



Improved K -value correlation for UAE crude oil components at high pressures using PVT laboratory data[☆]

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Received 11 July 2002; revised 10 December 2002; accepted 17 December 2002; available online 29 January 2003

Abstract

In this paper, 732 high-pressure K -values obtained from PVT analysis of 17 crude oil and gas samples from a number of petroleum reservoirs in the UAE are used. Material balance techniques are used to extract the K -values of crude oil and gas components from the constant volume depletion and differential liberation tests for the oil and gas samples, respectively. These K -values are then correlated and the resulting correlation compared with published correlations. Comparisons of results show that currently published correlations give poor estimates of K -values for non-hydrocarbon and hydrocarbon components, while the proposed new correlation improved significantly the average absolute deviation for non-hydrocarbon and hydrocarbon components. The average absolute error between experimental and predicted K -values for the new correlation was 20.5% compared with 76.1% for the Whitson and Torp correlation, 84.27% for the Wilson correlation, and 105.8 for the McWilliams correlation. Additionally, the bubble point and dew point pressures are calculated for these 17 samples and compared with experimental values. The average absolute error in the saturation pressures for the new correlation was 6.08% compared with 56.34% for the Wilson correlation, 57.84% for the Whitson and Torp correlation, and 9.28% for the Peng–Robinson equation of state with default parameters.

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Keywords: K -value; Bubble point; Dew point; Crude oil; Natural gas

1. Introduction

Equilibrium ratios play a fundamental role in the understanding of phase behavior of hydrocarbon mixtures. They are important in predicting compositional changes under varying temperature and pressure in reservoirs, surface separations, and production and transportation facilities. In particular, they are critical for reliable and successful compositional reservoir simulation. Equilibrium ratios, more commonly known as K -values, relate the vapor mole fractions, y_i , to the liquid fraction, x_i , of a component i in a mixture,

$$K_i = \frac{y_i}{x_i} \quad (1)$$

In a fluid mixture consisting of different chemical species at high pressure, K -values are dependent on pressure, temperature, and the composition of the mixture. This extra dependency on the fluid composition, for high-pressure

systems compared to low-pressure systems, has limited our ability to predict high pressure K -values empirically and shifted the emphasis for preferred methods to using the more sophisticated equations of state approach.

The objective of this work is to evaluate the published empirical correlations that could possibly be used for computing K -values for high-pressure systems, namely the Wilson, Whitson and Torp, and the polynomial equation of McWilliams, using the experimental K -values extracted through material balance techniques from PVT tests performed on UAE petroleum samples, and to develop a new correlation for UAE crudes formulated using the multi-variable regression technique. To test the merits of the new correlation, a comparison is performed for predictions from all correlations with experimental K -values and with measured bubble and dew point pressures.

2. Literature review

A search of the literature reveals that only few authors attempted to obtain a direct general correlation for K -values

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[☆] Published first on the web via [Fuelfirst.com](http://www.fuelfirst.com)—<http://www.fuelfirst.com>

Nomenclature		Z	compressibility factor
a_T, a_p	correlation parameters	<i>Greek</i>	
B_o	oil formation volume factor (bbl/STB)	σ	standard deviation
K_i	equilibrium ratio for component i	ρ_{STO}	density of stock-tank oil (lb _m /ft ³)
M	molecular weight (lb _m /lb mol)	ρ_{or}	density of reservoir oil (lb _m /ft ³)
n	mole fraction	ω_i	acentric factor for component i
\bar{n}_{gj}	mole fraction of gas separated in separator stage j , based on 1 lb mol of feed	<i>Subscripts and superscripts</i>	
\bar{n}_{Lj}	mole fraction of liquid separated in pressure stage j , based on 1 lb mol of feed	b	bubble point
p	pressure (psia)	c	critical
%AD	percent average deviation	cell	the PVT cell
%AAD	percent absolute average deviation	d	dew point
R	universal gas constant	g	gas
R_{sj}	gas to oil ratio in pressure stage j where $j = 1, 2$, etc. SCF/STB	i	component
S	liquid drop-out, fraction	k	pressure stage
T	temperature (°R)	L	liquid
V	volume (ft ³)	o	oil
x_i	mole fraction of component i in liquid phase	p	produced
y_i	mole fraction of component i in gas (vapor) phase	r	reservoir
z_i	mole fraction of component i in feed	ST	stock-tank
		v	vapor

from experimental data, especially for high-pressure systems. Wilson [1] proposed a simplified expression in the form

$$K_i = \frac{p_{ci}}{p} \exp \left[5.37(1 + \omega_i) \left(1 - \frac{T_{ci}}{T} \right) \right] \quad (2)$$

where p_{ci} is the critical pressure of component i (psia), T_{ci} is the critical temperature of component i (°R), ω_i is the acentric factor of component i , p is the system pressure (psia), and T is the system temperature (°R). This correlation is valid typically at relatively low pressures.

