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APPLICATION OF EOR TECHNIQUES FOR OIL SHALE FIELDS (IN-SITU COMBUSTION APPROACH)

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In this study, 1-D combustion tube experiments were performed with samples from the Turkish Seyitömer, Himmetoğlu and Hatıldağ oil shale deposits. The results demonstrate that these oil shales are suitable for oil production by in-situ combustion techniques. The calculated production values are 4.46 L/ton for Seyitömer oil shale, 32.22 L/ton for Himmetoğlu oil shale, and 18.27 L/ton for Hatıldağ oil shale.

Introduction

In-situ combustion is simply combustion heating of in-place oil shale within a deposit at the fire front. The main idea in *in-situ* combustion is burning of a portion of oil shale to produce sufficient heat to retort the remainder. A great portion of the potentially recoverable shale oil resource is in low-grade deposits that may never be recovered by primary mining techniques. *In-situ* processing presents the opportunity of recovering shale oil from these low-grade deposits without the adverse environmental impacts normally related with mining and aboveground processing.

Previous studies

Chu [1] stated the important variables that characterize the performance of combustion projects: fuel content, sweep efficiency, air requirement and air/oil ratio. It was observed that oil production increases with initial oil content. An increase in oil content also increases fuel availability and air requirment. However, this increase is relatively small when compared with the increase in oil production.

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Hayashitani et al. [2] postulated several thermal cracking reaction models that could be incorporated into numerical simulations of thermal recovery processes for the Athabasca oil sands. Several pseudo reaction mechanisms were proposed to simulate the experimental results. The reaction rate constants were represented by an Arrhenius-type expression, and the activation energies and corresponding frequency factors were determined for each reaction mechanism proposed. Diyashev et al. [3] focused on surface control of thermal front movement in a fire flooding process. Surface measurement methods of magnetic and electric fields, due to thermal influence on formation and saturation of fluids, were elaborated and tested. Results of the practical studies performed on a pilot field have shown application of suggested methods. Speight and Moschopedis [4] investigated methods of introducing oxygen functions into bitumen. Comparisons of the product properties with those of the untreated bitumen were described in order to study the effects of these functions and to evaluate their performance during *in-situ* recovery. Dieckmann et al. [5] studied primary kerogen-to-petroleum and secondary oil-to-gas conversion processes in source rocks by programmed-temperature closed-system pyrolysis of oil shale sample at different heating rates. The subsequent kinetic analysis resulted in potential versus activation energy distributions, which turned out to be comparatively broad for oil and primary gas and rather narrow for secondary gas, indicating that the former was generated from more inhomogeneous precursor materials than the latter. Mamora and Brigham [6] studied the effect of low-temperature oxidation (LTO) on the fuel and produced oil during *in-situ* combustion. Combustion tube experiments were performed with three matrix types: sand, sand and clay, and sand and sand fines. LTO was observed in the run where the matrix consisted of sand only. High temperature oxidation (HTO) was observed in runs where either clay or sand fines were a part of the matrix. Kok et al. [7–14] studied the factors influencing kinetic data, such as sample order geometry, heating rate and atmosphere, under non-isothermal conditions. It was observed that the products obtained through pyrolysis and combustion depend on oil shale composition and conditional variables, such as temperature, time, rate of heating, pressure, and gaseous environment.

Experimental

In this research, oil shale samples from Seyitömer, Himmetoğlu and Hatıldağ fields were used owing to their high grades, reserves and exploitability. These shales are of low grade or in the case of the Seyitomer deposit, a shale slightly enriched in organic matter. The oil shale samples used in this research had a particle size of <60 mesh and were prepared according to ASTM standards. Proximate and ultimate analyses [15] of samples are given in Table 1.

Table 1. **Proximate and ultimate analysis of studied oil shales**

Oil shale	Calorific value, cal/g	Components, %					
		H_2O	Ash	C	H	O, N	S
Seyitömer	1006	2.8	70.9	8.58	1.4	4.39	0.19
Himmetoğlu	1086	12.9	60.5	13.6	1.5	10.48	0.99
Hatıldağ	744	1.6	66.2	5.63	1.3	3.89	1.25

The experimental set-up used in this research is a combustion cell assembly consisting of a steel combustion tube into which oil shale is packed, and enclosed within an insulation jacket, (Fig. 1). The combustion tube is equipped with igniter, thermowell, external band heaters, and gas sampling ports. Fluids produced from the combustion tube were passed through the pressure separator to collect and measure the oil and water production and through water condenser from which the condensable gases

