

The spontaneous ignition potential of a super-light crude oil

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Abstract

The spontaneous ignition potential of a super-light crude oil was investigated employing adiabatic, packed-bed reactors. Various process parameters such as initial reactor temperature, oxidant gas flux, oxygen concentration in the oxidant gas, initial oil and water saturations and reactor pressure were varied to determine the set of conditions that would cause the sand–oil mixture to ignite spontaneously. All attempts to ignite the oil failed even when very favorable ignition conditions were tested including 174°C initial temperature, 7340 kPa reactor pressure, 40% oxygen in the oxidant gas and 26 h of oxidation time. Failure of the super-light crude to self-ignite was thought to be due to its low content of unsaturates, mainly aromatics and asphaltenes. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

A number of enhanced oil-recovery processes require the injection of air into the oil reservoir to promote in situ heat generation. The main target for such processes has been heavy oil reservoirs where high oil viscosity is the major hindrance to efficient natural recovery. More recently, however, air injection into light-oil reservoirs has proven successful [1,2]. The feasibility of this method depends on low-temperature oxidation (LTO) of the oil to generate heat and flue gases that would improve oil displacement. However, the risk of LTO escalating into spontaneous ignition and the consequent full-scale in situ combustion should be carefully controlled [3]. Similarly, when LTO is utilized to facilitate in situ sand consolidation [4], especially in light-oil reservoirs, spontaneous ignition would render the process useless.

LTO is a slow, mildly exothermic reaction, which is prompted whenever air contacts crude oil within the reservoir at normal reservoir temperatures. In situations where heat losses by convection and conduction are relatively small, the LTO-generated heat could accumulate within the rock causing the oil temperature to rise to ignition levels. Spontaneous ignition is usually signaled by two indicators: a

sharp rise in sand-face temperature, typically by 150–300°C, and a drop in the oxygen concentration in the produced gas [5]. LTO reactions of crude oil prevail at temperatures below 300°C producing mostly water and oxygenated hydrocarbons such as alcohols, aldehydes, ketones, carboxylic acids and hydroperoxides [6]. It had been concluded that light crudes are generally more susceptible to LTO because of their relatively high content of hydrogen [7] and thus would ignite more readily. However, another study [8] found that this conclusion might not be justified. More recently, the aromatics and resins in a crude have been shown to be the most susceptible to LTO, while the saturates are the least affected [9,10]. Moreover, by increasing the asphaltene content of an oxidized oil, LTO increases the oil's density and viscosity; such increases were also correlated with the extent of oxidation with light crudes showing minor increases [11]. Since LTO is a gas–liquid reaction, its rate is accelerated by a larger contact area provided by finer grained rock. The presence of clay or metallic derivatives either in the rock or in the oil also has catalytic effects on LTO reactions [6].

Due to their complex nature, crude oils have different oxidation characteristics. Therefore, laboratory investigation of a crude's spontaneous ignition potential is essential in order to successfully plan and execute an air injection project and to accurately interpret field observations. Furthermore, since spontaneous ignition could take between a few days to several months to occur in the field, an estimate of its delay time will assist operators in deciding the

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Table 1
Properties of oils and brine

Fluid	Density @ 15°C (g/ml)	°API @ 15°C	Viscosity @ 24°C (cP)	Composition (wt.%)			
				Saturates	Aromatics	Polars	Asphaltenes
Oil A	0.78	51.1	1.77	80.06	19.47	0.29	0.18
Oil B	0.95	17.9	6503	13.22	54.24	28.44	4.10
Brine	1.00	–	0.85	–	–	–	–

Table 2
Details of oxidation reactors

Reactor	Type	Length (cm)	OD (cm)	ID (cm)
Reactor 1	Short stainless-steel tube	10.16	3.32	2.54
Reactor 2	Copper slim-tube coil	378.20	1.27	1.14
Reactor 3	Long stainless-steel tube	40.00	1.90	1.19
Reactor 4	Stainless-steel pipe	35.56	4.77	4.11
Reactor 5	Galvanized-steel pipe	28.90	11.27	10.64

2.2. Setup

Fig. 1 shows the apparatus, which consisted basically of the reactor and its associated connections, gas supply,

metering and analysis system, temperature measurement and control system, and data acquisition system. Five reactors of different sizes, geometries and materials of construction were used. Details of these reactors are listed in Table 2 and a typical reactor design is shown in Fig. 2.

