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Full Length Article

Method for laboratory testing of solvents for enhanced oil recovery based on dispersiometry and thin layer chromatography

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ABSTRACT

We suggest a method to be used in laboratory testing of solvents for enhanced oil recovery based on thin layer chromatography. All solvents may be described with the help of the separation factor and solvent time. The former is defined by the position of the geometrical center of track left by the dark oil components, which characterizes the elution ability of the solvent. The latter is defined by the time it takes the solvent front to reach the final mark, which characterizes its wettability. The wetting ability of the solvent can be estimated using the multiplicative factors of the equation, describing the motion of the solvent front on the plate in time. We used the TLC silica plates (Silufol/Sorbfil) as a model of porous sandstone reservoirs. Each solvent was characterized by dispersion of the refractive index as one of the criteria for ranking solvents by their efficiency.

1. Introduction

In this paper we continue the traditions of the development of rapid methods for testing oilfield reagents and motor fuels [1–6]. We look into the possibilities of using thin layer chromatography for evaluating the effectiveness of industrial solvents in enhanced oil recovery as this technique is widely used to separate crude oils and other hydrocarbon materials into SARA (Saturated, Aromatics, Resins and Asphaltenes) fractions [7].

Recently, the prospects for the progress in the oil industry have been associated with the development of heavy oil and natural bitumen. A close interest in the fields of heavy oil and natural bitumen can be explained by the gradual depletion of conventional light crude oil and the progress made in the production technologies of unconventional oil.

The use of hydrocarbon solvents is one of the promising ways of increasing the efficacy of SAGD projects with respect to technological, economic and, more importantly, environmental aspects. In recent years a number of SAGD (Steam-Assisted Gravity Drainage) process modifications have been developed. They are Vapour Extraction (VAPEX), Expanding Solvent SAGD (ES-SAGD), Solvent Aided Process (SAP), Steam Alternating Solvent (SAS), etc. All these techniques are based on the removal (extracting) ability of solvents injected into oil wells in order to reduce the viscosity of heavy oil and to increase oil recovery [8,9].

It is known that any chemical or physical-chemical process is preceded by a stage of delivery of the components to the site of contact, whether it is a chemical reaction or dissolution. Rock-wetting [10] and diffusion activities of the solvent play an essential role in mass transfer processes in the case of viscous and multiphase systems. The transfer process of the solvent to heavy oil components, which it dissolves and disperses, can become a rate-limiting stage of the dissolution process in the case of implementing heavy oil recovery technologies (EOR). These issues have long been discussed in the international scientific literature [11–13].

Complex and bulky physical models are used to evaluate the efficacy of industrial solvents and their displacing ability in VAPEX, SAP, ES-SAGD and others processes. Authors [8,14,15] propose to use a hollow 3D glass model or a cylindrical metal 2D model filled with oily rock or oil-saturated sand. The thickness of the model, oil saturation, porosity of the structure is determined by the researcher himself. This method of research consists of two main steps: flowing steam or solvent through the model or alternating them (co-injection) and determining the amount of oil and its components removed from the rock. The obtained results make it possible to evaluate the processes occurring in the formation, such as volume diffusion of the solvent, the adsorption of heavy oil components on the porous medium, and to provide

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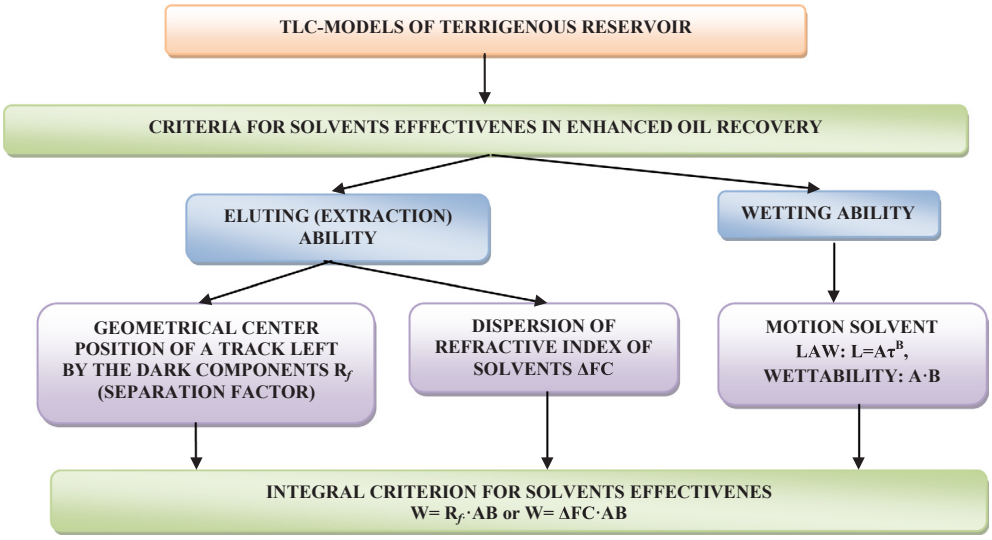

