	0.62	0.51

### 3.2. Pyrolysis and analysis of liquid fuel fractions

The oil shale sample was pyrolyzed in a Fischer assay retort under nitrogen to 500–550 °C. The pyrolysis converted kerogen into liquid products (22.30%: shale oil 11.21%, pyrogenetic water 11.09%), solid residue or semi-coke (69.50%), and gases including losses (8.20%).

Shale oil makes up 11.21 % of the kerogen in the original oil shale sample. The elemental analysis results summarized in Table 3 indicate that shale oil is primarily composed of hydrocarbons with a relatively low content of heteroatoms such as S, N and O. In addition to the low content of sulfur, shale oil exhibits a high ratio of H/C and a low ratio of O/C. These results reveal that there is a strong possibility to obtain high quality distillates by hydrotreating the Uvdug Khooloin Gashuun shale oil.

The shale oil produced was separated into light, middle and heavy fractions by distillation (Table 4). As Table 4 shows, the yields of the light and middle fractions were relatively high. This suggests that more than 50% of the shale oil could be used as raw material for gasoline and diesel fuels.

**Table 3. Elemental composition of shale oil, wt%**

No	Shale oil in oil shale, %	Elemental composition, %					H/C ratio	O/C ratio
		C	H	N	S	O		
I	11.21	84.44	11.26	0.83	0.35	3.41	1.60	0.03
II		85.04	11.32	0.85	0.23	2.56	1.60	0.02
III		84.63	11.23	0.84	0.21	3.09	1.60	0.03
Average		84.71	11.27	0.84	0.26	2.93	1.60	0.03

**Table 4. Fractional composition of shale oil, wt%**

Sample	Distillates			Total
	Light fraction, $t_{b.p.}^{\circ} = < 220 \text{ }^{\circ}\text{C}$	Middle fraction, $t_{b.p.}^{\circ} = 220\text{--}350 \text{ }^{\circ}\text{C}$	Heavy fraction, $t_{b.p.}^{\circ} > 350 \text{ }^{\circ}\text{C}$	
Shale oil by pyrolysis	12.58	37.85	49.56	100.00

### 3.3. GC-MS results of shale oil distillates

#### 3.3.1. GC-MS results of the light distillate ( $t_{b.p.}^{\circ} \leq 220 \text{ }^{\circ}\text{C}$ )

The chemical composition of the light distillate ( $t_{b.p.}^{\circ} < 220 \text{ }^{\circ}\text{C}$ ) was determined qualitatively and quantitatively by GC-MS and gas chromatography-flame-ionization detection (GC-FID) methods (Fig. 1 and Table 5). The qualitative GC-MS analysis detected 279 individual chemical compounds in the light distillate of shale oil. Of all the identified compounds,  $C_7\text{--}C_{17}$  n-alkanes and 1-alkenes were the largest. Indeed, we noted the presence of 20.53% n-alkanes and 16.16% 1-alkenes. Specifically,  $C_9\text{--}C_{12}$  alkanes and alkenes represent 14.99% and 11.93% of said total, respectively.

Also, straight-chain hydrocarbons are present in the light distillate. More than 40% of these hydrocarbons are unstable alkenes. For this reason, an extra treatment is required to use the light distillate as fuel material.

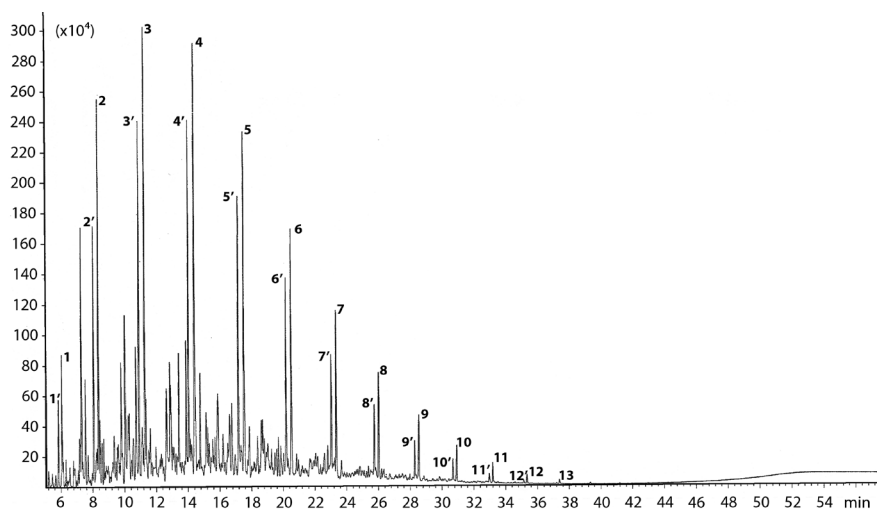


Fig. 1. A GC-MS chromatogram of the light distillate ( $t_{b.p.}^{\circ} < 220^{\circ} \text{C}$ ).