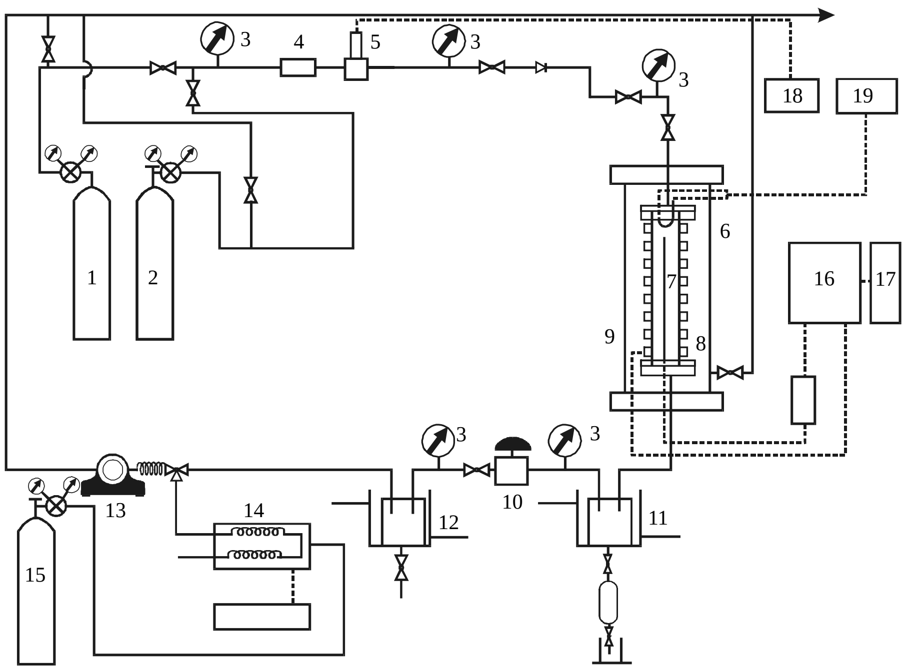

Fig. 1. Schematic diagram of the combustion tube apparatus.

1. High-pressure air cylinder
2. High-pressure nitrogen cylinder
3. Pressure gauges
4. Air filter
5. Flow transducer
6. Isolation jacket
7. Thermowell
8. Combustion tube
9. External band heaters
10. Back pressure regulator
11. High pressure separator
12. Low pressure separator
13. Wet test meter
14. Gas chromatograph
15. High pressure helium cylinder
16. Electronic temperature scanner
17. Digital temperature reader
18. Linear mass flow meter
19. Digital temperature control equipment

were collected. Before venting the produced gas, it was passed through a backpressure regulator to regulate the injection pressure. The produced gas was then passed through the rotameter at atmospheric pressure to measure produced gas rate and wet test meter to meter the total gas production. A gas chromatograph was used to analyze the composition of the gases produced from the combustion tube. Gas sampling ports installed at different points on the combustion tube were used for gas sampling and analysis, as the combustion front passes through these sections. During the combustion experiments, the amounts of CO_2, CO, and O_2 in the produced gas stream were measured by a continuous gas analyzer.

The initial temperature was 18–21 °C prior to all runs. The oil shale sample was heated to approximately 65–85 °C, while nitrogen was continuously injected. When preheating was completed, the igniter was turned on in accordance with a selected temperature profile by means of the temperature programmer. While the nitrogen injection was continued, the inlet of the combustion tube was heated to 250–300 °C, which was sufficient to initialize the combustion operation. At this time, nitrogen flow was terminated and air injection was started. The air injection rate and pressure were stabilized throughout the combustion tube by the backpressure regulator. During the combustion runs, temperatures, air injection pressure values, air injection rate values, produced gas rates, and oil and water productions were recorded. Produced gas samples were analyzed every 20 minutes by gas chromatography. Produced gases were also analyzed by the continuous gas analyzer. To verify the consistency and repeatability, the experiments were performed twice.

Results and discussion

In-situ processing presents the opportunity of recovering shale oil from these low-grade deposits, and the main idea in *in-situ* combustion is burning a portion of the oil shale to produce sufficient heat to retort the remainder. In this study *in-situ* combustion experiments were performed using 1-D physical laboratory models. Dry forward combustion tube runs were carried out using Seyitömer, Himmetoğlu, and Hatıldağ oil shale samples. Parameters measured during each combustion run were: temperature along the combustion tube, inlet and outlet pressure, air injection rate, produced gas rate, and produced gas rations. Also produced oil and water amounts were recorded intensively.