2.3. Procedure

A typical run began with packing the reactor with sand and saturating the sand with oil or oil and brine. The reactor was then insulated and mounted vertically in the heating oven, the thermocouple inserted in the reactor's thermowell and all connections made. The K-type, sheathed thermocouple is 30 cm long and 1.6 mm in diameter with

Table 3
Initial and operating conditions of experimental runs

Run #	Reactor	Sand	Porosity (%)	S_{oi}^a (%PV)	S_{wi}^b (%PV)	Pressure (kPa)	Initial temperature (°C)	Oxidant flow rate ^c	Oxidation time	
									Oxidant	in ml/min
01-ST	1	Outcrop	42.2	32.8	0	790	101	Air	300	26.0
02-ST		Outcrop	32.6	42.6	20.3	790	102	Air	36	6.0
03-ST		Outcrop	35.5	38.4	0	650	174	Air	36	8.0
04-ST		Outcrop	31.0	33.0	0	790	138	Air	43	8.0
05-ST		Outcrop	31.0	24.6	0	790	149	Air	44	8.0
06-ST		Outcrop	30.7	29.4	0	650	150	Air	294	8.5
01-CT	2	Outcrop	34.0	47.6	27.8	860	101	Air	200	8.0
02-CT		Outcrop	34.4	27.8 ^d	20.4	790	132	Air	600	13.6
01-LT	3	Outcrop	30.3	58.9	33.8	2860	136	Air	600	8.0
02-LT		Outcrop	32.1	30.0	0	2170	133	Air	300	11.9
03-LT		Outcrop	33.3	34.2	0	1820	124	Air	240	12.7
04-LT		Outcrop	31.7	33.5	0	1410	136	Air	180	13.4
05-LT		Outcrop	33.2	27.3	0	1310	136	Air	100	14.8
06-LT		Outcrop	38.2	32.3	0	1930	135	E. Air ^e	420	12.9
07-LT		Outcrop	31.6	26.8	0	3200	135	E. Air	250	14.4
08-LT		Outcrop	31.3	67.4	0	1760	134	E. Air	400	12.5
01-SP	4	Outcrop	39.5	56.2	0	1890	141	E. Air	370	12.3
02-SP		Outcrop	39.8	38.9	0	7340	133	E. Air	250	18.0
01-GP	5	Separator	31.7	41.2	0	4240	111	E. Air	250	10.7
02-GP		Separator	40.6	14.0	0	4410	122	E. Air	250	24.4
03-GP		Outcrop	30.0	40.0	0	3680	116	E. Air	80	11.7
04-GP		Separator	30.9	81.0	0	3550	113	E. Air	80	2.7

^a Initial oil saturation (percent of sand-pack pore volume).

^b Initial water saturation (percent of sand-pack pore volume).

^c Rate measured at standard conditions of 0°C and 1 atm.

^d Oil phase is blend of 90% (by weight) oil A and 10% oil B.

^e Enriched air (40% O₂, 60% N₂).