**Table 5. Aliphatic hydrocarbons of the light distillate, wt%**

Peak No	CG No	RT, min	TC, %	Identified compound	Peak No	CG No	RT, min	TC, %	Identified compound
Alkanes					Alkenes				
1.	3	5.012	0.0667	C <sub>7</sub> -Heptane	1 <sup>l</sup>	2	4.838	0.0536	C <sub>7</sub> -Heptene
2.	26	7.061	1.2147	C <sub>8</sub> -Octane	2 <sup>l</sup>	22	6.780	0.8672	C <sub>8</sub> -Octene
3.	83	9.891	3.8349	C <sub>9</sub> -Nonane	3 <sup>l</sup>	79	9.530	2.8074	C <sub>9</sub> -Nonene
4.	102	13.120	4.4147	C <sub>10</sub> -Decane	4 <sup>l</sup>	97	12.733	3.6315	C <sub>10</sub> -Decene
5.	138	16.411	3.6821	C <sub>11</sub> -Undecane	5 <sup>l</sup>	135	16.026	3.3708	C <sub>11</sub> -Undecene
6.	176	19.593	3.0675	C <sub>12</sub> -Dodecane	6 <sup>l</sup>	172	19.235	2.1373	C <sub>12</sub> -Dodecene
7.	206	22.617	1.9140	C <sub>13</sub> -Tridecane	7 <sup>l</sup>	203	22.283	1.4620	C <sub>13</sub> -Tridecene
8.	231	25.468	1.1098	C <sub>14</sub> -Tetradecane	8 <sup>l</sup>	228	25.162	0.9784	C <sub>14</sub> -Tetradecene
9.	252	28.156	0.6282	C <sub>15</sub> -Pentadecane	9 <sup>l</sup>	249	27.876	0.4658	C <sub>15</sub> -Pentadecene
10.	264	30.693	0.3308	C <sub>16</sub> -Hexadecane	10 <sup>l</sup>	263	30.435	0.2240	C <sub>16</sub> -Hexadecene
11.	270	33.092	0.1777	C <sub>17</sub> -Heptadecane	11 <sup>l</sup>	269	32.854	0.1050	C <sub>17</sub> -Heptadecene
12.	274	35.365	0.0911	C <sub>18</sub> -Octadecane	12 <sup>l</sup>	273	35.147	0.0555	C <sub>18</sub> -Octadecene
Total content: 20.532					Total content: 16.159				
Total hydrocarbons: 36.691									

CG – chromatogram; RT – retention time; TC – total content

### 3.3.2. GC-MS results of the middle distillate ( $t_{b.p.}^{\circ} = 220\text{--}350\text{ }^{\circ}\text{C}$ )

The qualitative and quantitative chromatographic results of the middle distillate ( $t_{b.p.}^{\circ} = 220\text{--}350\text{ }^{\circ}\text{C}$ ) are shown in Figure 2 and presented in Table 6.