Whitson and Torp [2] modified Wilson's equation to accommodate the compositional effects at high pressures by incorporating the convergence pressure, p_k (psia), to obtain

$$K_i = \left(\frac{p_{ci}}{p_k} \right)^{A-1} \left(\frac{p_{ci}}{p} \right) \exp \left[5.37A(1 + \omega_i) \left(1 - \frac{T_{ci}}{T} \right) \right] \quad (3)$$

where

$$A = 1 - \left(\frac{p - 14.7}{p_k - 14.7} \right)^{0.6} \quad (4)$$

The convergence pressure, p_k , concept is based on the observation that if we hold a hydrocarbon mixture of a certain composition at a constant temperature and increase the pressure, then the equilibrium values for all its components converge toward a common value of unity at a certain pressure called the convergence pressure. In

computing high pressure K -values using the Whitson–Torp correlation, one has to be careful not to use the correlation for pressures above the convergence pressure, as this is not meaningful.

There are a number of methods to calculate the convergence pressure [3]. For simplicity, the method we used here is Rzasas's Method [4], which is a simplified graphical correlation for predicting the convergence pressure of light hydrocarbon mixtures. Rzasas used the temperature and the product of the molecular weight and specific gravity of the heptane-plus fraction as correlating parameters. The graphical correlation is expressed mathematically by the following equation

$$P_K = -2381.8542 + 46.341487(MW \times \gamma)_{C_{7+}} + \sum_{i=1}^3 a_i [(MW \times \gamma)_{C_{7+}} / (T - 460)]^i \quad (5)$$

where $(MW)_{C_{7+}}$ is the molecular weight of C_{7+} , $(\gamma)_{C_{7+}}$ is the specific gravity of C_{7+} , a_1 – a_3 are the correlation coefficients with the following values: $a_1 = 6124.3049$; $a_2 = -2753.2538$; $a_3 = 415.42049$, and T is the reservoir temperature in °R.

DePriester [5] presented K -value charts for light hydrocarbons vs. pressure and temperatures that are valid up to around 6000 psi (41.37 MPa) pressures or more. McWilliams [6] fitted these charts to the following

polynomial equation

$$\ln K = \frac{a_{T1}}{T^2} + \frac{a_{T2}}{T} + a_{T3} + a_{p1} \ln p + \frac{a_{p2}}{p^2} + \frac{a_{p3}}{p} \quad (6)$$

where T is in °R and p is in psia. a_{T1} , a_{T2} , a_{T3} , a_{p1} , a_{p2} , and a_{p3} are constants. McWilliams equation is valid from -70 °C (365.7 °R) to 200 °C (851.7 °R) and from 14.69 to 870.7 psia (101 to 6 MPa).

Habiballah et al. [7] looked at some of the direct methods currently available in the literature for both high and low pressures, and commented that they generally lacked good accuracy. They used instead neural networks that are trained on a large group of data, and reported quick estimates with accuracy similar to the traditional methods, provided that some functional relations are provided relating K -values to pressure and temperature. We will not deal with neural nets in this paper.

Even though the Whitson and Torp correlation is the only direct method designed for high-pressure systems, we will include in the comparisons both the Wilson correlation as the basis for the Whitson–Torp correlation, and the McWilliams correlation, which it and the Whitson–Torp correlation both form the basis for the developed correlation.

3. Developed K -values correlation

In this study, the form of equation that is developed is based on the polynomial form used by the McWilliams correlation (Eq. (6)) but with additional term as a function of ω used for the C_{7+} fraction only, and an adjustment for the effect of composition similar to the one suggested by Whitson and Torp (Eq. (3)). The developed equation is

$$K_i^{\text{New}} = \left(\frac{P_{ci}}{P_k}\right)^{A-1} \left(\frac{P_{ci}}{P}\right) \exp[A \times K_i^*] \quad (7)$$

where K_i^* is

$$K_i^* = \frac{a_{T1}}{T^2} + \frac{a_{T2}}{T} + a_{T3} + a_{p1} \ln p + \frac{a_{p2}}{p^2} + \frac{a_{p3}}{p} + \frac{a_{\omega}}{\omega} \quad (8)$$

