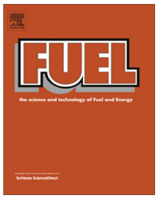
Fuel xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel



New correlations for prediction of viscosity and density of Egyptian oil reservoirs

A.N. El-hoshoudy [b],*, A.B. Farag [a], O.I.M. Ali [a], M.H. EL-Batanoney [b], S.E.M. Desouky [b], M. Ramzi [b]

[a] *Helwan University, Faculty of Science, Department of Chemistry, Ain Helwan, Cairo, Egypt*
[b] *Department of Production, Egyptian Petroleum Research Institute, Naser City, Cairo, Egypt*

HIGHLIGHTS

- Evaluate the existing density and viscosity correlations.
- Conducting PVT analysis at reservoir conditions.
- Measuring oil density and viscosity at different reservoir conditions.
- Develop new empirical correlations.
- Test accuracy of developed correlations by statistical and graphical error means.

ARTICLE INFO

Article history:
Received 23 April 2012
Received in revised form 9 May 2013
Accepted 14 May 2013
Available online xxxx

Keywords:
Oil density
Oil viscosity
PVT correlation
Live oil
Dead oil

ABSTRACT

Density and viscosity are of the most important governing parameters of the fluid flow, either in the porous media or in pipelines. Ideally, viscosity and density determined experimentally in the laboratory on actual fluid samples taken from the field under study. However, in the absence of experimentally measured data, especially during the prospecting phase, or when only invalid samples are available, one can resort to empirically derived PVT correlations. Correlations are also needed for the calculation of multiphase flowing pressure gradients which occur in pipe. These calculations require the prediction of fluid properties at various pressures and temperatures. Even though laboratory measurements of these properties may be available as a function of pressure, they are usually measured under isothermal conditions. The behavior of these properties as a function of temperature is usually predicted by using empirical correlations. So it is of great importance to use accurate correlations to calculate the crude oil density and viscosity at various operating conditions. During the last decades, several correlations have been developed to estimate density and viscosity of oil at different reservoir conditions. However, these correlations may be useful only in regional geological provinces and may not provide satisfactory results when applied to crude oils from other regions since oil properties differ according to its source, origin and core type .Also, crude oil composition is complex and often undefined. Therefore, based on Egyptian oil reservoirs data; new correlations have been developed for predicting density and viscosity of dead and live crude oil. Validity and accuracy of these correlations have been confirmed by comparing the obtained results of these correlations and other ones with experimental data for Egyptian oil samples. Checking results of these correlations show that correlations developed by this study revealed more accurate results than the literature correlations.

1. Introduction

Crude oil density and viscosity are important physical properties that control the flow of oil through porous media and pipe lines; also used in designing the production separation facilities and their values substantially affect crude oil volume calculations. The crude oil density is defined as the mass of a unit volume of the crude at a specified pressure and temperature, mass/volume. While, crude oil viscosity is defined as the internal resistance of the fluid to flow [1]. Crude oil density and viscosity are a strong function of many thermodynamic and physical properties such as the reservoir temperature, pressure, bubble point pressure, oil gravity, gas gravity, gas solubility, and composition of the crude oil. Whenever possible, oil density and viscosity should be determined by laboratory measurements at reservoir temperature and pressure [2]. The oil density and viscosity usually reported in standard PVT analyses. Increasing pressure always cause increase in

---

* Corresponding author. Tel.: +20 21226153276.
E-mail address: azizchemist@yahoo.com (A.N. El-hoshoudy).

0016-2361/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.fuel.2013.05.045

Nomenclature

API	stock tank oil API gravity	P_{res}	reservoir pressure (psia)
T_{res}	reservoir temperature (F)	P_b	bubble point pressure (psia)
ρ_{sc}	oil density, gm/cc at standard conditions	γ_g	gas specific gravity, air = 1
γ_o	oil specific gravity, water = 1	γ_{gs}	separator gas gravity @100 psi, air = 1
R_s	solution gas/oil ratio, scf/STB	R_{sb}	solution gas/oil ratio at bubble point (scf/STB)
μ_{od}	dead oil viscosity (cp)	μ_{ob}	gas-saturated oil viscosity (cp)
ρ_{od}	dead oil density (gm/cc)	μ_o	live oil viscosity (cp)
ρ_o	live oil density (gm/cc)	ρ_{ob}	gas-saturated oil density (gm/cc)
E_r	average percent relative error	MW_{STO}	molecular weight of stock-tank oil
E_a	average absolute percent relative error	S	standard deviation
$E_{min.}$	minimum absolute percent relative error	E_{rms}	the root mean square error
$E_{max.}$	maximum absolute percent relative error	R	correlation coefficient

