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A Modified Model for Prediction of Gas Viscosities of Yemeni Gas Fields

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Abstract

Gas viscosity is an important physical property that controls and influences the flow of gas through porous media and pipe networks. An accurate gas viscosity model is essential for use with reservoir and process simulators. The present study is concerned with the evaluation of available gas viscosity correlations. The paper also presents new models for predicting gas viscosity for Yemeni gas reservoir. The most often used different correlations for gas viscosity were assist for Yemeni gas samples. The limitations of these correlations have been analyzed using Yemeni field data. Calculations are made using 120 experimental data points from Yemeni gas reservoirs. The most common gas viscosity correlations such as Lee et al., Carr et al. and Dean and Stile were selected as a suitable compositional viscosity model for developing new models using fitting the Yemeni gas reservoirs data. Initially, all considered models in this study were evaluated for the Yemeni gas data. To improve the performance of these correlations their coefficients were regenerated to fit the Yemeni gas samples data set using linear and nonlinear regression methods. The behavior of new developed models was evaluated using statistical error analysis. The new developed models show accuracy with the desirable engineering limits.

Key Words: Models; Natural gas; Viscosity; Empirical Correlation; Yemeni gas.

Introduction:

Prediction of the hydrocarbon gas properties is necessary in several hydrocarbon gas engineering calculations, such as gas metering, gas compression, estimating the pressure gradient in gas wells, and design of pipeline and surface facilities.

Gas viscosity is one of the properties in the gas production and processing. Due to the complex composition of petroleum fluids and high pressure, high temperature conditions of reservoirs, traditionally, graphs and empirical correlations were used to estimate the viscosity of natural gases. Several correlations have been proposed for determining gas viscosity.

Most of the existing empirical and semi-empirical viscosity correlations are applicable only to either gas phase or liquid phase within limited temperature and pressure ranges. Limitations concerning the validity of these correlations for different types of gas accuracy, range of applicability etc., have been controversial. Because gases from different regions have different properties, it is recommended to assess the accuracy of the available correlations.

The objective of this study is to develop a general compositional viscosity model for Yemeni gas fields that is applicable to natural gas mixtures.

Gas Viscosity Correlations:

Ideally, viscosity is experimentally measured in a laboratory. However, experimental determination of gas viscosity is difficult. When such direct measurements are not available, viscosity is obtained from correlations. Fundamentally, there are different types of correlations in the literature. Several correlations are available to predict the natural gas viscosity. Carr et al. [1] and Dean and stile [2] proposed a correlation for calculation of natural gas as a function of reduced pressure, reduced temperature, reduced density of gas and molecular weight. The Lucas [6] method requires the critical temperature, critical pressure, critical compressibility factor, and the dipole moment. Londono et al. [5] viscosity correlations are highly dependent upon the gas viscosity at atmospheric pressure. Lee et al. [4] proposed a correlation that is the most reliable for determining the viscosity of natural gas. Guo et al. [3] presented two viscosity models based on Peng-Robinson EOS and Patel-Teja EOS and found that their model is capable of satisfactorily describing pure component hydrocarbon viscosity. Vogel [9] presents correlation for the viscosity of pure hydrocarbon gas, namely for propane.

The first type of correlations is developed using randomly selected datasets. Such correlations could be called generic correlations. The second

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group of correlations, called specialized correlations, is developed using a certain geographical area or a certain type of gas. Correlations using randomly selected datasets may not be suitable for certain type of gas, or certain geographical areas.

Even though the authors of the general correlations want to cover a wide range of data, specialized correlations represent the properties of a certain type of gas or developed for specific geographical area which still works better than the general correlations. The correlations used for prediction are shown in the appendix.

Data Acquisition for Modeling:

About 120 experimentally gas viscosity data points were collected from different Yemeni gas fields which are being used in this study to evaluate the gas viscosity correlations and for developing the new models. The data ranges and description of these data are shown in Table (1). Composition of gas samples utilized for modeling is listed in Table (2).

Table (1) Statistical description of gas data used

Property	Max.	Min.	Average	STD
P, psia	3365	15	924.69	914.41
Bg, ft^3/SCF	1.3577	0.0047	0.20	0.40
Z	1.020	0.310	0.91	0.08
T, °F	220	90	172.47	35.68
S.G	2.073	0.670	0.94	0.35
MW, lb/lb.mole	60.03	19.39	27.41	10.26
Density, lb/ft^3	12.71	0.045	3.47	3.34
N_2, fraction	0.684	0	0.03	0.09
CO_2, fraction	0.103	0	0.00	0.01
H_2S, fraction	0.0004	0	0.00	0.00
Viscosity, Cp	0.02242	0.00588	0.01	0.00

Table (2) Composition of gas samples utilized for modeling

Component,%	Max.	Min.	STD	Mean
N_2	16.29	0	2.143	1.32
CO_2	3.4	0	0.540	0.38
H_2S	0.04	0	0.007	0.002
C1	87.78	1.8	25.122	62.74
C2	32.62	4.67	5.615	13.25
C3	39.88	2.97	9.171	11.02
i-C4	9.08	0.4	1.877	1.67
n-C4	23.7	0.11	4.908	4.15
i-C5	6.942	0.21	1.541	1.14
n-C5	9.349	0.17	2.065	1.43
n-C6	8.43	0.1	1.607	1.07
C7+	17.62	0.0006	2.968	1.42

Results and Discussion:

The statistics were used in this study to evaluate the performance of difference models. The statistical parameters calculated were average percent relative error (ARE), mean percent absolute relative error (MAPE), minimum/ maximum absolute percent relative error, standard deviation (STD), skewness, kurtosis, the coefficient of determination and the coefficient of correlation.