and P_{ci} , P_k , and A are as defined previously in the Whitson and Torp correlation. The polynomial equation of the McWilliams correlation provided a more flexible form to fit the data while the theoretical requirement that all K -values should converge to one at the convergence pressure was provided by the Whitson–Torp adjustment. The constants of Eq. (8) have been computed by minimization of the following objective function

$$Q = \sum_{i=1}^{n_{\text{data}}} \left| \left(\frac{K_i^{\text{Ext}} - K_i^{\text{Cal}}}{K_i^{\text{Ext}}} \right) \right| \quad (9)$$

where K_i^{Ext} are the extracted K -values from experimental data, and, n_{data} is the number of data points. Minimizing over the sum of absolute relative errors gave the best results

as the data had some scattered points, and its accuracy would have been affected if the more common minimization over the sum of squares of relative errors were used. The results from this equation are compared next with other correlations.

For the C_{7+} pseudo-component, the Riazi–Daubert [8] correlation was used to obtain the critical pressure. Also, the Edmister [9] correlation was used to obtain the acentric factor, ω . Both of these correlations are widely used for characterizing the plus fraction [3].

4. Extracting K -values from CVD and DL Tests

Extracted K -values can be obtained from three types of PVT tests, namely differential liberation test (DL), constant volume depletion test (CVD), and separator tests, provided that measurements of the composition of the gas exiting the PVT cell are performed at each pressure stage. The separator test is normally carried out at relatively low pressures, approximating surface separator conditions for crude oil systems. These type of data for UAE crudes were analyzed by Almehaideb et al. [10], who showed how to extract K -values from separator tests and proposed a new correlation for UAE crude oil at low pressures.

The DL test and the CVD tests, on the other hand, are for high-pressure oil and gas-condensate systems, respectively [11]. These data were extracted using a similar methodology but with equations suitable for the DL and CVD tests. Relevant equations are reported in number of papers and textbooks. Here, the equations reported by McCain [12], and Whitson and Torp [2] will be used as a starting point. The equations are normally used to estimate PVT parameters. These equations were used in this work in the reverse manner, i.e. to obtain extracted K -values using these equations with the experimental measurements of the above PVT parameters.

For CVD Data, the total moles at pressure stage k , n_{tk} equals initial moles n_{1k} minus cumulative moles of the vapor produced, based on 1 mol of feed, then

$$n_{tk} = 1 - \sum_{j=2}^k \Delta n_{pj} \quad (10)$$

Also, the total composition of the fluid in the cell for the i component at pressure stage k , can be expressed as

$$z_{ik} = \frac{z_{i1} - \sum_{j=2}^k \Delta n_{pj} \times y_j}{n_{tk}} \quad (11)$$

where Δn_{pj} is the incremental moles of vapor produced from the cell during stage j , and z_{i1} is the initial fluid composition at stage 1 (saturation conditions).

Based on 1 mol initial fluid, cell volume can be calculated from initial fluid properties, which for gas

condensate is

$$V_{\text{cell}} = \frac{Z_d \times R \times T}{p_d}, \quad (12)$$

and for volatile oils,

$$V_{\text{cell}} = \frac{M_b}{\rho_b}, \quad (13)$$

where $R = 10.73$ psia cu ft/mol °R, M_b , ρ_b are bubble-point molecular mass and density, respectively, Z_d , p_d are the dew-point fluid compressibility factor and pressure, respectively.

At each depletion pressure, liquid volume is measured visually and reported as a fraction, S_{Lk} , of the cell volume. And, from a volume balance, vapor volume, V_{vk} , is

$$V_{vk} = (1 - S_{Lk})V_{\text{cell}} \quad (14)$$

Using the real gas law, the corresponding moles of vapor n_{vk} are calculated from

$$n_{vk} = \frac{p_k \times V_{vk}}{Z_k \times R \times T} \quad (15)$$

where Z_k is the vapor compressibility factor which is measured at each stage, corresponds to pressure p_k . Then the liquid composition of the component i at pressure stage k is calculated from:

$$x_{ik} = \frac{n_{tk} \times z_{ik} - n_{vk} \times y_{ik}}{n_{tk} - n_{vk}} \quad (16)$$

The final step is the evaluation of the K_{ik} ,

$$K_{ik} = y_{ik}/x_{ik} \quad (17)$$

The data measured directly from CVD test and appearing in the above equations is:

- Dew-point pressure,
- Composition change of gas phase with pressure depletion,

- Compressibility factor at reservoir pressure and temperature,
- Recovery of original in-place hydrocarbon at any pressure,
- Retrograde condensate accumulation, i.e. liquid saturation.