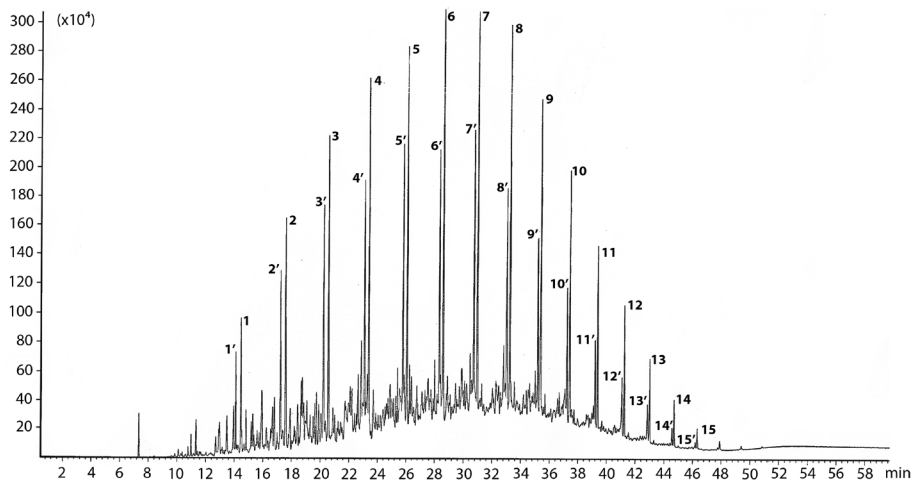


Fig. 2. A GC-MS chromatogram of the middle distillate ( $t_{b.p.}^{\circ} = 220\text{--}350\text{ }^{\circ}\text{C}$ ).

The qualitative GC-MS analysis detected 323 individual chemical compounds in the middle distillate. Of all the identified compounds,  $C_{12}\text{--}C_{18}$  n-alkanes and  $C_{13}\text{--}C_{19}$  1-alkenes were the largest. Indeed, we noted the presence of 25.00% n-alkanes and 18.10% 1-alkenes. Specifically,  $C_{12}\text{--}C_{19}$  alkanes and alkenes represent 19.90% and 19.50% of said total, respectively. As shown in Table 6, unstable alkenes are highly abundant in the middle distillate, suggesting that the pyrolysis should be performed in a hydrogen atmosphere.

### 3.3.3. GC-MS results of the acidic and basic sub-fractions of the middle distillate

The basic (3.51%), acidic (3.35%) and neutral (93.14%) sub-fractions were extracted from the shale oil middle distillate. The yields of the acidic and basic sub-fractions were relatively low. The chromatograms of these sub-fractions are shown in Figures 3 and 4, respectively.



Table 6. Aliphatic hydrocarbons of the middle distillate, wt%

Peak No	CG No	RT, min	TC, %	Identified compound	Peak No	CG No	RT, min	TC, %	Identified compound	
Alkanes										
1.	17	13.071	0.2923	C <sub>10</sub> -Decane	1 <sup>1</sup>	14	12.693	0.1999	C <sub>10</sub> -Decene	
2.	49	16.372	1.0893	C <sub>11</sub> -Undecane	2 <sup>1</sup>	46	15.993	0.9836	C <sub>11</sub> -Undecene	
3.	83	19.572	2.1497	C <sub>12</sub> -Dodecane	3 <sup>1</sup>	79	19.216	1.4222	C <sub>12</sub> -Dodecene	
4.	114	22.611	2.5486	C <sub>13</sub> -Tridecane	4 <sup>1</sup>	111	22.277	1.90811	C <sub>13</sub> -Tridecene	
5.	141	25.477	2.7949	C <sub>14</sub> -Tetradecane	5 <sup>1</sup>	138	25.166	2.5464	C <sub>14</sub> -Tetradecene	
6.	168	28.172	3.0271	C <sub>15</sub> -Pentadecane	6 <sup>1</sup>	164	27.887	2.1889	C <sub>15</sub> -Pentadecene	
7.	195	30.718	2.8996	C <sub>16</sub> -Hexadecane	7 <sup>1</sup>	193	30.450	2.0901	C <sub>16</sub> -Hexadecene	
8.	217	33.117	2.8041	C <sub>17</sub> -Heptadecane	8 <sup>1</sup>	216	32.872	1.9095	C <sub>17</sub> -Heptadecene	
9.	243	35.390	2.3468	C <sub>18</sub> -Octadecane	9 <sup>1</sup>	242	35.165	1.7673	C <sub>18</sub> -Octadecene	
10.	266	37.545	1.7545	C <sub>19</sub> -Nonadecane	10 <sup>1</sup>	265	37.337	1.1371	C <sub>19</sub> -Nonadecene	
11.	281	39.593	1.2637	C <sub>20</sub> -Icosane	11 <sup>1</sup>	280	39.402	0.6905	C <sub>20</sub> -Icosene	
12.	295	41.545	0.7917	C <sub>21</sub> -Henicicosane	12 <sup>1</sup>	294	41.370	0.4267	C <sub>21</sub> -Henicosene	
13.	307	43.410	0.5639	C <sub>22</sub> -Docosane	13 <sup>1</sup>	306	43.248	0.4039	C <sub>22</sub> -Docosene	
14.	313	45.194	0.3606	C <sub>23</sub> -Tricosane	14 <sup>1</sup>	312	45.044	0.2214	C <sub>23</sub> -Tricosene	
15.	317	46.904	0.2149	C <sub>24</sub> -Tetracosane	15 <sup>1</sup>	316	46.768	0.1146	C <sub>24</sub> -Tetracosene	
16.	319	48.544	0.1111	C <sub>25</sub> -Pentacosane	16 <sup>1</sup>	318	48.418	0.0603	C <sub>25</sub> -Pentacosene	
Total content: 25.013							Total content: 18.071			
Total hydrocarbons: 43.084										