density and viscosity above the bubble point due to compression of the oil. However below the bubble point, increasing pressure cause an increase in solution gas, which in turn decrease the oil density and viscosity. At atmospheric pressure and reservoir temperature, there is no dissolved gas in the oil [i.e., $R_s = 0$] and therefore the oil has its highest density and viscosity values. Thus, oil density correlations all belong to three categories: dead oil, saturated oil, undersaturated oil density correlations, also, oil viscosity correlations all belong to three categories: dead oil, saturated oil, undersaturated oil viscosity correlations. Numerous correlations have been proposed to calculate the oil density and viscosity [3]. These correlations are categorized into two types. The first type refers to black oil type correlations which predict density and viscosity from available field-measured PVT data, such as reservoir temperature, oil API gravity, solution gas–oil ratio, saturation pressure, reservoir pressure. The second type refers to oil composition models which derive mostly from the principle of corresponding states and its extensions. In these correlations beside previous properties, other properties such as reservoir fluid composition, molar mass, critical temperature and acentric factor of components are used [4]. The reservoir fluid data have many applications in different areas of the Exploration and Production process. While reservoir engineers generally have the greatest claim on such data, reservoir fluid analyses are also quite valuable to geologists and production specialists. The process of collecting fluid samples may be repeated during different phases of a field since discovery till its mature phase. A geologist may use correlations along with an oil or gas gravity measurement from a near-by well for help in obtaining an estimate of the potential reserves to be found in an exploration prospect. After the exploration well is drilled and successful, a well test may allow those same correlations to be used with the known gravity, gas–oil ratio, and pressure data from the discovery well. In an ideal situation, a fluid sample may be recovered from the discovery well for analysis. This more precise information on the properties of the hydrocarbon accumulation may be used by geologists and engineers to justify further development drilling. One or several of the development wells may then be completed and reservoir fluid samples retrieved. The laboratory analysis of such samples provides the more accurate information needed to help plan the development of the field, design production facilities, determine the size and cost of equipment, and thereby make economic decisions. After production has been established, further sampling and analysis may by requested by the engineer to evaluate potential improved recovery projects, consequently, empirical correlations are of great importance to determine these physical properties with high precision at each stage. One can resort to empirical PVT correlations to estimate the reservoir fluid data in the following cases: (1) inability to obtain a representative sample, (2) sample volume is insufficient to obtain a complete analysis, (3) collected sample is non representative, (4) quality check lab analysis, (5) lab analyses are in error, (6) estimating the potential reserves to be found in an exploration prospects, and (7) evaluating the original oil in place and reserve for a newly discovered area before obtaining the laboratory analysis to justify a primary development plan [5]. All correlations were concerned with crudes from different locations and presumably of different characteristics. Each study claimed that the resulting correlation would provide the best approximation of PVT properties for the local region compared to the other commonly used correlations. Studies performed by Macary and Batanony [6], Hanafy et al. [7], Glasso [3], Dokla and Osman [8], Marhoun [9], Labedi [1] all supported this conclusion [5].

Multiple linear/nonlinear least-squares regression analysis will be used to develop the new correlations. In addition, accuracy of developed correlations determined by comparing the obtained results with the published ones through statistical error means (E_r, E_a, E_{max}, E_{min}, S, E_{rms}, and r) and graphical error means (cross plot analysis). Furthermore, the new correlations will be validated using other experimental data sets not used in the correlations development [10].

2. PVT correlations

The frequently used empirical correlations for the prediction of dead, saturated and undersaturated oil densities and viscosities are reviewed in the following sections. For Egyptian oils, Hanafy et al. [7] reported that Ahmed [11] correlation is the most accurate for determining undersaturated oil density while Katz [12] and Standing [13] correlations are the best to estimate dead and gas saturated oil densities respectively, also, correlation after Beggs and Robinson [4] is the best to estimate dead oil viscosity while, the gas saturated and undersaturated oil viscosities are best determined with Khan's [14] correlations.

2.1. Dead oil density correlations

Standing expressed the mathematical form of Katz's chart for dead oil density [12]. Ahmed published two correlations; one correlation uses the stock tank oil molecular weight while the second correlation approximates the estimation of dead oil density if the stock-tank oil molecular weight is not available [11].

2.2. Gas saturated oil density correlations

Standing [13] by using 105 data points [22 fields], published his correlation, In this correlation, a weighted average separator and stock tank gas specific gravities should be used for γ_g, however

Please cite this article in press as: El-hoshoudy AN et al. New correlations for prediction of viscosity and density of Egyptian oil reservoirs. Fuel (2013), http://dx.doi.org/10.1016/j.fuel.2013.05.045