An example of the calculations to extract K -values from CVD data for one of the gas samples is shown in Table 1.

For the DL, the GOR coming from the cell, in (SCF/STB), can be expressed as [12]

$$R_{si} = \frac{2138 \times n_{gi} \times \rho_{\text{STO}}}{n_{Li} \times n_{L(i+1)} \times \dots \times n_{L(\text{final})} \times M_{\text{STO}}} \quad (18)$$

where n_{gi} is the mole fraction of the gas released at pressure stage i , based on one mole feed; n_{Li} is the mole fraction of the liquid in the cell at pressure stage i , based on one mole feed; ρ_{STO} the density of the remaining oil in the cell, lb_m/ft³, M_{STO} the molecular weight of the remaining oil, and the oil formation volume factor, B_o is expressed as

$$B_o = \frac{M_{\text{or}} \times \rho_{\text{STO}}}{\rho_{\text{or}} \times M_{\text{STO}} \times n_{L1} \times n_{L2}} \quad (19)$$

where ρ_{or} , and M_{or} are the reservoir density and molecular weight, respectively. Dividing Eq. (19) by Eq. (20), one can obtain a simple equation to evaluate the gas mole fraction as:

$$n_{gi} = \frac{R_{si} M_{\text{or}} n_{L(i+1)} \dots n_{L(\text{final}-1)}}{2138 B_o \rho_{\text{or}}} \quad (20)$$

The liquid mole fraction x_i for each stage are then calculated using the component material balance given the feed mole fraction z_i and the gas mole fraction y_i coming out of each stage:

$$x_i = \frac{z_i - n_g y_i}{(1 - n_g)} \quad (21)$$

Table 1

Calculation of K -values from CVD data for well G1, pressure step from 3983 to 3480 psia (27.5 to 24 MPa) and 250 °F

Comp.	M	Z_i	y_i	$M \times Z_i$	$\sum \Delta n_p \times Z_i$	$M \times y_i$	z_{jk}	x_{jk}	K
N ₂	28.01	0.0027	0.28	0.075627	0.00024	0.078428	0.0027	0.0027	1
CO ₂	44.01	0.0435	4.55	1.914435	0.003952	2.002455	0.043403	0.023143	1.922788
H ₂ S	34	0.0235	2.38	0.799	0.002113	0.8092	0.023471	0.017393	1.368363
C ₁	16.04	0.731	75.17	11.72524	0.06581	12.05727	0.730016	0.525399	1.410547
C ₂	30.07	0.06002	6.02	1.804801	0.005364	1.810214	0.059983	0.052285	1.155218
C ₃	44.1	0.0348	3.39	1.53468	0.003037	1.49499	0.034858	0.047014	0.727444
<i>I</i> -C ₄	58.12	0.00812	0.77	0.471934	0.000702	0.447524	0.008141	0.012598	0.627062
<i>n</i> -C ₄	58.12	0.01763	1.66	1.024656	0.001527	0.964792	0.017672	0.026383	0.651927
<i>I</i> -C ₅	72.15	0.0073	0.67	0.526695	0.000639	0.483405	0.00731	0.009336	0.771237
<i>n</i> -C ₅	72.15	0.00919	0.78	0.663059	0.000746	0.56277	0.009267	0.025272	0.332388
C ₆	84.89	0.0115	0.99	0.976235	0.00095	0.840411	0.011578	0.027785	0.385097
C ₇₊	134.71	0.05074	3.34	6.835185	0.003721	5.397977	0.051601	0.230692	0.181628

Data: $T = 250$ K; $P_d = 3983$ psia; $\sum \Delta n_p = 0.0888$ mol. Calculations: $V_{\text{cell}} = 1.68509$ cu ft; $V_L = 0.05207$ cu ft; $V_g = 1.63302$ cu ft; $N_v = 0.86438$ cu ft; $n_{tk} = 0.9112$ cu ft.