CG – chromatogram; RT – retention time; TC – total content

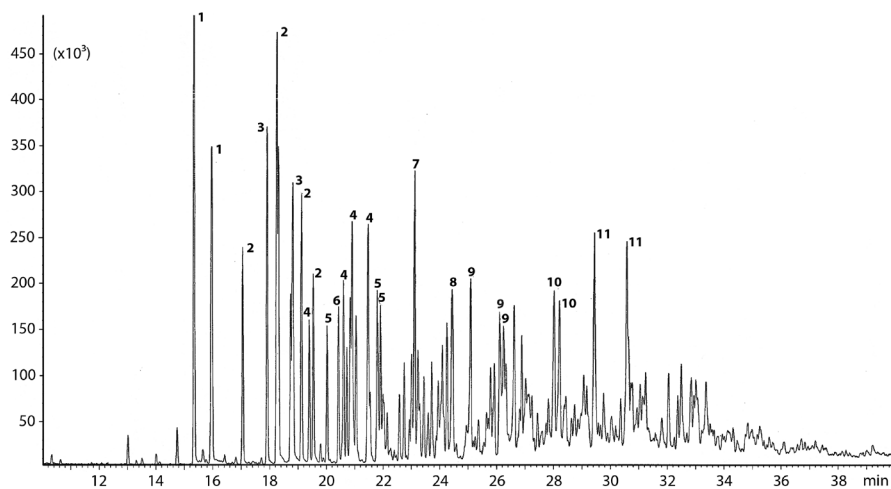


Fig. 3. A GC-MS chromatogram of the acidic sub-fraction of the middle distillate.

The most abundant compounds identified were 25 oxygen-containing acidic compounds, including alkylphenol, naphthalenol, aldehyde. Figure 3 displays the chromatograms of ortho- and para-1-methylphenol, 2-dimethylphenols, ortho- and para-3-ethylphenol, 4-ethylmethylphenols, 5-trimethylphenols, 6-propylphenols, 7-ethylbenzaldehyde, 8-diethylphenol, 9-methylindanols, 10-naphthalenols and 11-methyl-naphthalenols.

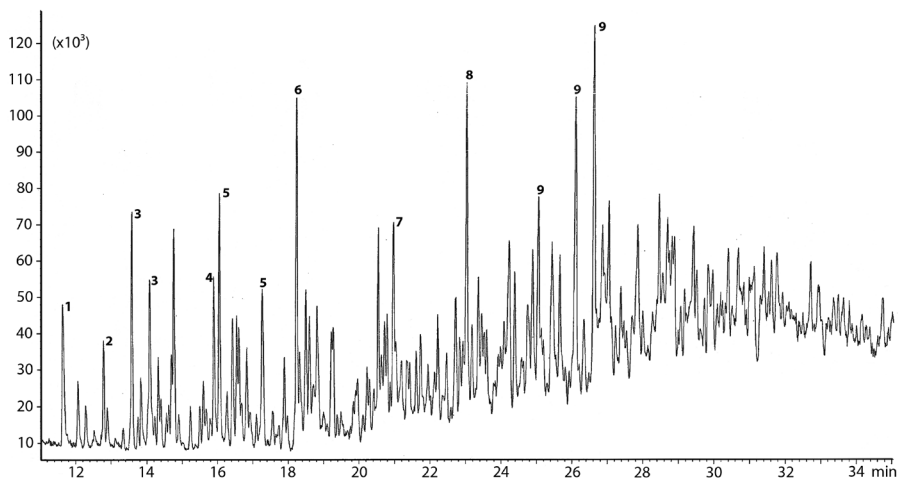


Fig. 4. A GC-MS chromatogram of the basic sub-fraction of the middle distillate.

