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Parametric study to develop an empirical correlation for undersaturated crude oil viscosity based on the minimum measured input parameters

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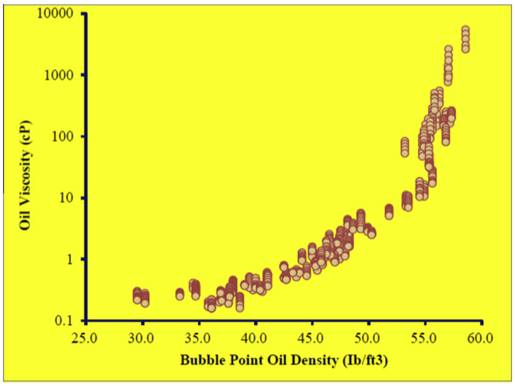
HIGHLIGHTS

- Published correlations for undersaturated oil viscosity were evaluated and compared.
- A new correlation was developed for the bubble point oil viscosity.
- The developed undersaturated oil viscosity correlation outperformed published models.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, the correlations published in the literature for predicting undersaturated oil viscosity data have been evaluated based on field-measured data collected from PVT reports for different Omani fields. It was found that most of these correlations provide good prediction for undersaturated Omani crude oil viscosity with Bergman and Sutton [1] being the best. Then, evaluation analysis was carried out using both calculated bubble point pressure and bubble point oil viscosity data and adopting published correlations for these two parameters. It was found that the calculated bubble point pressure have insignificant effect on the predicted viscosity; therefore it was indicated that the correlations published by Standing [2] and Al-Shammasi [3] can be used to predict bubble point pressure in case of lack of these data. On the other hand, the calculated bubble point oil viscosity was found to have a significant effect on the calculated undersaturated oil viscosity. Therefore, a new correlation for this parameter was developed by applying the genetic algorithm optimization methodology on the collected experimental data. The validation test indicated that the correlation developed in this study for bubble point oil viscosity outperformed all the correlations available in the literature. Hossain et al. [4] correlation proved to have the best prediction for the undersaturated oil viscosity, while the Standing [2] correlation is recommended for predicting the bubble point pressure. On the other hand, the newly developed correlation gave the best performance for predicting the bubble point oil viscosity.

1. Introduction

Viscosity is defined as a measure of fluid resistance to flow. It is one of the important fluid properties in oil industry since it determines how easily the fluid can flow through the porous media. It is important to be predicted at the initial stages of well development since it plays an important role in well test interpretation, well problem analysis, determination of oil reserves, design of surface and subsurface facilities, etc.

Oil samples from new wells are usually sent for experimental PVT analysis from which detailed compositional and PVT

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Table 1
The published undersaturated oil viscosity correlations.

