Introduction

Thermophysical characteristics of carbon dioxide are vital for execution, and planning of carbon capture and storage (CCS) processes. While thermodynamic properties such as vapor pressure are more important, the transport parameters such as viscosity play crucial role for design of CCS processes. It is straightforward to use an equation of state (EoS) to predict such parameters; however, these methods cannot predict all parameters precisely. Review of literature shows that an EoS is not suitable for estimation of viscosity (Heidaryan et al. 2011). Recently, some models were proposed for estimation of the viscosity of CO₂ (Bahadori and Vuthaluru 2010, Heidaryan, Hatami, Rahimi and Moghadasi 2011). Present study investigates the applicability of a new correlation for estimation of carbon dioxide viscosity. The new correlation is put into comparison with the literature available correlations and it was concluded that the despite its simple form, the new correlation provides accurate predictions with low deviations from experimental data.

Method and/or Theory

In present study, several resources were utilized to gather 1124 data of carbon dioxide. Figure 1 shows P-T diagram of these data. As is clear wide range of temperature and pressures are covered by these data in a span of 220 K to 700 K and 0.1 MPa to 7960 MPa.

In the process of implementation of a model or empirical correlation, an important point which must be taken into consideration is adequate knowledge about the main influencing parameters on target parameter which is desired to predict. Literature review revels that the main parameters in which effectively influences on the viscosity of carbon dioxide in supercritical regions are temperature and pressure. Knowing this fact, multiple regression analysis was conducted to represent a new method for estimation of CO₂ viscosity in terms of temperature and pressure. The mathematical formulation of proposed correlation is as follows:

\[
\mu = \frac{9.156T^2 - 0.2092P^2 - 2.915PT - 3419T + 4097P}{0.059T^2 - 0.0072P^2 - 0.055PT + 130T + 40.18P - 45180}
\]  

(1)

Where \(\mu\) is viscosity of supercritical CO₂ (μPa.s), \(T\) is temperature (K) and \(P\) is pressure (bar). In this equation \(A_1\) to \(A_{11}\) terms are correlation constants in which their value was found by nonlinear fitting of proposed correlation to experimental data.

![Figure 1 The pressure and temperature range of gathered carbon dioxide viscosity data](image)
Results and Discussion

Figure 2 (a) shows the estimated values against actual viscosity data. The high accumulation of data near the unit slope line for the new correlation reflects that there is an acceptable agreement between the experimental values and the estimations. Figure 2 (b) shows the relative deviations plot of predictions of new correlation versus literature gathered data. The plot reveals the precision of the developed method as is reflected by stacked presence of data points near the line with zero error. In another word, the new correlation is able to predict experimental values with lowest possible relative errors. The outcomes of proposed correlation and actual viscosity data were plotted against temperature and pressure as is depicted in Figure 3 for some data. This figure shows that the new correlation is able to predict experimental data with high accuracy. Table 1 shows the comparison between AARD% values of new correlation in this work and two literature models. The AARD% formula is as follows:

\[
AARD\% = \frac{100}{N} \sum_{i=1}^{N} \frac{(\mu_{\text{Pred}}(i) - \mu_{\text{Exp}}(i))}{\mu_{\text{Exp}}(i)}
\]  

(2)

In which \(\mu_{\text{Pred}}(i)\) is estimated viscosity, \(\mu_{\text{Exp}}(i)\) represents experimental viscosity and the total data is represented by \(N\). As is clear from Table 1, the overall AARD% value of new proposed correlation is 1.76% which is lower than AARD% value of Heidaryan et al. (Heidaryan, Hatami, Rahimi and Moghadasi 2011) and Bahadori and Vuthaluru (Bahadori and Vuthaluru 2010) correlation which are 2.19% and 3.78%, respectively. The pattern of the new correlation is also shown in Figure 4. According to this plot, the viscosity increases at higher densities and lower temperature values.

![Figure 2](image)
Figure 3 Trend estimation capability of developed correlation, (a) Haep (Haep 1976), (b) Abramson (Abramson 2009), (c) Michels (Michels et al. 1957) (d) Golubev (Golubev 1970).

Table 1 Comparison between different models for prediction of CO₂ viscosity

<table>
<thead>
<tr>
<th>Model</th>
<th>AARD%</th>
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<tbody>
<tr>
<td>This study</td>
<td>1.76</td>
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<tr>
<td>Heidaryan et al. (Heidaryan, Hatami, Rahimi and Moghadasi 2011)</td>
<td>2.19</td>
</tr>
<tr>
<td>Bahadori and Vuthaluru (Bahadori and Vuthaluru 2010)</td>
<td>3.78</td>
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</table>
Conclusions
A new correlation is developed to precisely predict the carbon dioxide viscosity at wide range of pressure and temperatures. The new method exhibited acceptable accuracy to estimate the viscosity data with as was shown by different methods. Due to acceptable correlation coefficient ($R^2$) and small AARD% values, the proposed correlation is accurate and effective. In addition, the new method is superior to other literature correlations for prediction of viscosity of CO$_2$ which further supports the precision and reliability of implemented methods. Outcomes of this research are applicable in planning of carbon dioxide transporting facilities where precise and reliable predictions of its viscosity are needed.

References