Of the individual compounds detected on a qualitative GC-MS chromatogram of the basic sub-fraction, 13 nitrogen-containing basic amines were identified qualitatively. Figure 4 exhibits the chromatograms of 1-dimethylpyridine, 2-ethylmethylpyridine, 3-trimethylpyridine, 4-diethylbenzamine, 5-ethylmethylpyridines, 6-trimethylbenzamine, 7-quinoline, 8-methylquinoline and 9-dimethylquinolines.

### 3.3.4. Composition and GC-MS results of the neutral sub-fraction of the middle distillate

The neutral sub-fraction extracted from the middle distillate was separated by CC into three different hydrocarbon components as mentioned in the Experimental section. The compositions of each component were determined by GC-MS analysis. The neutral sub-fraction consists of aliphatic (61.47%), aromatic (22.98%) and polar (15.54%) hydrocarbon components. Figure 5 shows the chromatogram of the aliphatic hydrocarbons of this sub-fraction.

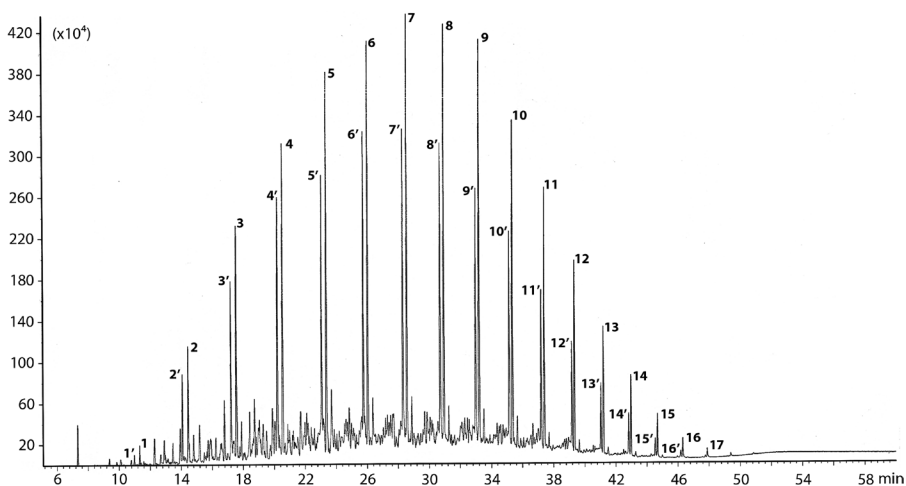


Fig. 5. A GC-MS chromatogram of the aliphatic component of the neutral sub-fraction.

As shown in Figure 5, the aliphatic component of the neutral sub-fraction contains more than 30 individual hydrocarbons, including straight-chain  $C_{10}$ – $C_{23}$  alkanes and alkenes, which make up 70.1% (40.17% alkanes and 29.94% alkenes) of the neutral sub-fraction. Therefore, the ratio of alkanes to alkenes is 1.34. This ratio clearly indicates that unstable products containing unsaturated hydrocarbons will be produced if we convert the middle distillate into petroleum liquid products.