Table (3) shows the error analysis for some published gas viscosity correlation for the Yemeni gas. Table (3) revealed the average relative error, absolute average relative error and standard deviation for gas viscosity correlation which show an increase in error. Figures (1) and (2) show the statistical analysis for studying the performance of difference models. Figure (3) is a plot of gas viscosity distribution for different correlation depending on molecular weight.

Figure (4) shows the error of the correlations according to different ranges of reservoir temperature. Carr et al. Correlation is the best in the ranges of temperature 180-199^o *F*, while Lee et al. and Dean and Stile correlations have the same accuracy. At temperature greater than 199^o*F*, all correlations show approximately the same accuracy. Dean and Stile correlation is the worst in all ranges of temperature. Figure (5) presents the error of the correlation according to different ranges of gas molecular weight. Lee et al. correlation is the best in predicting gas viscosity with molecular weight ranging from 19 to 23. In small value of molecular weight all correlations behave well. Carr et al. correlation gives accuracy in all ranges of molecular weight. The error of the correlations according to different ranges of pressure is shown in Figure (6). It shows that all correlations have the lowest error for pressure greater than 1365 psi. Carr's et al. correlation is the most accurate in all ranges of pressure. For pressure less than 180 psi Carr's et al. and Lee's et al. correlations represent more accurate model. In pressure more than 215 psi all correlations show the same accuracy.

Cross plots of actual versus predicted gas viscosity are presented in Figures (7) through (9). Data points from Lee et al., Dean and Stile and Carr's et al. correlations fall below 45^o line. Carr's et al. correlation underestimates the gas viscosity. Dean and Stile's correlation underestimates viscosity at pressure values greater than 1300 psi. Lee's et al. correlation overestimates gas viscosity at pressure greater than 1115 psi. Investigation of these figures shows that Carr's et al. correlation outperforms all correlations.

To improve the performance of the most common correlations, the new coefficients are recalculated for Yemeni data using regression analysis.

Tables (5) through (7) show the original and generated new coefficients for these correlations. Figures (10) through (12) show scatter plot for developed models in this study. The cross plot of gas viscosity for models developed in this study almost fall on the 45^o line implying excellent models. Good correlation between calculated and experimental values gives Carr et al. and Lee et al. models. Lee's et al. model achieves the best correlation coefficient among other models. It is clearly seen that the proposed models outperform correlations.

Table (3) Statistical accuracy of gas viscosity correlations using Yemeni data

Parameter	Dean and Stile	Carr et al.	Lee et al.
Er	0.01	0.01	3.84
MAPE	9.62	7.67	7.63
Emin	0.11	0.02	0.00
Emax	124.68	121.83	59.93
ERMS	3.10	2.77	13.22
STD	9.46	0.01	0.00
C.V	23345.74	20840.89	99535
R	0.83	0.93	0.90
Skew	0.00	761037.30	0.79
Kurtos	-3.00	112000000	-0.81

Table (4) Statistical accuracy of modified gas viscosity correlations using Yemeni data

Parameter	Dean and Stile	Carr et al.	Lee et al.
Er	0.013	0.013	0.013
MAPE	5.986	6.852	5.791
Emin	0.000	0.007	0.000
Emax	58.369	114.778	44.860
R	0.918	0.931	0.939

Table (5) Original and modified coefficient for Dean & Stile's correlation

Coefficient	Original correlation	Modified correlation for Yemeni data
a1	5.4402	3.539704
a2	0.166667	6.01E-08
a3	0.5	0.114361
a4	0.666667	0.676713
a5	0.001668	0.001111
a6	0.1338	0.115368
a7	0.0932	0.075736
a8	0.555556	0.511659
a9	0.00034	0.000215
a10	0.888889	1.169785
a11	0.000108	0.00028
a12	1.439	0.786749
a13	-1.111	1E-05
a14	1.888	1.896121

Table (6) Original and modified coefficient for Lee's et al. correlation

Coefficient	Original correlation	Modified correlation for Yemeni data
a1	9.4	16.181402
a2	0.02	0.001000
a3	1.5	0.129999
a4	209	90.042760
a5	19	1.913630
a6	3.5	780.041282
a7	986	0.039770
a8	0.01	2.724560
a9	2.4	0.389303
a10	-0.2	1.529756

Table (7) Original and modified coefficient for Carr's et al. correlation

Coefficient	Original correlation	Modified correlation for Yemeni data
a0	-2.462	-2.32989
a1	2.97	2.035635
a2	-0.2862	-0.83249
a3	0.008054	0.197363
a4	2.808	2.338847
a5	-3.498	-3.15604
a6	0.3603	0.3179
a7	-0.01044	-0.05744
a8	-0.7933	-0.17713
a9	1.396	2.398748
a10	-0.1491	0.258844
a11	0.00441	-0.11791
a12	0.08393	-0.12021
a13	-0.1864	-0.73679
a14	0.02033	-0.08074
a15	-0.00061	0.047692