The temperature profiles along the combustion tube for Himmetoğlu oil shale are given in Fig. 2. Peak temperatures and thermocouple locations for Himmetoğlu oil shale as a function of time are given in Table 2. Following ignition in all runs, temperatures reached their maximum values, then decreased gradually towards the end of the tube. However, for the Seyitömer oil shale sample, some fluctuations in temperature curves were observed.

These fluctuations might be the results of heterogeneous permeability due to improper packing. Also heterogeneous mesh size could play an important role in temperature fluctuation.

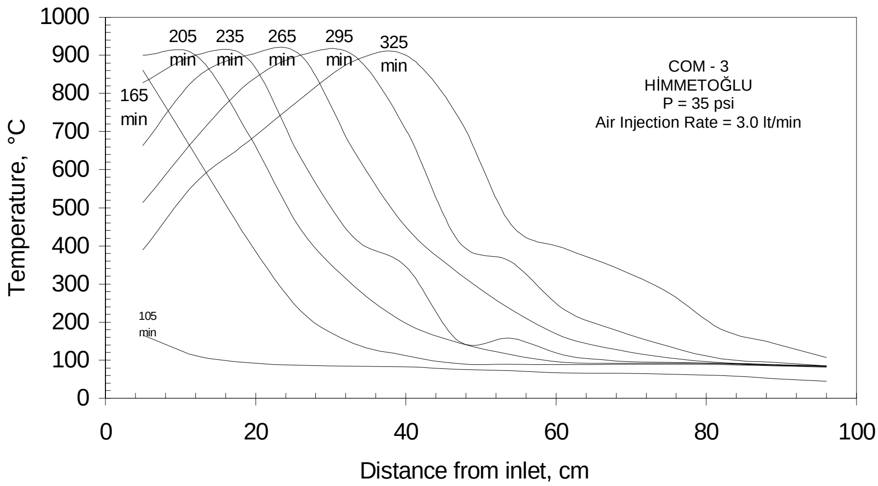

Fig. 2. Temperature profile along combustion tube (Himmetoğlu oil shale).

Table 2. **Peak temperatures of combustion of Himmetoğlu oil shale, °C**

Distance, cm	Time, min						
	105	165	205	235	265	295	325
5	166	861	900	828	663	513	389
12	112	637	900	900	839	683	566
19	93	415	695	890	900	827	673
26	87	229	444	632	900	900	785
33	84	144	296	423	651	900	884
40	82	112	197	346	450	705	900
47	76	91	145	150	328	412	736
54	72	90	115	157	233	358	456
61	67	89	94	114	161	234	394
68	66	90	92	98	128	179	342
75	63	90	92	94	106	136	277
82	60	89	91	92	93	104	181
89	52	85	87	88	89	94	144
96	44	81	83	84	85	85	107

The frontal velocity curve for Himmetoğlu oil shale is given in Fig. 3. Peak temperatures are assumed to be the maximum values of the temperature curves. The maximum temperature values for each thermocouple location were read from recorded temperature data. The data were graphed with the corresponding time values. The first derivative of the time *versus* location graph gave the velocity of frontal movement. The combustion front

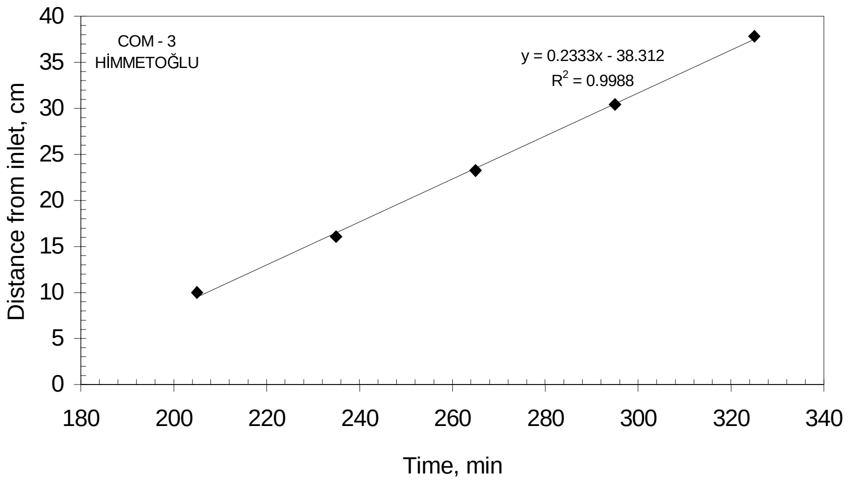

Fig. 3. Locations of the fronts (Himmetoğlu oil shale).

velocities (cm/hr) of the oil shale samples were as follows: 0.2965 (Seyitömer), 0.2333 (Himmetoğlu), 0.2948 (Hatildağ). The results show that, with a constant air injection rate and operating pressure, the rate of combustion was consistent throughout the runs.