Table 7. Hydrocarbons in the aliphatic component of the neutral sub-fraction

Peak No	CG No	RT, min	TC, %	Identified compound	Peak No	CG No	RT, min	TC, %	Identified compound
Alkanes									
1.	3	12.286	0.258	C <sub>10</sub> -Decane	1 <sup>1</sup>	2	11.319	0.162	C <sub>10</sub> -Decene
2.	8	14.451	0.932	C <sub>11</sub> -Undecane	2 <sup>1</sup>	7	14.086	0.850	C <sub>11</sub> -Undecene
3.	16	17.556	2.600	C <sub>12</sub> -Dodecane	3 <sup>1</sup>	15	17.207	1.941	C <sub>12</sub> -Dodecene
4.	29	20.548	3.456	C <sub>13</sub> -Tridecane	4 <sup>1</sup>	28	20.215	3.220	C <sub>13</sub> -Tridecene
5.	42	23.377	4.342	C <sub>14</sub> -Tetradecane	5 <sup>1</sup>	40	23.069	3.522	C <sub>14</sub> -Tetradecene
6.	54	26.045	4.631	C <sub>15</sub> -Pentadecane	6 <sup>1</sup>	52	25.761	3.434	C <sub>15</sub> -Pentadecene
7.	63	28.567	4.736	C <sub>16</sub> -Hexadecane	7 <sup>1</sup>	62	28.307	3.688	C <sub>16</sub> -Hexadecene
8.	71	30.950	4.667	C <sub>17</sub> -Heptadecane	8 <sup>1</sup>	70	30.707	3.386	C <sub>17</sub> -Heptadecene
9.	77	33.204	4.294	C <sub>18</sub> -Octadecane	9 <sup>1</sup>	76	32.985	2.973	C <sub>18</sub> -Octadecene
10.	81	35.353	3.361	C <sub>19</sub> -Nonadecane	10 <sup>1</sup>	80	35.150	2.323	C <sub>19</sub> -Nonadecene
11.	85	37.396	2.617	C <sub>20</sub> -Icosane	11 <sup>1</sup>	84	37.202	1.839	C <sub>20</sub> -Icosene
12.	87	39.334	1.814	C <sub>21</sub> -Henicicosane	12 <sup>1</sup>	86	39.164	1.173	C <sub>21</sub> -Henicicosene
13.	89	41.191	1.239	C <sub>22</sub> -Docosane	13 <sup>1</sup>	88	41.029	0.992	C <sub>22</sub> -Docosene
14.	91	42.974	0.774	C <sub>23</sub> -Tricosane	14 <sup>1</sup>	90	42.820	0.438	C <sub>23</sub> -Tricosene
15.	92	44.677	0.452	C <sub>24</sub> -Tetracosane					
	Total content: 40.173					Total content: 29.942			
Total hydrocarbons: 70.115									

CG – chromatogram; RT – retention time; TC – total content

Figure 6 and Table 8 show the qualitative and quantitative GC-MS results of the aromatic component of the neutral sub-fraction. The 12.1% of the aromatic component is made up of 10 types of aromatic hydrocarbons, from 1- and 2-methylindenes to phenanthrene. Also, the aromatic component contains 8.5% straight-chain alkane types with 5–6 carbon atoms within the range  $C_{14}$ – $C_{23}$ .

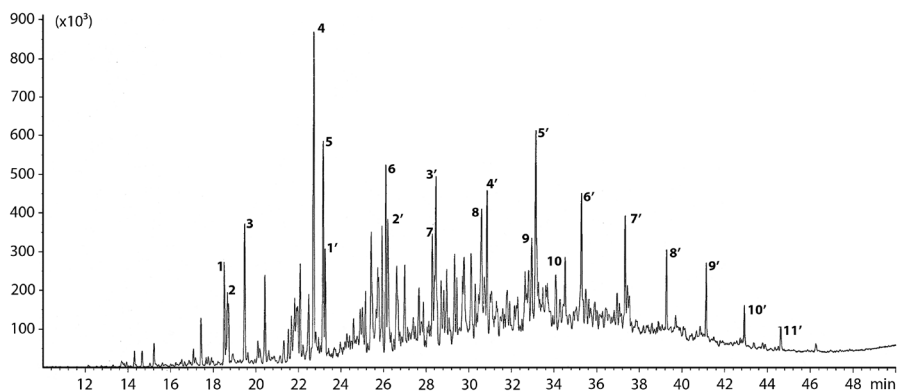


Fig. 6. A GC-MS chromatogram of the aromatic component of the neutral sub-fraction.

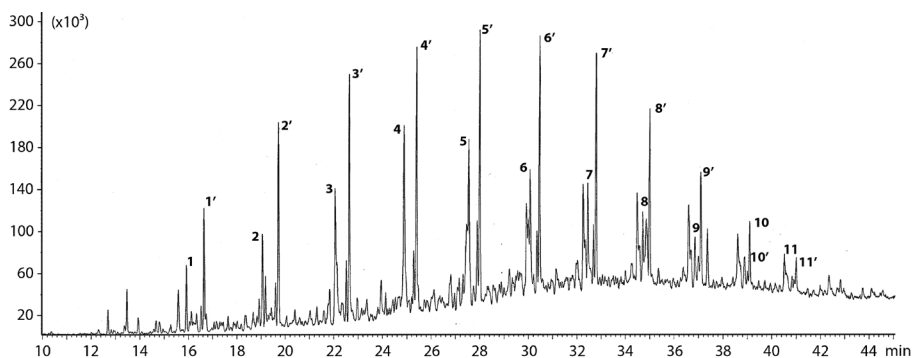


Fig. 7. A GC-MS chromatogram of the polar component of the neutral sub-fraction.