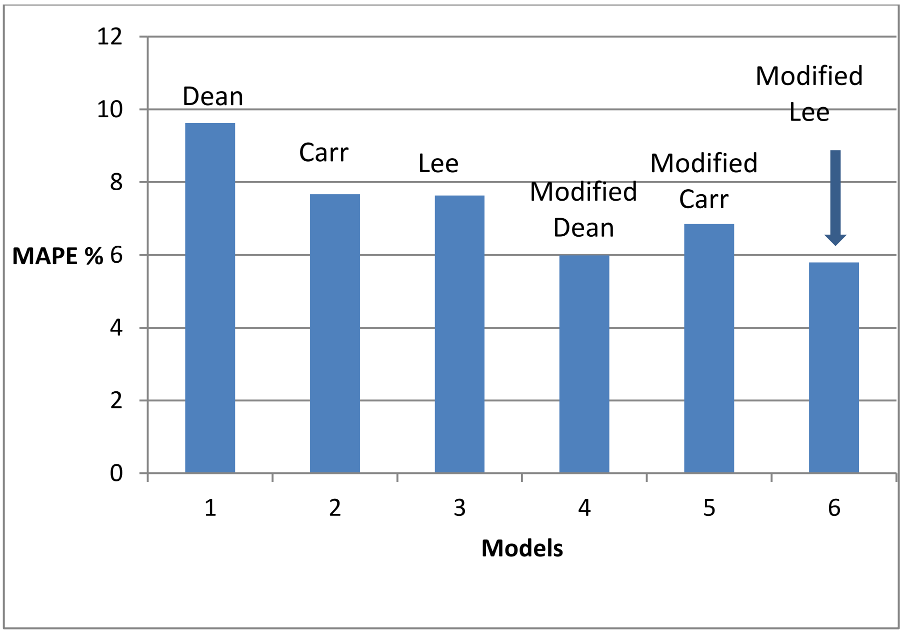

Figure (1) Error analysis (MAPE) for different models

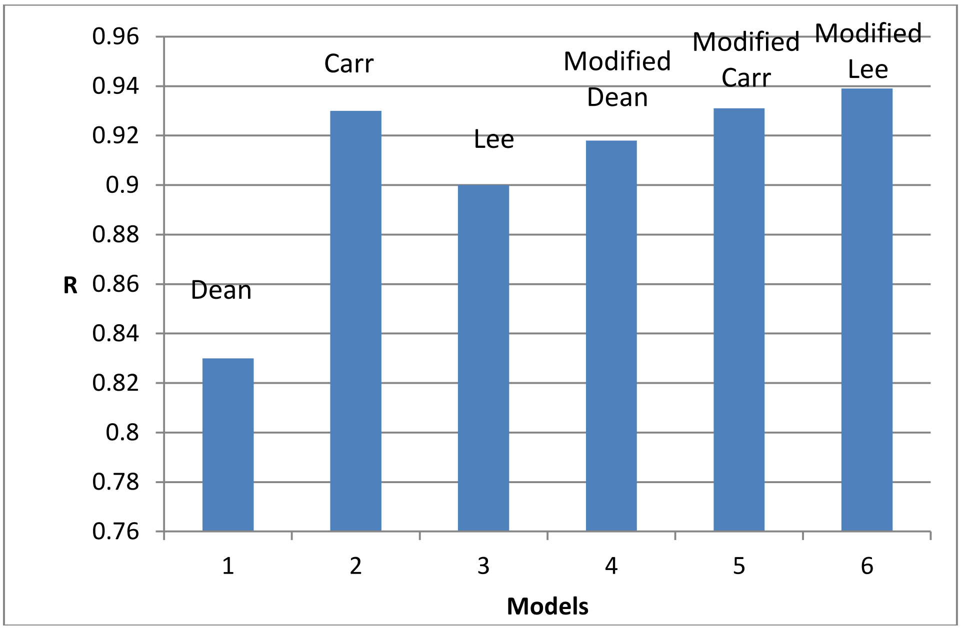

Figure (2) Error analysis (R) for different models

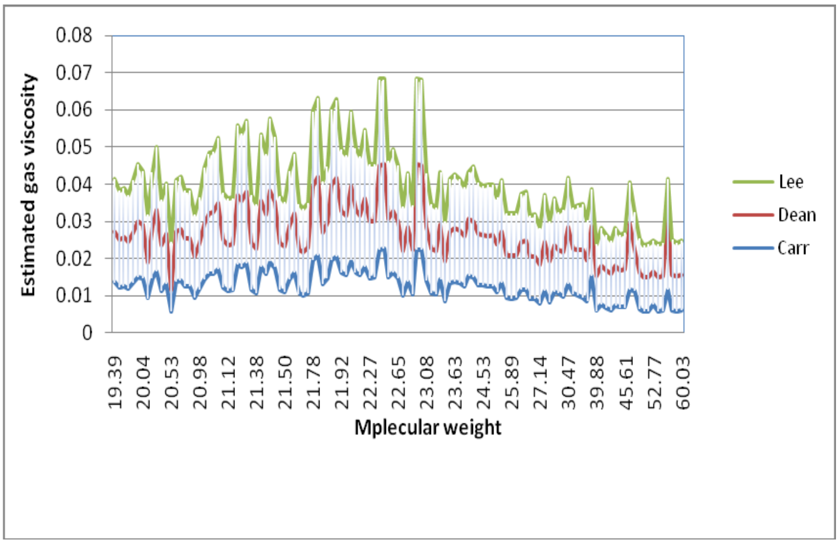

Figure (3) Estimated gas viscosity as a function of molecular weight

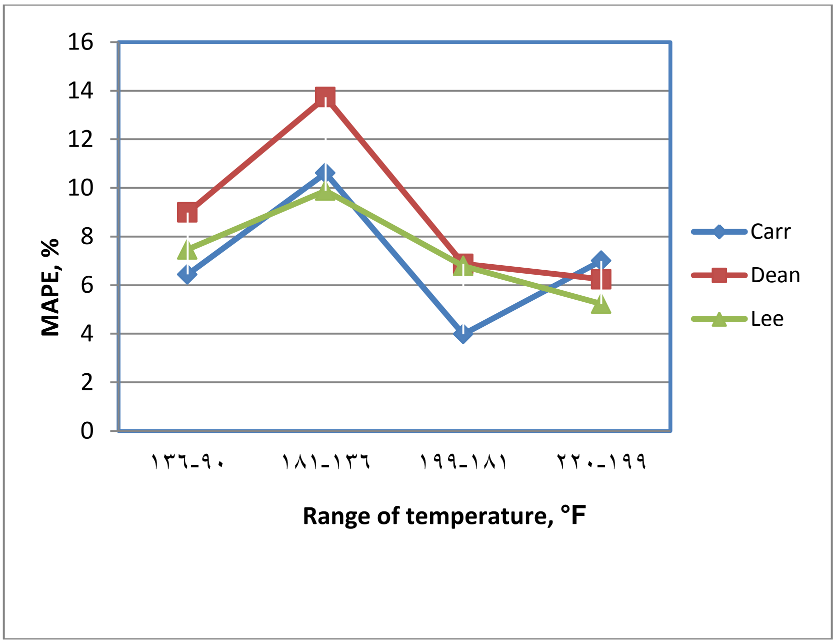