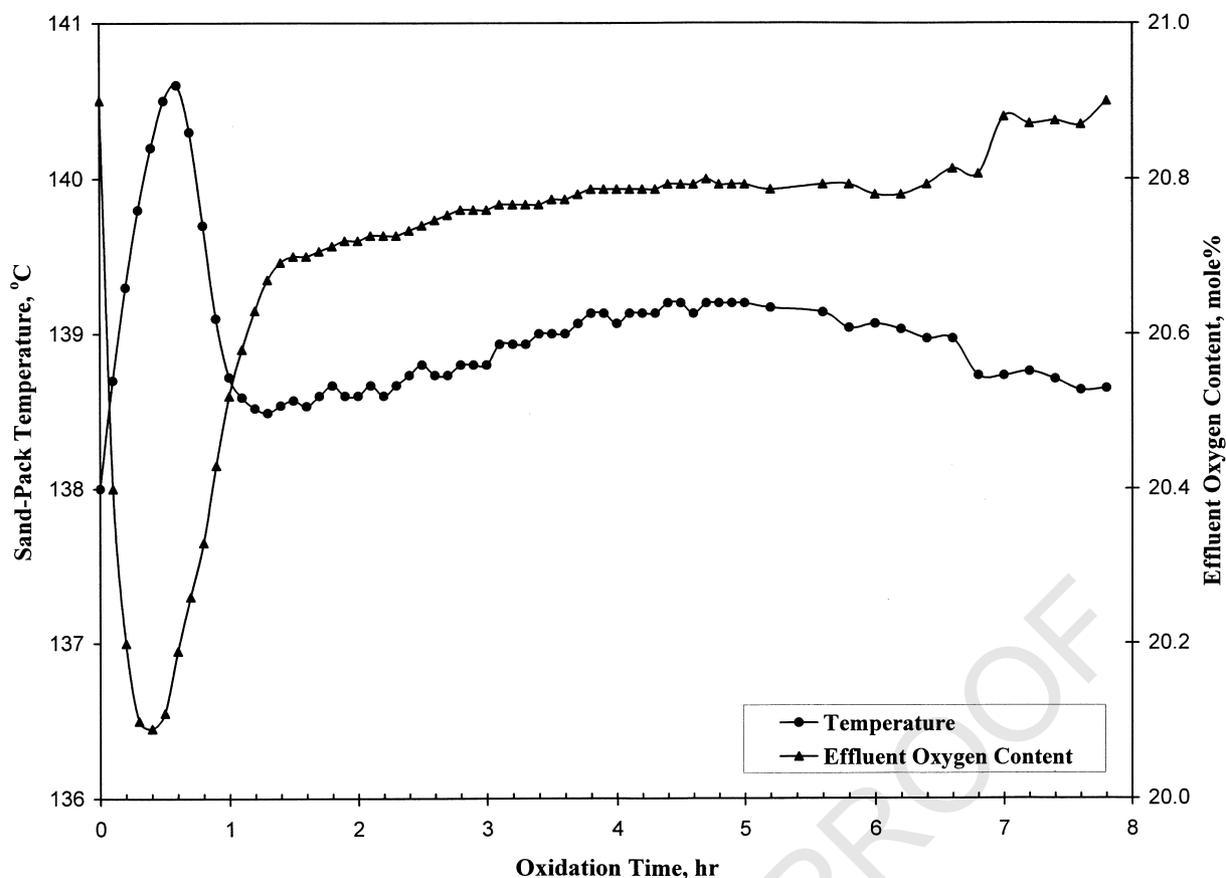


Fig. 3. Sand-pack temperature and effluent gas composition for Run 04-ST.

a response time of less than 500 ms. While the reactor was being heated to the desired initial temperature, nitrogen flow at the desired pressure was maintained through the reactor to avoid premature oxidation and to drive out any excess oil. When the desired temperature (usually about 100°C) was reached, flow was switched from nitrogen to the oxidant gas (air or oxygen-enriched air) and maintained at the specified rate and back pressure. Essential parameters such as sand-pack temperature, flow rates of oxidant and effluent gases as well as the oxygen content of the effluent gas were continuously measured and recorded. A run was terminated either when ignition was detected or when the oxygen content of the effluent gas and the sand-pack temperature remained constant for a sufficiently long period of time.

3. Results and discussion

A total of 22 experimental runs were conducted. The initial and operating conditions for these runs are listed in Table 3. In the earlier runs, an initial rise in the sand-pack temperature was observed accompanied by a drop in the oxygen concentration in the effluent gas.

