Petroleum 2 (2016) 415–424

Contents lists available at ScienceDirect

Petroleum

journal homepage: www.keaipublishing.com/en/journals/petlm

Original Article

Experimental study of Iranian heavy crude oil viscosity reduction by diluting with heptane, methanol, toluene, gas condensate and naphtha

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A R T I C L E I N F O

Article history:
Received 14 March 2016
Received in revised form 28 August 2016
Accepted 29 August 2016

Keywords:
Heavy oil
Viscosity reduction
Dilution
Toluene
Methanol
n-Heptane
Naphtha
Gas condensate

A B S T R A C T

Due to the high viscosity of heavy crude oils, production from these reservoirs is a demanding task. To tackle this problem, reducing oil viscosity is a promising approach. There are various methods to reduce viscosity of heavy oil: heating, diluting, emulsification, and core annular flow. In this study, dilution approach was employed, using industrial solvents and gas condensate. The viscosity of two Iranian heavy crude oils was measured by mixing with solvents at different temperatures. Dilution of both oil samples with toluene and heptane, resulted in viscosity reduction. However, their effect became less significant at higher concentrations of diluent. Because of forming hydrogen bonds, adding methanol to heavy crude oil resulted in higher viscosity. By adding condensate, viscosity of each sample reduced. Gas condensate had a greater impact on heavier oil; however, at higher temperatures its effect was reduced. Diluting with naphtha decreased heavy oil viscosity in the same way as n-heptane and toluene. Besides experimental investigation, different viscosity models were evaluated for prediction of heavy oil/solvent viscosity. It was recognized that Lederer' model is the best one.

1. Introduction

By growing depletion of conventional oil reservoirs potential, heavy and extra-heavy reserves have gained attention [1]. Heavy oil reservoirs contain more than 80% of current petroleum resources, most of which are on developing stage [2,3]. By definition, heavy oil is of API gravity lower than 20 and/or viscosity higher than 100 cp [4]. Also, world heavy oil conference considered heavy oil to be of API gravity lower than 22.3 [5]. Bitumen, oil-shale and tar sand are common instances of extra heavy resources, which even after production, are of high viscosity to be transported through production chain [6]. In this regard, viscosity is of vital importance, controlling production of heavy oils. High content of impurities, typically CO_2 and H_2S, and high molecular weight species, particularly asphaltene, lead to high viscosity of heavy oils [7].

To date, various approaches have been employed to facilitate oil transportation by viscosity reduction. Generally, they fall into four categories: (1) Thermal remediation, (2) Emulsification, (3) Core annular flow; and (4) Dilution [8]. Crude oil pre-heating is the most attractive method, due to quite rapid reduction of oil viscosity [9]. Despite its apparent efficiency, thermal treatment possesses some drawbacks such as needing extra equipment at well site and costly heating process, which poses economic limitations especially at cold climates [10].

Making oil in water emulsion markedly diminishes oil viscosity. However, restoration of original hydrocarbon by breaking the emulsion is a subject of controversy [8]. In addition, choosing the best surfactant for a given oil and aqueous phase depends on their composition. Most importantly, surfactants are expensive materials and economic considerations may pose limitation on amount of surfactant [11]. Core annular flow (CAF) is applied particularly to improve oil flow through pipes. In fact, this

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Peer review under responsibility of Southwest Petroleum University.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.petlm.2016.08.012

approach does not deal with oil viscosity; in turn it forms a lubricating thin water layer on inner surface of pipe wall so as to facilitate the oil flow [8]. Despite its ostensible efficiency, it is often difficult to maintain an annular flow through a pipeline, because most often flow regime would be altered, forming liquid slug and subsequently blending the segregated phases [12]. Forming an annular regime through pipe line necessitates high velocity and high flow rate. Additionally, maintaining the flow velocity all over a pipe line is practically impossible.

Dilution with solvent has drawn attention of most researchers due to its convenient application [13]. Moreover, viscosity reduction by combining a light solvent, for example toluene, with heavy oil has other advantages including: maintaining original characteristic of hydrocarbon in contrast to emulsification approach [12], it could be applied at different locations irrespective to climate conditions while thermal method might be inefficient at cold weather [14], and last but not least, insurance of ultimate performance in comparison with the core annular flow [15]. Applying crude oil dilution with solvent is divided into two successive operations including enhanced oil recovery by injecting solvent into a heavy oil reservoir to reduce in-situ viscosity, namely, solvent-aided steam-assisted gravity drainage (SA-SAGD) [16], and subsequently combing the produced oil with solvent to be transferred from well site to refinery unit through pipe lines.

