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FEASIBILITY STUDY OF CRUDE OIL FIELDS BY THERMAL ANALYSIS TECHNIQUES

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Abstract

This paper investigates the minimum oil content necessary for self-sustained combustion, which is introduced as a criterion for the selection of suitable reservoirs for *in-situ* combustion processes. Differential scanning calorimetry was used to determine the heat values of oil-limestone mixtures. The minimum temperature required for the total consumption of the fuel was obtained by thermogravimetry (TG/DTG). The minimum amount of oil necessary to sustain combustion was calculated from these two parameters and compared with the oil content of the reservoir. Reservoirs with an oil content greater than or equal to this minimum value were considered feasible. It was seen that the fields examined are generally not suitable for *in-situ* combustion processes.

Keywords: combustion, crude oil, DSC, TG/DTG

Introduction

In-situ combustion is a thermal method in which oil is ignited underground, creating a combustion front that is propagated through the reservoir by continuous air injection. The fuel necessary to sustain the combustion front is supplied by the heavy residual material (coke) that deposits on the sand grains during distillation, thermal and catalytic cracking, pyrolysis, etc. of the crude oil ahead of the combustion front. During this process, a small portion of the oil in place is burned, giving heat to the rock and its fluids. This heat reduces the viscosity of the oil by increasing its mobility. In recent years, the application of thermogravimetry (TG/DTG) and differential scanning calorimetry (DSC) for study of the pyrolysis and combustion behaviour of fossil fuels has gained wide acceptance among research workers, and is of exceptional significance for industry and the economy. Vossoughi [1] has used TG and DSC techniques to study the effects of clay and surface area on the combustion of selected oil samples. The results indicate that there is a significant reduction in the activation energy of the combustion reaction, regardless of the chemical composition of the additives. Moreover, the low-temperature oxidation of the oil and probably coke deposition are strongly affected by the specific surface area of the solid matrix. Kamal and Verkocy [2] used TG/DTG and DSC on two Lloydminster region, heavy oil cores and extracted oils obtained in helium and air atmospheres, and demonstrated at least three groups of chemical reactions occurring in three temperature

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regions. Drici and Vossoughi [3] applied DSC and TG/DTG to crude oil combustion in the presence and absence of metal oxides. Vanadium, nickel and ferric oxides behaved similarly in enhancing the endothermic reactions. In the presence of materials with a large surface area, such as silica, the surface reactions are predominant and unaffected by the small amount of metal oxides present. Kök [4] characterized the pyrolysis and combustion properties of two heavy crude oils. On combustion in air, three different reaction regions were identified, referred to as low-temperature oxidation, fuel deposition and high-temperature oxidation. Heat values and reaction parameters of the samples were also determined. Bardon and Gadelle [5] investigated the effects of the matrix on the oxidation reactions of French oil. They used different grain size of sand and compared the results with those for the original matrix. The activation energy reported for the original core was always lower than that of the sand pack because of the presence of kaolinite in the matrix. Nickle *et al.* [6] studied the effects of certain experimental conditions on the thermal curves and calculated the combustion parameters, e.g. fuel consumption, peak temperature and activation energy. One of the studies carried out by Kharrat and Vossoughi [7] dealt with the importance of the reservoir rock composition. They studied the effects of the reservoir rock on the minimum oil content of the reservoir necessary for self-contained combustion.

Experimental

Experiments were performed by using the DuPont 9900 thermal analysis system with differential scanning calorimetry (DSC) and thermogravimetry (TG/DTG) modules. DSC monitors the differential heat flow of the samples, whereas TG/DTG has the capability of measuring the mass loss as a function of either temperature or time in a varied, but controlled atmosphere. Prior to the experiments, the DSC system was calibrated for temperature readings by using indium as a reference standard. The TG/DTG system was also calibrated with calcium oxalate monohydrate for temperature readings, and silver was used in order to correct for buoyancy effects. For the feasibility study of *in-situ* combustion processes, experiments were performed at a heating rate of 10°C min^{-1}. The airflow rate was kept constant at 50 ml min^{-1} during the experiments, which corresponds to an excess oxygen supply. The temperature interval was 20–600°C and the mass of the sample was 10 mg. In order to check

Table 1 Reservoir rock and crude oil properties

Properties	Çamurlu	Bati Raman	Raman	Adiyaman	Garzan
Rock type	limestone	limestone	limestone	limestone	limestone
°API Grav.	10.3	12.9	18.7	26.6	26.7
Perm./md	40	58	50	92	16
Porosity/%	20	18	14	9	13
S_o/%	18	21	25	30	20
Viscosity/cP	63000	52000	2260	65	40

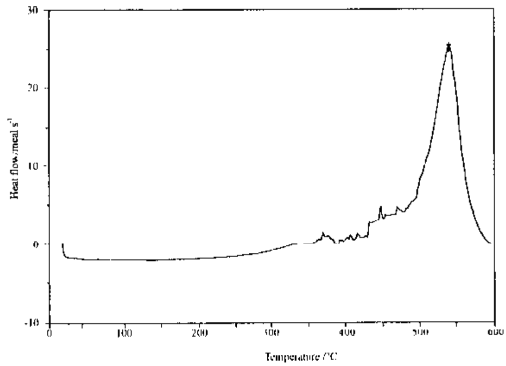

Fig. 1 DSC curve of Raman crude oil

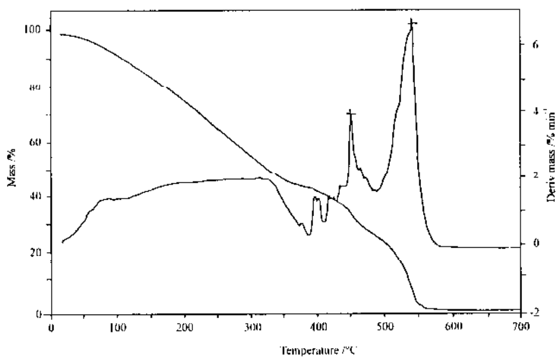

Fig. 2 TG/DTG curve of Raman crude oil

n the reproducibility, experiments were performed twice. Properties of the crude ils and reservoir rocks are given in Table 1. DSC and TG/DTG experiments were erformed under the experimental conditions mentioned above and typical curves vere obtained (Figs 1 and 2).