Figure (4) Statistical accuracy of correlations for gas viscosity for Yemeni data grouped by temperature

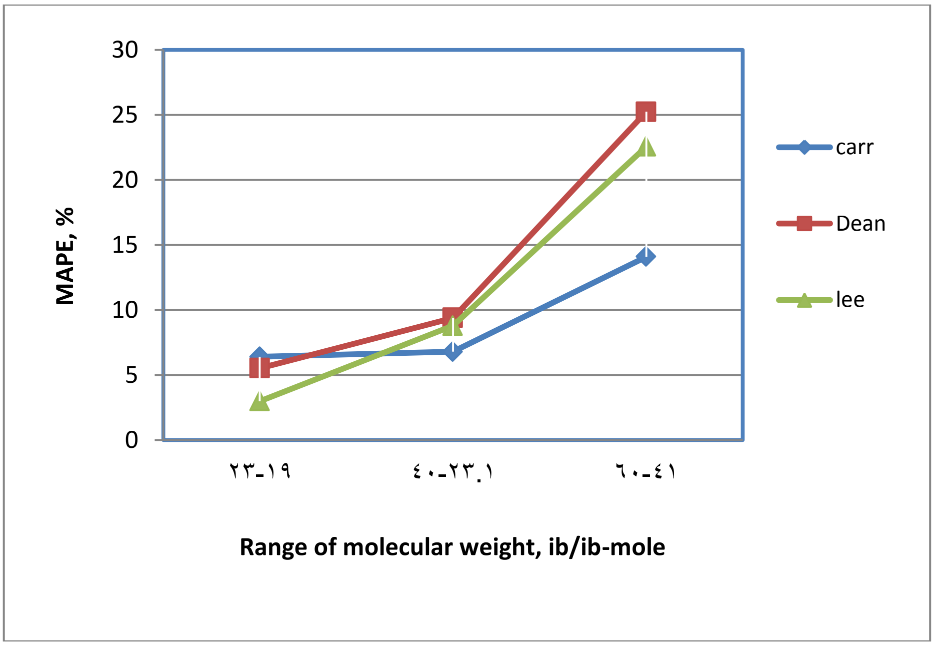

Figure (5) Statistical accuracy of correlations for gas viscosity for Yemeni data grouped by molecular weight

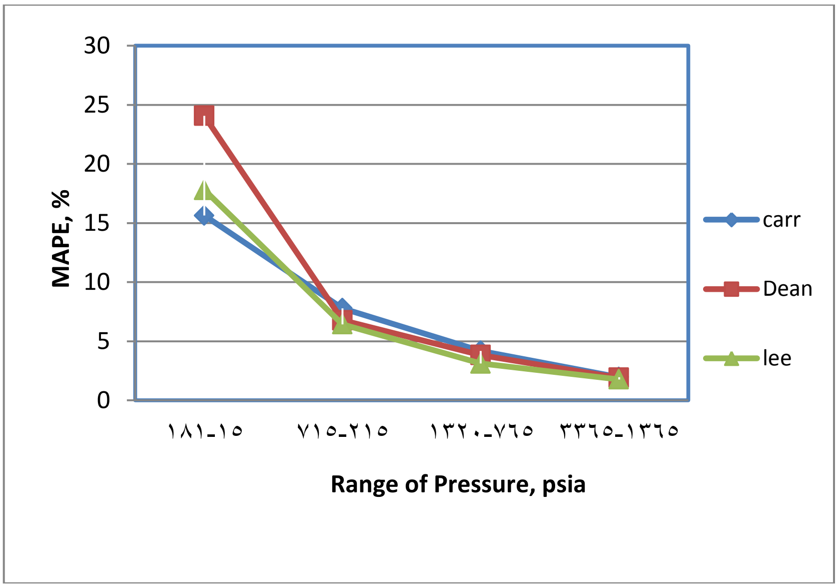

Figure (6) Statistical accuracy of correlations for gas viscosity for Yemeni data grouped by pressure