The magnitude of these initial changes varied between 1 and 5°C and 2 and 10%, respectively, and the shortest period over which these changes took place was about 2.5 h. Invariably, however, these two parameters reverted back to near their starting levels for the rest of the run. A typical performance is shown in Fig. 3 for Run 04-ST. This trend was interpreted as failure of the sand–oil mixture to sustain its initial rate of heat generation that would drive its temperature to ignition levels. Such failure could be the result of excessive heat loss through the sweeping gas or simply running out of LTO fuel.

All subsequent attempts to induce the oil to auto-ignite failed. These included using larger and longer reactors, raising the initial temperature up to 174°C, reducing the air flow rate, increasing the pressure nearly four-fold and introducing water (brine) into the sand pack. All these modifications caused a slight improvement in the response, but not sufficient to promote ignition. In one trial (Run 02-CT) a blend of 90% (by weight) oil A and 10% oil B was used in an attempt to enrich the oil phase with unsaturates. As Fig. 4 shows, the pack temperature rose by 10°C during the first hour of oxidation while the oxygen content of the effluent gas dropped from 21 to 3%. However, the

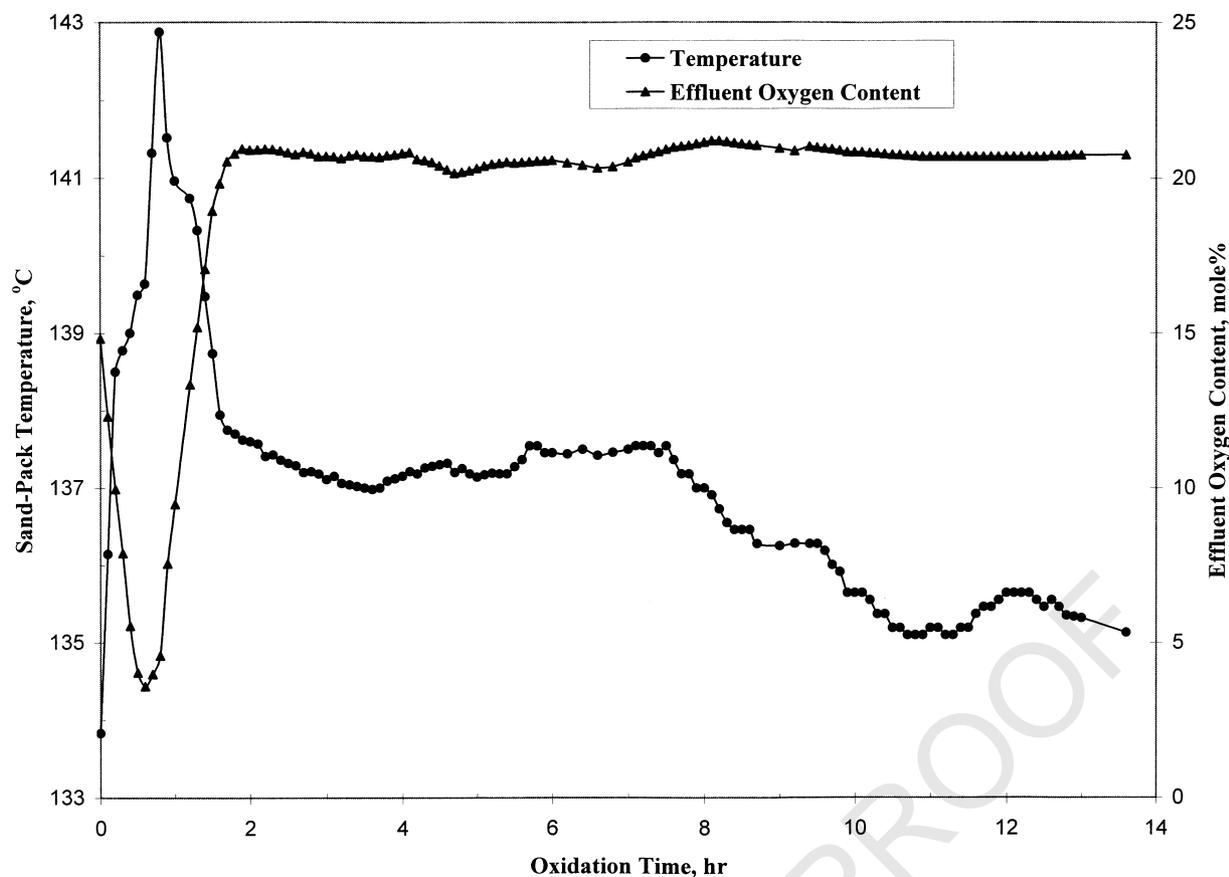


Fig. 4. Sand-pack temperature and effluent gas composition for Run 02-CT.

pack quickly cooled down over the following hour to about 137°C and oxygen consumption dropped to a negligible level.