Nourozieh et al. investigated viscosity of Athabasca bitumen/n-hexane mixture at various temperatures and pressures. They also examined performance of different mixing-rule models for prediction of hydrocarbon mixture viscosity. They pointed out that blending the bitumen with n-hexane dramatically reduces resulting mixture viscosity, particularly at lower amounts of solvent and then viscosity approaches asymptotically to a plateau. In their investigation, increasing temperature was of considerable influence on viscosity reduction especially at lower solvent concentrations. By Comparing several predictive mixing-rules, they concluded that power law and Cargoe's model can accurately estimate viscosity of the Athabasca bitumen/n-hexane mixture [17]. Bassane et al. determined viscosity of heavy oil/gas condensate mixture at various temperatures. They used four heavy oil samples of API gravity in range of 13.7–21.6. They observed viscosity reduction up to 98% of the original heavy oil viscosity by blending with gas condensate of 32 vol.%. Based on experimental measurement, they deduced making mixture of 14 vol.% gas condensate is an optimum point such that adding more amount of solvent would be not economical [18].

Luo et al. investigated viscosity reduction of a heavy oil sample by diluting with propane at high pressures, up to 800 kPa [14,19–21]. In this manner, they took steric colloidal theory of asphaltene suspension in maltene [12], and made synthetized oil samples with different asphaltene concentrations. Their experimental analysis demonstrated sensitivity of oil viscosity on propane concentration. Simply, large asphaltene macromolecules hinder dissolution of any lower molecule into the heavy oil. As a result, slight dissolution of propane renders pronounced reduction of heavy oil viscosity, particularly at lower asphaltene content [19]. Hu analyzed contribution of different solvents (n-heptane, toluene and butanol) and surfactants into reducing viscosity of Frog Lake oil. To this purpose, he focused on molecular interactions between polar moieties of the asphaltene particles and solvent molecules. In this respect, he diluted a heavy oil sample by blending with a thinner containing a polar and a non-polar solvent. They pointed out choosing the proper solvent could inhibit asphaltene association and thus is the best plausible way for reducing viscosity of a heavy oil [12]. Argillier et al. made efforts to investigate contribution of polarity, hydrogen bonding and asphaltene content into reducing oil viscosity using polar thinners and naphtha. They described heavy oil as a colloidal solution in which maltene takes role of continuous phase solvating entangled asphaltene particles. Their observation supports steric colloid theory of asphaltene configuration in crude oil [22,23]. In this view, breaking asphaltene entanglements would reduce oil viscosity.

In spite of growing popularity of dilution method, there is a huge gap in reported data yet; in particular data for effect of different solvents on viscosity of Iranian heavy oils. In this paper, several combinations of two Iranian heavy oils with light hydrocarbons were prepared and their viscosities were measured at various temperatures. Evaluation of viscosity reduction of Iranian heavy oils by dilution method is the main goal of this study. Additionally, different predictive models have been evaluated by comparing their estimation with experimental data.

2. Experiment

2.1. Materials and apparatus

Two heavy oil samples from an Iranian oil reservoirs were selected to carry out experiment. Table 1 summarizes their SARA analysis. Methanol, n-heptane and toluene of 99.9% purity were purchased from Merck GmbH in Germany. Table 2 presents specifications of the solvents used for diluting heavy oils. Also, Table 3 represents their ball-and-stick model. A gas condensate sample of 50 API degree and heavy naphtha were obtained from a refinery unit located in Iran. Table 4 presents specifications of naphtha and gas condensate used in this work. To measure viscosity, four Canon Fenske Opaque viscometers model 9721-B71, 9721-B77, 9721-B80 and 9721-B83 were employed. This device is a modern version of traditional viscometer invented by Ostwald [24], which enables measuring viscosity at various temperatures and atmospheric pressure. Fig. 1 depicts schematic of Ostwald viscometer. For detailed description of this tool refer to [25].

2.2. Method

Firstly, hydrocarbon samples were prepared by volume fraction. Heavy oil and a solvent of known concentration (4, 8 or 12 vol.%) were mixed in a closed beaker by stirrer device via magnet rotation. After proper mixing, glass viscometer was employed to measure viscosity. First, as seen in Fig. 1, the instrument was inverted and the tube A was immersed in liquid. After applying suction and drawing the fluid just to mark B, the instrument was turned back to its normal position. Immediately, tool was placed in a thermostatic bath to reach equilibrium temperature. While holding tool in a fix state, liquid began to come down to fill bulb C. Then tube A was plugged to prevent further liquid flow. Next, by removing stopper from tube A, liquid rised through the capillary from mark D to E and F. By recording passage time and multiplying by the calibration coefficient (obtained through experiment), it is straightforward to obtain viscosity of sample. It should be emphasized that Fig. 1 is merely a

Table 1
Oil samples specifications.

Oil gravity (API)	SARA analysis (wt.%)			
	Asphaltenes	Resins	Aromatics	Saturates
16	14.3	4.77	34.3	46.63
20.5	3.75	0.49	52.09	43.67