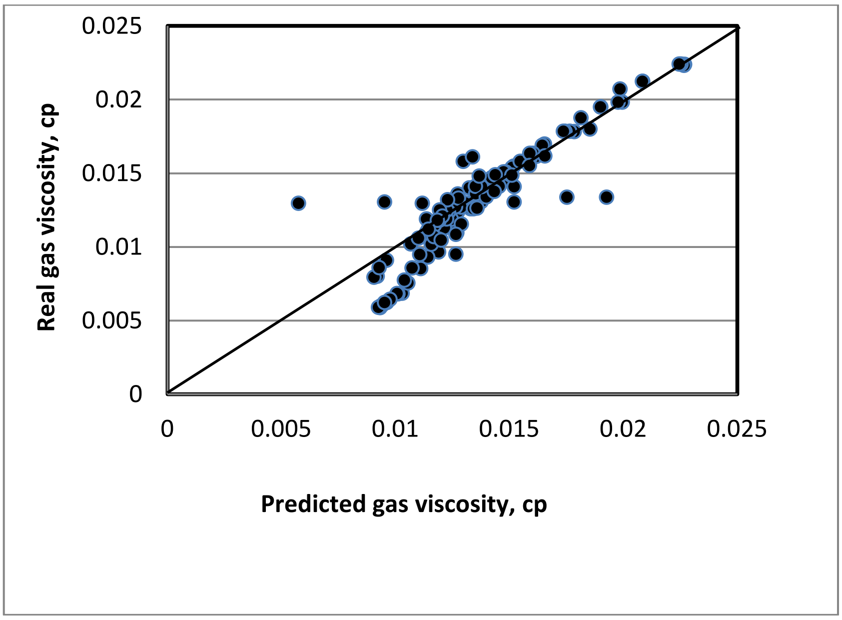

Figure (7) Cross plot of field data against predicted data (Dean and Stile's Correlation)

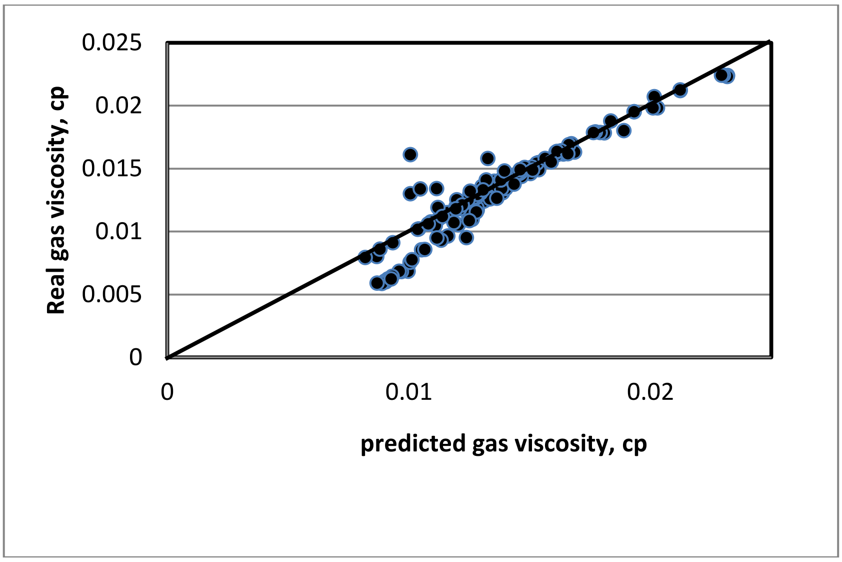

Figure (8) Cross plot of field data against predicted data (Lee's et al. Correlation)

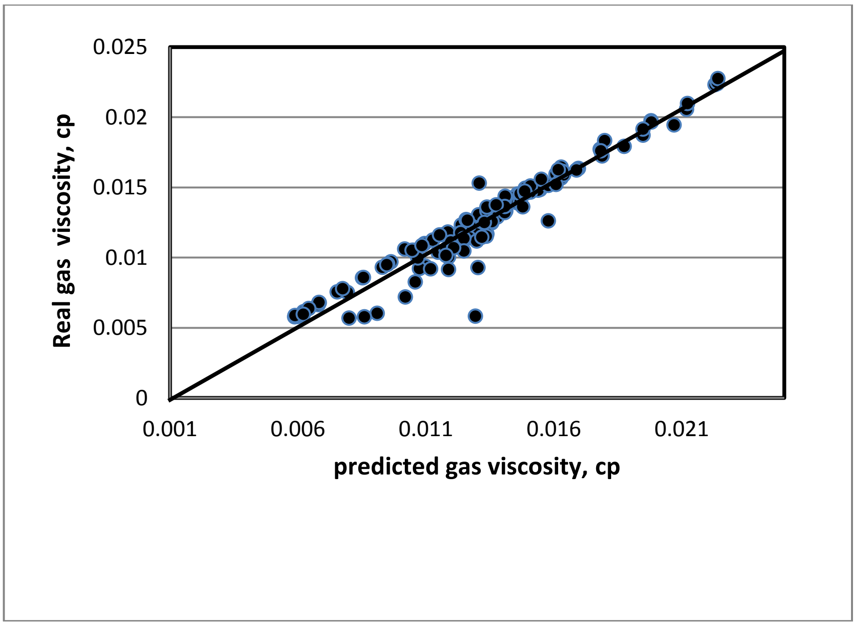

Figure (9) Cross plot of field data against predicted data (Carr's et al. Correlation)