Results and discussion

The first step was to identify the oxidation behaviour of the crude oils. By anaysing the curves, it was possible to obtain transition zones as low-temperature oxilation, fuel deposition and high-temperature oxidation, and also the required front emperature from the TG/DTG curves. The heats of reaction of the samples were obained from the DSC curves. The minimum crude oil content required for self-susained combustion, W_{min}, was found by applying an energy balance over a unit volme of the rock in the vicinity of the combustion front:

$$W_{min}=\frac{\rho_{bulk}C_{bulk}\Delta T_{min}}{\Delta H} \quad (1)$$

$$\rho_{bulk}C_{bulk}=(1-\Theta)\rho_{solid}C_{solid}+\Theta\rho_{gas}C_{gas} \quad (2)$$

where W_{min} mass per unit volume, lbm cuft^{-1}; ΔT_{min} – the required minimum front temperature minus room temperature, °F; ΔH – heat value of crude, Btu lbm^{-1}; Θ – porosity, %; ρ – density, lbm cuft^{-1} and C – specific heat constant, Btu lbm^{-1} °F^{-1}.

The temperature at which the total crude oil sample was consumed by the required minimum front temperature, T_{min}, was obtained by conducting series of TG/DTG experiments. ΔT_{min} was found by subtracting the room temperature from this value. The heat value of the samples (ΔH) was determined from the area of reaction, (DSC), which includes the energy required for cracking and vaporization. However, due to the distillation and evaporation, some of the sample mass is lost. The true heat of combustion should therefore by greater than the value reported. In order to determine the oil content of the reservoir, the following equation was utilized:

$$W_R=S_o\rho_o\Theta \quad (3)$$

where S_o – oil saturation, ρ_o – oil density and Θ – porosity.

Table 2 DSC and TG/DTG results

Properties	Çamurlu	Bati Raman	Raman	Adiyaman	Garzan
T_{min}/°F	1066	1072	1078	1102	1112
ΔT_{min}/°F	998	1004	1010	1034	1044
ρC/Btu cuft^{-1} °F^{-1}	10.97	10.85	10.11	9.96	9.93
ΔH/Btu lbm^{-1}	54	50	58	32	28

The measured and calculated data used in the calculation of W_{min} and W_R are given in Table 2, whereas the required minimum oil, W_{min}, and the reservoir crude oil content, W_R, values of the crude oil fields were calculated and are given in Table 3. In order to evaluate the feasibility of the process, the minimum crude oil content and the reservoir crude oil content values were compared (Fig. 3). When the reservoir

Table 3 W_{min} and W_R values

Properties	Çamurlu	Bati Raman	Raman	Adiyaman	Garzan
W_{min}/lbm cuft^{-1}	19.72	21.8	17.6	32.04	37.0
W_{min}/g cm^{-3}	0.32	0.35	0.28	0.51	0.59
W_R/lbm cuft^{-1}	8.43	8.7	6.14	5.98	5.68
W_R/g cm^{-3}	0.13	0.14	0.10	0.096	0.09

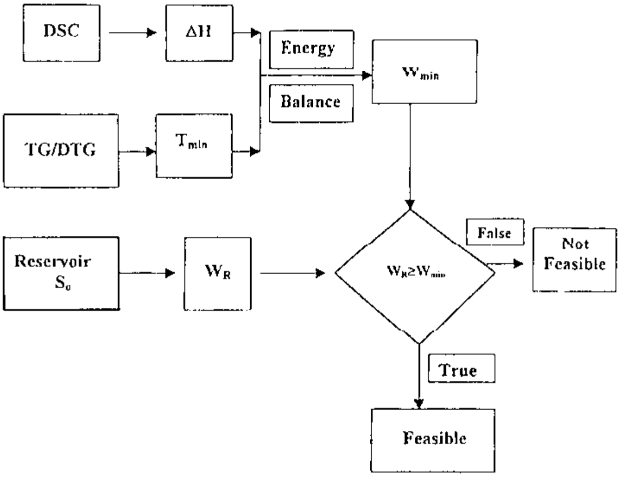

Fig. 3 Schematic flow chart of feasibility study

crude oil content was greater than or equal to the minimum crude oil content of the reservoir for self-sustained combustion, the *in-situ* combustion process was considered feasible.

Conclusions

This feasibility study provides information on the applicability of the *in-situ* combustion process. The minimum crude oil content, W_{min}, obtained from DSC and TG/DTG experiments, was used as a parameter to investigate the feasibility of the *in-situ* combustion process. The method appeared to be an alternative procedure for a quick decision of the *in-situ* combustion process. The results showed that the fuel amount was not sufficient to sustain the combustion front for all the fields studied. Therefore, it was concluded that these oil fields were not generally feasible for a self-sustained combustion process.

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