A GC-MS chromatogram of the polar component of the neutral sub-fraction is shown in Figure 7. Obviously,  $C_8$ – $C_{18}$  organic nitriles and ketones were detected as polar compounds in the neutral sub-fraction as summarised in Table 9.

**Table 8. Arenes and alkanes in the aromatic component of the neutral sub-fraction**

Peak No	CG No	RT, min	TC, %	Identified compound	Peak No	CG No	RT, min	TC, %	Identified compound
Arenes									
1.	2	18.513	0.721	1-Methylindene	1 <sup>1</sup>	8	23.257	0.804	C <sub>14</sub> -Tetradecane
2.	3	19.478	1.250	2- Methylindene	2 <sup>1</sup>	13	26.208	1.440	C <sub>15</sub> -Pentadecane
3.	6	22.721	2.734	Naphthalene	3 <sup>1</sup>	17	28.462	2.367	C <sub>16</sub> -Hexadecane
4.	7	23.159	1.961	1-Methylnaphthalene	4 <sup>1</sup>	20	30.594	2.011	C <sub>17</sub> -Heptadecane
5.	12	26.111	1.624	2-Methylnaphthalene	5 <sup>1</sup>	23	33.116	1.851	C <sub>18</sub> -Octadecane
6.	16	28.292	1.047	Dimethylnaphthalene					
7.	19	30.100	1.026	Trimethylnaphthalene					
8.	22	32.937	0.861	Methylbiphenyl					
9.	24	35.273	1.635	Methyl-9H-fluorene					
10.				Phenanthrene					
	Total content: 12.138				Total content: 8.473				

CG – chromatogram; RT – retention time; TC – total content

**Table 9. Organic nitriles and ketones in the polar component of the neutral sub-fraction**

Organic nitriles		Organic ketones	
1.	C <sub>8</sub> : Octanonitrile	1 <sup>1</sup>	C <sub>9</sub> : Nonanone
2.	C <sub>9</sub> : Nonanonitrile	2 <sup>1</sup>	C <sub>10</sub> : 2-Decanone
3.	C <sub>10</sub> : Decanonitrile	3 <sup>1</sup>	C <sub>11</sub> : 2-Undecanone
4.	C <sub>11</sub> : Undecanonitrile	4 <sup>1</sup>	C <sub>12</sub> : 2-Dodecanone
5.	C <sub>12</sub> : Dodecanonitrile	5 <sup>1</sup>	C <sub>13</sub> : 2-Tridecanone
6.	C <sub>13</sub> : Tridecanonitrile	6 <sup>1</sup>	C <sub>14</sub> : Tetradecanone
7.	C <sub>14</sub> : Tetradecanonitrile	7 <sup>1</sup>	C <sub>15</sub> : Pentadecanone
8.	C <sub>15</sub> : Pentadecanonitrile	8 <sup>1</sup>	C <sub>16</sub> : Hexadecanone
9.	C <sub>16</sub> : Hexadecanonitrile	9 <sup>1</sup>	C <sub>17</sub> : Heptadecanone

#### 4. Conclusions

The Mongolian Uvdug Khooloin Gashuun oil shale has a relatively high content of volatiles (28.40%), but its caloric value is low, 1780.0 kJ/kg. In addition, this oil shale was found to have a relatively high content of hydrocarbons and a low content of heteroatomic compounds containing N, S, O, X, etc. The acidic ash of oil shale was dominated by aluminosilicates (SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub>/CaO + MgO = 10) and contained more than 40 heavy and toxic elements.

The pyrolysis carried out under nitrogen at 500–550 °C produced shale oil (11.21%), pyrogenetic water (11.09%), gases including losses (8.10%), and semi-coke (69.50%). By GC-MS analyses, 279 (mainly C<sub>7</sub>–C<sub>17</sub> n-alkanes and n-alkenes, 36.69%) and 323 (mainly C<sub>12</sub>–C<sub>19</sub> n-alkanes and n-alkenes, 43.08%) individual organic compounds were identified in the light and middle shale oil distillates, respectively. The neutral sub-fraction (93.1%) of the middle distillate was composed of a large amount of C<sub>10</sub>–C<sub>24</sub> aliphatic hydrocarbons (70.1%) and a negligible amount of acidic and basic organic compounds (6.9%). Therefore, the pyrolytic liquid could be used as gasoline and diesel fuels after isolating its acidic and basic organic components.

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