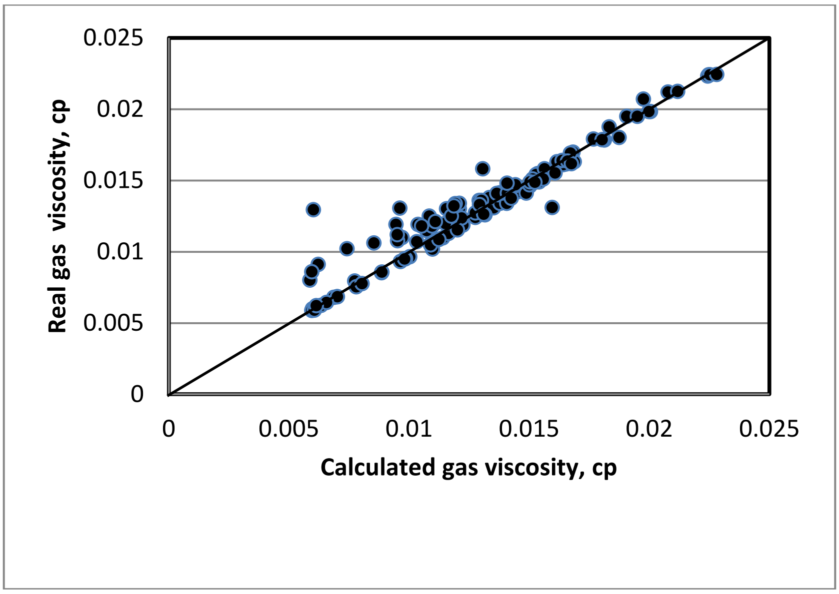

Figure (10) Cross plot of field data against predicted data (proposed Carr's et al. Correlation)

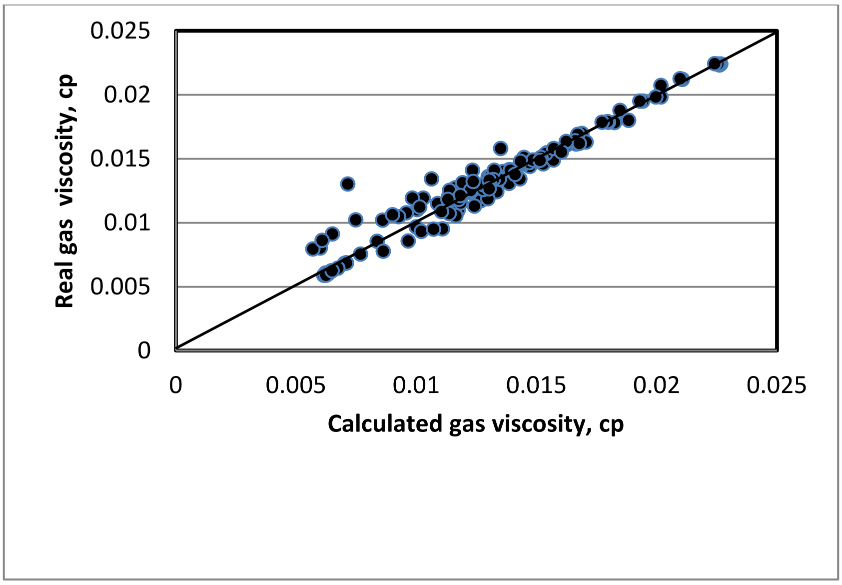

Figure (11) Cross plot of field data against predicted data (proposed Lee's et al. Correlation)

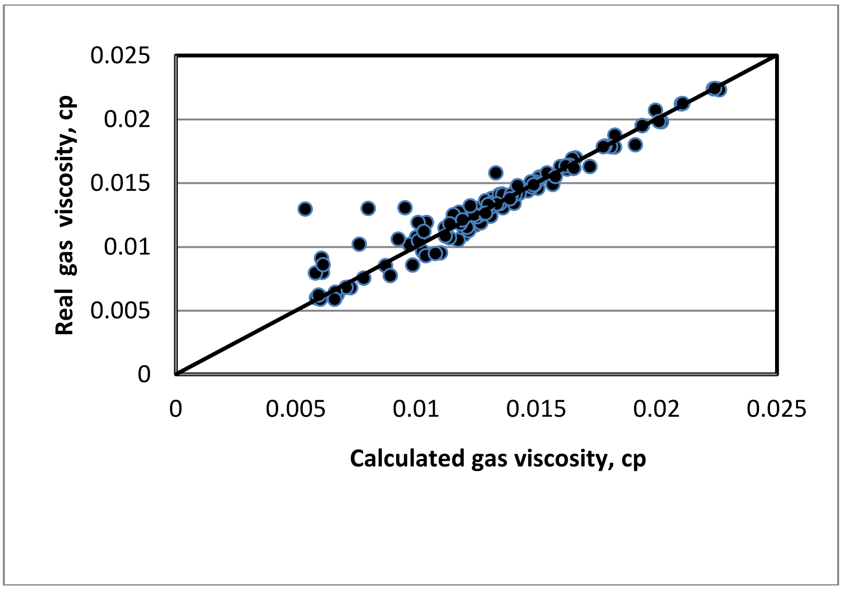

Figure (12) Cross plot of field data against predicted data (proposed Dean and Stile's Correlation)