Authors	Samples origin	No. of data points used	Correlation
Kouzel [7]	Worldwide	3593	$\mu_o = \mu_{ob} e^{\left[\left(5.50318\times10^{-5}+3.77163\times10^{-5}\mu_{ob}^{0.278}\right)(p-p_b)\right]}$
Standing [8]	United States	52	$\mu_o = \mu_{ob} + 0.001(p - p_b)(0.024.\mu_{ob}^{1.6} + 0.038\mu_{ob}^{0.56})$
Vazquez and Beggs [9]	Worldwide	600 PVT reports	$\mu_o = \mu_{ob}(p/p_b)^E$ $E = 2.6.p^{1.187}\exp(-11.513 - 8.98 \times 10^{-5}.p)$
Khan et al. [10]	Saudi Arabia	75 bottom hole samples	$\mu_o = \mu_{ob} e^{9.6\times10^{-5}(p-p_b)}$
Al-Khafaji et al. [11]	Middle East	300 oil samples	$\mu_o = \mu_{ob} + 10^F$ $F = -0.3806 - (0.1845 \times API) + (0.004034 \times API^2)$ $-(3.716 \times 10^{-5} \times API^3) + 1.11\log(p - p_b)$
Abdul-Majeed et al. [12]	North Africa and Middle East	253	$\mu_o = \mu_{ob} + 10^G$ $G = 1.9311 - 0.89941\ln(5.614R_{sb}) - (0.001194API^2)$ $+9.2545 \times 10^{-3} API\ln(5.614R_{sb})$ $-5.2106 + 1.11\log(p - p_b)$
Kartoat-modjo and Schmidt [13]	Southeast Asia, North America, Middle East and Latin America	3588	$\mu_o = 1.00081\mu_{ob} + 0.001127(p - p_b)\ \ - 0.006517\mu_{ob}^{1.8148} + 0.038\mu_{ob}^{1.590})$
Labedi [14]	Libya	91	$\mu_o = \mu_{ob} - \left[\left(1 - \frac{p}{p_b}\right)\left(\frac{10^{-2.488}\mu_{od}^{0.9036}p_b^{0.6151}}{10^{0.01976.API}}\right)\right]$
De Ghetto et al. [15]	Mediterranean Basin, Africa, Arabian Gulf and North Sea	3700	Extra heavy oil: $\mu_o = \mu_{ob} - \left[\left(1 - \frac{p}{p_b}\right)\left(\frac{10^{-2.19}\mu_{od}^{1.055}.p_b^{0.3132}}{10^{0.0099.API}}\right)\right]$ Heavy oil: $\mu_o = 0.9886.\mu_{ob} + 0.002763(p - p_b)(-0.01153.\mu_{ob}^{1.7933} + 0.0316.\mu_{ob}^{1.5939})$ Medium oil: $\mu_o = \mu_{ob} - \left[\left(1 - \frac{p}{p_b}\right)\left(\frac{10^{-3.8055}\mu_{od}^{1.4131}.p_b^{0.6957}}{10^{-0.00288API}}\right)\right]$ Entire oil samples: $\mu_o = \mu_{ob} - \left[\left(1 - \frac{p}{p_b}\right)\left(\frac{10^{-1.9}\mu_{od}^{0.7423}.p_b^{0.5026}}{10^{0.0243.API}}\right)\right]$
Pertosky and Farshad [16]	Gulf of Mexico	126 PVT reports	$\mu_o = \mu_{ob} + 1.3449 \times 10^{-3}(p - p_b).10^K$ $K = -1.0146 + 1.3322\log(\mu_{ob}) - 0.4876\log(\mu_{ob})^2 - 1.15036\log(\mu_{ob})^3$
Almehaideb [17]	United Arab Emirates	15 Reservoirs	$\mu_o = \mu_{ob}\left(\frac{p}{p_b}\right)^L$ $L = 0.134819 + 1.94345 \times 10^{-4}.R_{sb} - 1.93106 \times 10^{-9}.R_{sb}^2$
Elsharkawy and Alikha [18]	Middle East	254 Oil samples	$\mu_o = \mu_{ob} + 10^{-2.0771}(p - p_b)(\mu_{od}^{1.19279}.\mu_{ob}^{-0.40712}.p_b^{-0.7941})$
Elsharkawy and Gharbi [19]	Kuwait	805	$\mu_o = \mu_{ob} + M(p - p_b)$ $M = (-5612 + 9481.\mu_{od} - 1459.\mu_{od}^2 + 81.\mu_{od}^3).10^{-8}$
Dindoruk and Christman [20]	Gulf of Mexico	More than 100 PVT reports	$\mu_o = \mu_{ob} + 6.334 \times 10^{-5}(p - p_b).10^O$ $O = 0.776644115 + 0.987658646\log(\mu_{ob}) - 0.190564677\log(R_{sb})$ $+9.147711 \times 10^{-3}.\mu_{ob}\log(R_{sb}) - 1.9111 \times 10^{-5}(p - p_b)$
Kulchanya-vivat [21]	Worldwide	1968	$\mu_o = \mu_{ob}\left(\frac{\rho_o}{\rho_{ob}}\right)^a \rho_{ob\_tr} = -61.5246\ln\rho_{ob}^3 + 709.6163\ln\rho_{ob}^2 - 2717.621\ln\rho_{ob} + 3455.599p_{b\_tr} = 0.0365\ln p_b^2 - 0.29579\ln p_b + 0.19966z_{tr}$ $= \rho_{ob\_tr} + p_{b\_tr}a = \mathrm{e}^{(0.12572.z_{tr}^3 + 0.04923.z_{tr}^2 + 0.7801\cdot z_{tr} + 2.3724)}$
Hossain et al. [4]	Worldwide	390	$\mu_o = \mu_{ob} + 0.004481(p - p_b)(0.555955\mu_{ob}^{1.068099} - 0.527737\mu_{ob}^{1.063547})$
Bergman and Sutton [1]	Worldwide	10,248	$\mu_o = \mu_{ob} e^{\alpha(p-p_b)^\beta}$ $\alpha = 6.5698 \times 10^{-7}\ln(\mu_{ob})^2 - 1.48211 \times 10^{-5}\ln(\mu_{ob}) + 2.27877 \times 10^{-4}$ $\beta = 2.24623 \times 10^{-2}\ln(\mu_{ob}) + 0.873204$
Isehunwa et al. [22]	Niger Delta	More than 400 oil reservoirs	$\mu_o = \mu_{ob} e^{1.02\times10^{-4}(p-p_b)}$