When enriched air (40% O₂) was used in the last group of runs, marked improvements were seen. The most promising result, however, was achieved with Run 04-GP employing the largest reactor, the highest initial oil saturation, the lowest gas flux and the fine-grained separator sand. As seen in Fig. 5, the temperature surged by 16°C and the oxygen concentration dropped from 40 to 2% in just about 18 min. Shortly thereafter, however, the reactor began cooling down and the oxygen consumption started dropping gradually. The run was terminated after 2.7 h because no signs of reversal of these trends were visible.

The oil's failure to achieve spontaneous ignition was attributed to its poor LTO tendency, which could stem from its highly paraffinic nature. Examination of the oil's basic oxidation characteristics employing thermal analysis techniques was thus necessary to confirm such a hypothesis. This is the subject of an ongoing study the results of which will be reported shortly.

4. Conclusions

Based on the results of this study, the following conclusions can be made:

1. Under the various experimental conditions of this investigation, spontaneous ignition did not occur with the super-light crude oil.
2. Blending the super-light crude with an asphaltic crude promoted LTO and elevated the potential of the former to self-ignite. Ignition, however, did not occur.
3. Enriching the sweeping air with oxygen caused a significant rise in temperature through acceleration of LTO. This rise, however, was insufficient to cause ignition.
4. Inability of the super-light crude oil to self-ignite is attributed to insufficient heat generation during LTO, which could be attributed to the oil's low content of unsaturates.
5. Injecting air into the super-light crude reservoir as an EOR technique may prove ineffective. However, application of in situ sand consolidation using LTO could be successful.