Conclusions:

In this study, using the laboratory data of Yemeni gas fields, a new viscosity models have been developed. The proposed models cover an acceptable range of validity, and are superior in predicting gas viscosity to other published correlations in the literature. The comparisons with the published correlations show that the proposed models better predict the viscosity of Yemeni gas field.

- The best correlation for predicting the gas viscosity is Carr's correlation with an average error 7.66 % when the actual coefficients for all correlations were used.

- After modified the coefficients of the all correlations, Lee's Model is the best for estimating gas viscosity with an MAPE of 5.7 % and correlation coefficient.

Nomenclatures:

E_r= Average percent relative error
MAPE = Mean absolute relative error
E_{min} = Minimum absolute percent relative error
E_{max} = Maximum absolute percent relative error
ERMS = Root mean squared error
STD = Standard deviation
C.V = Coefficient of validation
R = Correlation coefficient
Skew = Skewness
Kurtos = Kurtosis
μ_g= Gas viscosity at reservoir pressure and temperature, cp
μ_1=Gas viscosity at atmospheric pressure and reservoir temperature, cp
ρ_r= Reduced gas density, lb/ft^3
ρ_g = Gas density, lb/ft3
M_w= Gas molecular weight, lb/lb-mole
T = Reservoir temperature, °R
P_r = Reduced pressure, psia
T_r = Reduced temperature, °R
y_{N_2}, y_{CO_2} *and* y_{H_2S} = Mole fraction of N_2, CO_2, and H_2S
γ_g= Gas gravity specific
Z = Gas Compressibility factor
P_c = Pseudo pressure, psia
T_c = Pseudo temperature, °R
ϵ = Pseudo critical temperature adjustment factor

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Appendix A: Gas Viscosity Correlations

Lee's et al Correlation:

$$\mu_g = 10^{-4} K exp\left[X\left(\frac{\rho_g}{62.4}\right)^Y\right] \quad (1)$$

Where:

$$K = \frac{(a_1 + a_2 M_w)T^{a_3}}{a_4 + a_5 M_w + T} \quad (2)$$

$$X = a_6 + \frac{a_7}{T} + a_8 M_w \quad (3)$$

$$Y = a_9 - a_{10} X \quad (4)$$

Carr's et al. Correlation:

Standing [7] developed equations representing Carr et al. Correlation chart in the ranges $0.55 < \gamma_g < 1.55$ *and* $100 < T < 300°$F

$$\mu_1 = (\mu_1)_{uncorrected} + (\Delta\mu)_{CO_2} + (\Delta\mu)_{N_2} + (\Delta\mu)_{H_2S} \quad (5)$$

Where:

$$(\mu_1)_{uncorrected} = [1.709 \times 10^{-5} - 2.062 \times 10^{-6}\gamma_g]T + 8.188 \times 10^{-3} - 6.15 \times 10^{-3} log(\gamma_g) \quad (6)$$

$$(\Delta\mu)_{N_2} = y_{N_2} \times 10^{-3}[8.48 log(\gamma_g) + 9.59] \quad (7)$$

$$(\Delta\mu)_{CO_2} = y_{CO_2} \times 10^{-3}[9.08 log(\gamma_g) + 6.24] \quad (8)$$

$$(\Delta\mu)_{H_2S} = y_{H_2S} \times 10^{-3}[8.49 log(\gamma_g) + 3.73] \quad (9)$$

Then the viscosity ratio can be calculated as:

$$ln\left[T_r\left(\frac{\mu_g}{\mu_1}\right)\right] = a_0 + a_1 P_r + a_2 P_r^2 + a_3 P_r^3 + T_r(a_4 + a_5 P_r + a_6 P_r^2 + a_7 P_r^3) + T_r^2(a_8 + a_9 P_r + a_{10} P_r^2 + a_{11} P_r^3) + T_r^3(a_{12} + a_{13} P_r + a_{14} P_r^2 + a_{15} P_r^3) \quad (10)$$

$$ln\left(\frac{\mu_g}{\mu_1}\right) = X \quad (11)$$

$$X = ln\left[T_r\left(\frac{\mu_g}{\mu_1}\right)\right] = a_0 + a_1 P_r + a_2 P_r^2 + a_3 P_r^3 + T_r(a_4 + a_5 P_r + a_6 P_r^2 + a_7 P_r^3) + T_r^2(a_8 + a_9 P_r + a_{10} P_r^2 + a_{11} P_r^3) + T_r^3(a_{12} + a_{13} P_r + a_{14} P_r^2 + a_{15} P_r^3) - \ln(T_r) \quad (12)$$

$$\frac{\mu_g}{\mu_1} = e^X \quad (13)$$

$$\mu_g = \mu_1 e^X \quad (14)$$

Dean and Stile's Correlation:

$$\mu_1 = a_9 \frac{T_r^{a_{10}}}{\varepsilon_m} \quad for\ T_r \le 1.5 \quad (15)$$

$$\mu_1 = \frac{a_5(a_6 T_r - a_7)^{a_8}}{\varepsilon_m} \quad for\ T_r > 1.5 \quad (16)$$

$$\varepsilon_m = a_1 \times \frac{T_c^{a_2}}{M_w^{a_3} P_c^{a_4}} \quad (17)$$

$$\mu_g = \mu_1 + \frac{a_{11}[exp(a_{12}\rho_r) - exp(a_{13}\rho_r^{a_{14}})]}{\varepsilon_m} \quad (18)$$

$$\rho_r = \frac{0.27\, P_r}{Z T_r} \quad (19)$$

Pseudo critical properties are calculated by using Standing [7] correlation:

$$P_c = 709.6 - 58.7\gamma_g \quad (20)$$

$$T_c = 170.5 + 307.3\gamma_g \quad (21)$$

Wichert- Aziz's [8] Correlation is used for correcting the Pseudo critical properties as:

$$A = Z_{CO_2} + Z_{H_2S} \quad (22)$$

$$B = Z_{H_2S} \quad (23)$$

$$\epsilon = 120(A^{0.9} - A^{1.6}) + 15(B^{0.5} - B^4) \quad (24)$$

$$T_c = \acute{T}_c - \epsilon \quad (25)$$

$$P_c = \frac{\acute{P}_c \acute{T}_c}{T_c + B\acute{\epsilon}(1 - B)} \quad (26)$$

Where:

$$P_r = \frac{P}{P_c} \quad (27)$$

$$T_r = \frac{T}{T_c} \quad (28)$$

Appendix B: Sample of calculations:

1- Input data:

Property	Value	Property	Value
P, psia	3300	B_g, ft^3/SCF	0.0048
Z	0.853	T,°F	193.7
γ_g	0.79	M_w, lb/lb-mole	22.878
ρ_g, lb/ft^3	12.619	N_2, fraction	0.013
CO_2, fraction	0.0068	H_2S, fraction	0
μ_g, cp	0.022396		

2- Calculation:

Property	Value	Number of Equation used for calculation
P_c, psia	663.8	25
T_c, °R	413.87	26
P_r	4.971	27
T_r	1.579	28
ρ_r, lb/ft^3	0.9963	19

3- Determination gas viscosity by using Lee's et al Correlation:

	X	Y	K	μ_g, cp	Error
Lee's et al Correlation	5.237117	1.352577	126.9899	0.023203	3.481
Modified Lee's et al Correlation	4.016977	1.160957	121.0360	0.0226817	1.27585
Number of Equation used for calculation	3	4	2	1	

4- Determination gas viscosity by using Carr's et al Correlation:

	Carr's et al Correlation	**Modified Carr's et al Correlation**	**Number of Equation used for calculation**
$(\mu_1)_{uncorr.}$	0.011812	0.011812	6
$(\Delta\mu)_{N_2}$	0.000113	0.000113	7
$(\Delta\mu)_{CO_2}$	3.61×10^{-5}	3.61×10^{-5}	8
$(\Delta\mu)_{H_2S}$	0	0	9
μ_1	0.001196	0.001196	5
X	1.083535	1.088509	12
μ_g, cp	0.02237979	0.022491336	13
Error	0.07266	0.42388	

5- Determination gas viscosity by using Dean and Stile's Correlation:

	ε_m	**μ_1**	μ_g, cp	**Error**
Dean and Stile's Correlation	0.040802	0.012479	0.0226817	1.3435
Modified Dean and Stile Correlation	0.030465	0.011597	0.022527	0.586483
Number of Equation used for calculation	17	15 & 16	18	

نموذج جديد للتنبؤ بلزوجة الغاز في حقول الغاز اليمنية

خالد سعيد باجعالة **عباس محمد الخذفي**

عامر بدر بن مرضاح

الملخص

تعد لزوجة الغاز من الخواص الفيزيائية التي تسيطر وتؤثر في تدفق الغاز خلال الأوساط المسامية وأنابيب النقل. وتستخدم معادلات حساب لزوجة الغاز في عمليات محاكاة المكامن. وفي هذه الدراسة تم تقويم معادلات حساب لزوجة الغاز المتوفرة وكذلك تطوير معادلات جديدة لحساب لزوجة الغاز في حقول الغاز اليمنية. وقد تم استخدام 120 نقطة من خزانات الغاز اليمنية لتقويم أشهر العلاقات المستخدمة في حساب لزوجة الغاز مثل Lee et al ., Carr et al. and Dean and Stile في البداية تم تقويم أداء العلاقات المستخدمة في حساب لزوجة الغاز باستخدام بيانات من حقول الغاز اليمنية. ولتحسين أداء هذه العلاقات تم تجديد معاملاتها لتتناسب مع مجموعة بيانات عينات الغاز اليمنية باستخدام أساليب الانحدار الخطي وغير الخطي. كما تم تقويم سلوك العلاقات الجديدة باستخدام تحليل الخطأ الإحصائي. حيث أظهرت العلاقات الجديدة دقة عالية في حساب لزوجة الغاز في حقول الغاز اليمنية.

كلمات مفتاحية : علاقات ، الغاز ، لزوجة الغاز ، معادلات حساب لزوجة الغاز ، حقول الغاز اليمنية.