Fig. 1. Criteria for assessing the effectiveness of solvents.

component and thermal analysis of the oil-saturated medium from various oil-solvent interface zones, etc. Typically, such models are very large, and the experiment time and analysis of the results can take from several hours to several days. The proposed method of laboratory TLC (thin-layer chromatographic) analysis of the effectiveness of solvents that are used, or investigated for enhanced oil recovery, is intended for comparative rapid assessment of their effectiveness. A thin layer of sorbent simulates the porous structure of the formation. The process takes place under usual conditions (at atmospheric pressure and temperature of 20 °C). The experimental data obtained can be source information and will allow estimating both the wetting and extracting ability of composite solvents with respect to heavy colored (dark) components of oils and bitumens. The time for one test and processing of the obtained data usually takes about 15–20 min.

2. Methodology

Fig. 1 shows a diagram describing the criteria for evaluating the effectiveness of solvents for oil recovery using thin-layer chromatography plates. Scientific literature analysis has shown that the main criteria for the effectiveness of solvents for oil production are the extracting and wetting abilities of solvents. For rapid analysis properties of the solvent, it was proposed to use TLC plates, which allow modeling of the porous structure of both terrigenous and carbonate reservoirs. To estimate the extraction ability we used the well-known parameter known in TLC as the separation factor (R_f), as well as the dispersion of the refractive index ΔFC. To estimate the wetting ability of the product the coefficients AB of the multiplicative equation $L = A \cdot t^B$ was used. The product of wettability AB and extraction ability (R_f) allows to obtain an integral criterion (W) of solvent efficiency. The main criteria for solvent choosing are the wettability and extraction abilities. We adopted the conventional efficiency scale for the extraction ability when R_f, = 1 – is the ideal case (the solvent dissolves all high-molecular components of oil), including asphaltenes, and when R_f, = 0 is the case when the solvent precipitates or does not dissolve high-molecular components of oil, including asphaltenes. As for wetting ability – the more it is the better AB will be.

This method is designed to evaluate the effectiveness of any hydrocarbon and multicomponent solvents. The choice of solvents is based on the simultaneous evaluation of both extractive and wetting properties, which is the main requirement for solvents used in the process of heavy oil recovery [16].

2.1. Heavy oil and solvents samples

The SARA analysis of a heavy oil sample was conducted according to ASTM D4124-09 and GOST 32269-2013. The oil had the following group composition: saturates – 31.73%, aromatics – 15.26%, resins – 43.96%, asphaltenes – 9.05%.

Also for our investigation we chose pure compounds and industrial samples of solvents. The pure solvents were: isopropyl alcohol (Aldrich, 99%), n-hexane (Aldrich, 99%), chloroform (Aldrich, 99%), benzene (Aldrich, 99%). Industrial reagents to remove paraffin deposits from oil pipelines were Sonpar 5402 produced at «Experimental factory Neftekhim» (reagent for dissolution and dispersion of paraffin deposits), BSF (benzene-containing fraction) produced at oil and gas production department «Elhovneft» of PJSC «Tatneft», RP (benzene-containing fraction) produced at oil and gas production department «Elhovneft» of PJSC «Tatneft», absorbent NK (solvent for oil recovery process) produced at JSC «Nizhnekamskneftekhim», RTS-1 (paraffin deposits solvent) produced by JSC «Reakhim», FLEK R-020 (paraffin deposits solvent) produced by Ltd. «FLEK», SNPH 7r-14A – (paraffin deposits solvent) produced by ANO “Nefteprom khim”. Also we used kerosene, that is a mixture of liquid hydrocarbons (from C_8 to C_{15}) with a boiling point in the range 150–250 °C (GOST 18499–73), and triple composition “TC” (a mixture of equal volumes of chloroform, isopropanol and benzene used in the laboratory for complete extraction of organic compounds from oily rock [17]).

As a simple model of terrigenous reservoir we used TLC plates. It is an aluminum plate coated with a working layer of microfractionated sorbent of silica gel STX-1A and CTX-1VE, 90–120 μm thick, fixed with a special binder. The thickness of the sorbent layer on one plate is ± 5 μm. The sorbent fraction is 8–12 μm. Sorbfil- (TU 4215-002-43636866-2007).

2.2. Use of TLC plates

We propose to use TLC plates, containing a silica gel sorbent as a porous model of terrigenous reservoirs at the stage of searching for synergistic compositions of the solvent. Such models make it possible to investigate the effectiveness of the solvent in extracting or dissolving oil components and to assess its rock-wetting ability quickly and effectively [7,18]. Similarly, the solvents can be studied on plates with calcareous sorbent (the model of a carbonate reservoir). This is an express (routine) method, which allows obtaining valuable information on both the extraction and rock-wetting ability of test solvents for a minimum amount of time. As noted earlier, we tested the solvents for their eluting