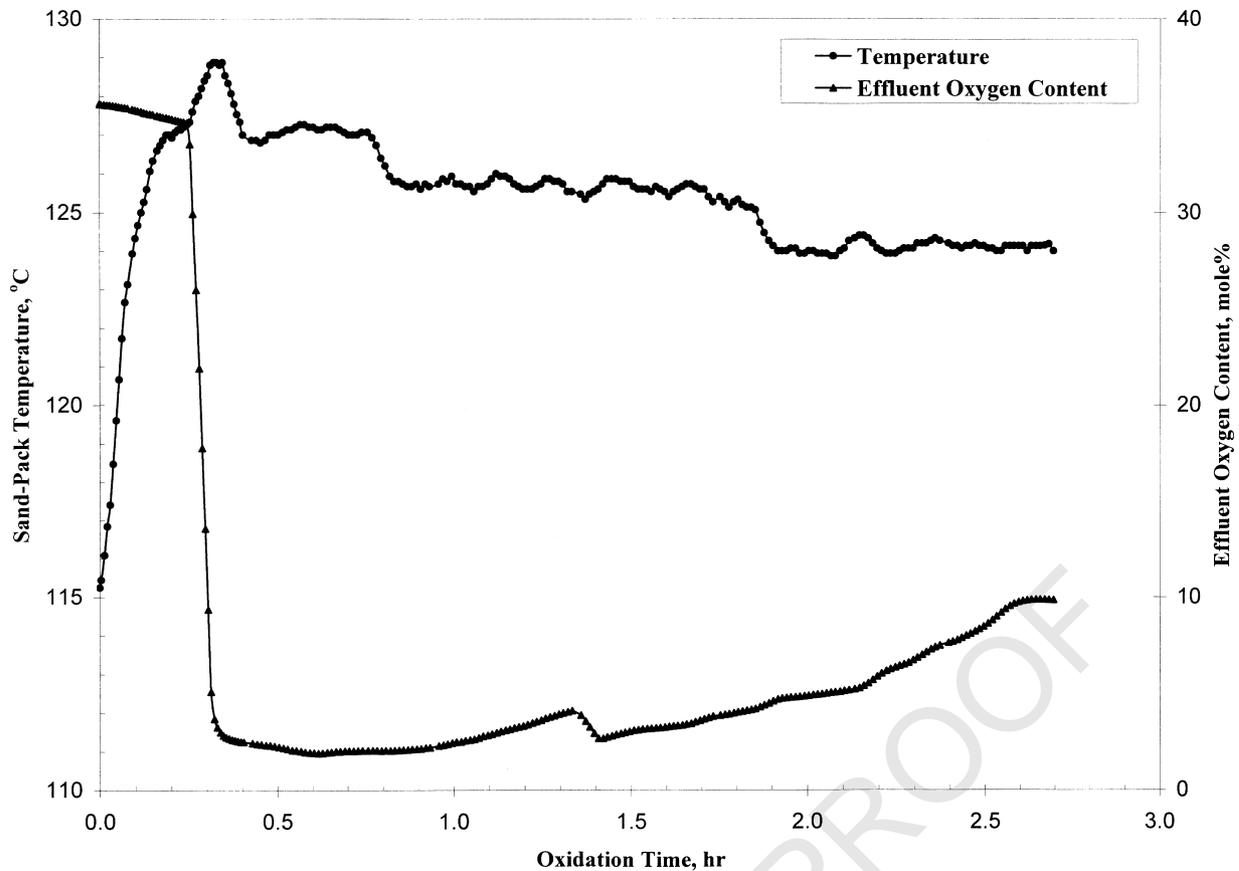


Fig. 5. Sand-pack temperature and effluent gas composition for Run 04-GP.

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References

- [1] Sakthikumar S, Madaouri K, Chastang J. An investigation of the feasibility of air injection into a waterflooded light oil reservoir. SPE Paper 29806. The SPE Middle East Oil Show, Bahrain, 1995. p. 343–56.
- [2] Fassihi MR, Yannimaras DV. Estimation of recovery factor in light-oil air-injection projects. SPE Reservoir Engng 1997;12(3):173–8.
- [3] Kisler JP, Shallcross DC. An improved model for the oxidation processes of light crude oil. Trans IChemE 1997;75:392–400.
- [4] Osman EA, Aggour MA, Abu-Khamsin SA. In-situ sand consolidation by low-temperature oxidation. SPE Prod Facilities 2000;15(1):42–9.
- [5] Strange LK. Ignition, key phase in combustion recovery. Pet Engr 1964;November:105–9.
- [6] Burger JG, Sahuquet BC. Chemical aspects of in-situ combustion — heat of combustion and kinetics. Soc Pet Engng J 1972;12(5):410–22.
- [7] Dabbous MK, Fulton PF. Low-temperature oxidation reaction kinetics and effects on the in-situ combustion process. Soc Pet Engng J 1974;14(3):253–62.
- [8] Bae JH. Characterization of crude oil for fireflooding using thermal analysis methods. Soc Pet Engng J 1977;17(3):211–8.
- [9] Babu DR, Cormack DE. Effect of low-temperature oxidation on the composition of Athabasca bitumen. Fuel 1984;63:858–61.
- [10] Adegbesan KO, Donnelly JK, Moore RG, Bennion DW. Low-temperature oxidation kinetic parameters for in-situ combustion: numerical simulation. SPE Reservoir Engng 1987;2(4):573–82.
- [11] Fassihi MR, Meyers KO, Basslie PF. Low-temperature oxidation of viscous crude oils. SPE Reservoir Engng 1990;5(4):609–16.
- [12] Tadema HJ, Weijdema J. Spontaneous ignition of oil sands. Oil Gas J 1970;68(50):77–80.
- [13] Burger JG. Spontaneous ignition in oil reservoirs. Soc Pet Engng J 1976;16(2):73–81.