Gas produced during combustion operations was composed of mostly N_2, CO_2, CO, and O_2. Gas analysis was performed by both continuous gas analyzer and gas chromatograph. Two different data were correlated and a result was obtained for each run. The results are given in Table 3. Gas compositions as a function of time for Himmetoğlu oil shale are illustrated in Fig. 4. In Seyitömer and Himmetoğlu oil shale samples, low oxygen concentrations in the exhaust gases were determined. This phenomenon is a sign of effective utilization of oxygen. Also since organic matter content of Himmetoğlu oil shale is very high compared to other samples, it is hard to control the experimental parameters. Table 4 represents the calculated mean values for each combustion tube experiment. The results obtained from each experiment show no difference from the others. To calculate oil production performance of these samples, a volumetric material balance was constructed. The amounts of oil and water produced are given in Table 5. The results show that Seyitömer, Himmetoğlu and Hatıldağ oil shales are feasible for oil production.

Table 3. **Stabilized composition of produced gas , vol. %**

Composition	Seyitömer	Himmetoğlu	Hatıldağ
Oxygen	1.85	2.58	3.00
Carbon dioxide	16.59	14.32	16.09
Carbon monoxide	2.60	4.14	1.91
Nitrogen	78.96	78.96	79

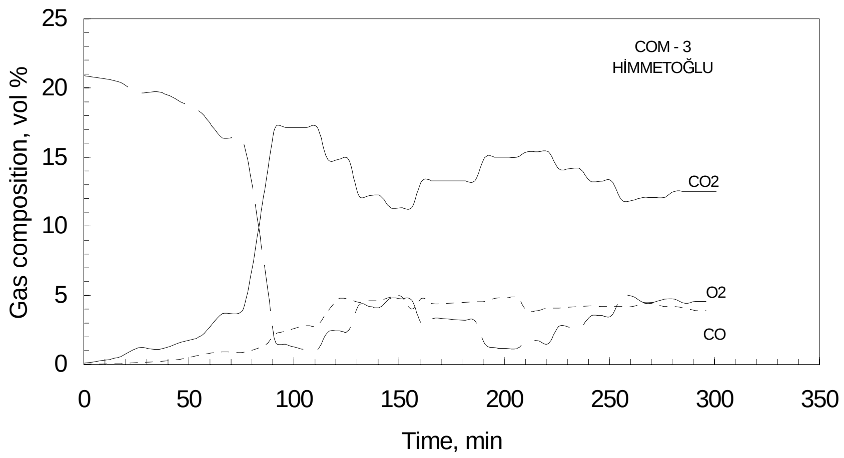

Fig. 4. Composition of produced gas vs. time (Himmetoğlu oil shale).

Table 4. **Calculated results of combustion experiments of oil shale samples**

Results	Seyitömer	Himmetoğlu	Hatıldağ
Carbon dioxide, vol. %	16.59	14.32	16.09
Carbon monoxide, vol. %	2.60	4.14	1.91
Nitrogen, vol. %	78.96	78.96	79
Atomic H/C ratio	0.26	0.44	0.21
Av. peak temperature, °C	730	900	577
Fuel cons. Rate, g fuel/min	0.32	0.31	0.29
Fuel/sand ratio, g/cm^3	0.017	0.021	0.016
Air/fuel ratio, L/g	9.52	9.75	10.19
Air/sand ratio, L/cm^3	0.16	0.21	0.16
Carbon burned, g/min	53.97	49.62	51.33
Air/oil ratio, L/cm^3	0.16	0.21	0.16

Table 5. **Oil and water production of tube runs**

Oil Shale.	Sample amount, g	Oil production, cc	Oil production, L/ton	Water production, cc
Seyitömer	4260	19	4.46	357
Himmetoğlu	3600	116	32.22	298
Hatıldağ	6950	127	18.27	67

Conclusions

- Oil distillation from oil shales with *in-situ* combustion technique was accomplished. It was proved that Himmetoğlu and Hatıldağ oil shale fields are suitable for retorting operations.

- Himmetoğlu oil shale seemed to be highly reactive when compared to other oil shale samples. High reactivity of Himmetoğlu oil shale is believed to be resulted from high organic content of this type of oil shale.
- According to the combustion front velocities calculated, it can be said that the combustion rates were consistent throughout the runs. All runs were carried out at a constant air injection rate.
- Since the oxygen percentage in output gases was relatively less, oxygen consumption during combustion operations was concluded to be effective.

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