Table 2
Calculation of K -values from DL data for well O5 at 3315 psia (22.92 MPa) and 255 °F (124 °C)

Comp.	Data		Calculation		
	M	Z_i	Y_i	X_i	K_i
N ₂	28.02	0.0017	0.004	0.001477448	2.84274
CO ₂	44.01	0.0209	0.029	0.020152225	1.453934
H ₂ S	34.08	0.0092	0.007	0.009360238	0.790578
C ₁	16.04	0.4428	0.806	0.410467628	1.963614
C ₂	30.07	0.0566	0.064	0.055976854	1.136184
C ₃	44.09	0.0482	0.038	0.049090208	0.778159
<i>I</i> -C ₄	58.12	0.0132	0.008	0.013636202	0.608674
<i>n</i> -C ₄	58.12	0.0299	0.017	0.031030565	0.554292
<i>I</i> -C ₅	72.15	0.0162	0.007	0.0170546	0.386992
<i>n</i> -C ₅	72.15	0.0205	0.008	0.021639467	0.355831
C ₆	84	0.0362	0.006	0.038852821	0.164724
C ₇₊	191.31	0.3046	0.005	0.331261744	0.015396

Data: $B_o = 1.866$ bbl/STB; $R_s = 155$ SCF/STB; $\rho_{ob} = 37.39$ lb/ft³.
Calculation: $M_{or} = 78.68$ lb_m/lb mol; $n_g = 0.08174$.

The experimental data needed to evaluate K -values are thus:

- Compositional analysis of the reservoir fluid and its average molecular weight (M_{or}),
- The oil density and the oil formation factor at the bubble point (ρ_{ob} , B_{ob}),
- The gas/oil ratio for each stage (R_{si}),
- And the compositional analysis for gas exiting at each stage (y_i).

An example of the calculations to extract K -values from DL data for one of the oil samples is shown in Table 2.

5. Data sources

Data used in this study comprise 732 K -values extracted from DL and CVD tests on 17 fluid samples (14 oil wells

and three gas wells) from different fields in UAE with overall ranges of PVT properties as follows:

$$2455 \leq P_B \leq 3983 \text{ psia} \quad (16.93 \leq P_B \leq 27.46 \text{ MPa})$$

$$245 \leq T \leq 265 \text{ °F} \quad (48 \leq T \leq 129 \text{ °C})$$

$$0.584 \leq \gamma_o \leq 0.631$$

$$0.938 \leq \gamma_g \leq 1.057$$

6. Results and discussion

Extracted K -values were statistically compared in this study with results predicted using the Wilson correlation, Whitson and Torp correlation, McWilliams correlation, and the new proposed correlation. The new correlation for UAE crudes was obtained by tuning the correlation to better fit the UAE data using multi-variable regression. Here, the multi-variable regression technique was used to obtain the best values for a_{T1} , a_{T2} , a_{T3} , a_{p1} , a_{p2} , a_{p3} , and a_ω constants. All a_ω values are considered to be zero except for C₇₊. The new correlation parameters are listed in Table 3. Fig. 1 shows graphically the K -values for all components vs. pressure and temperature generated by the proposed correlation for a typical crude oil at 8000 psi convergence pressure.

The following is a statistical comparison of the results obtained by the three published correlations and the new correlation with the extracted values of equilibrium ratios.

6.1. All components

Figs. 2–9 provides a general comparison between experimental and calculated K -values for hydrocarbon and non-hydrocarbon components using the Wilson correlation, Whitson and Torp correlation, McWilliams correlation and the new proposed correlation. For non-hydrocarbons figures, the smallest K -values represent K -H₂S while the highest values represent K -N₂, and for hydrocarbon figures, the smallest K -values represent K -C₇₊ while the highest

Table 3
Constant for the new proposed correlation for UAE crudes at high pressures

Comp.	a_{T1}	a_{T2}	a_{T3}	a_{p1}	a_{p2}	a_{p3}	a_ω
N ₂	-292.859	-0.0414778	26.2743	0.863344	53.9314	-326.847	0
CO ₂	-292.859	-0.0141359	16.2443	-0.564467	48.8615	-1331.41	0
H ₂ S	-292.860	-0.0143991	10.9477	-0.132753	59.900	57.1915	0
C ₁	-292.865	-0.00517572	5.92040	0.00998217	35.2435	54.8676	0
C ₂	-687.248	0	-1.78470	0.426990	40.1669	541.117	0
C ₃	-970.689	0	-3.56546	0.622591	5.09279	688.0477	0
<i>i</i> -C ₄	-1,166.846	0	-2.95603	0.560224	2.02686	444.792	0
<i>n</i> -C ₄	-1,280.557	0	-4.035319	0.671446	-2.93233	674.646	0
<i>i</i> -C ₅	-1,481.582	0	-6.38713	0.968672	-3.39020	747.110	0
<i>n</i> -C ₅	-1,524.891	0	-3.54244	0.587370	-8.57084	397.476	0
C ₆	-1,778.903	0	-8.45991	1.159219	-5.06920	873.201	0
C ₇₊	-1,778.901	0.0143639	-6.00502	-1.10606	-1.03540	-376.926	0.733643

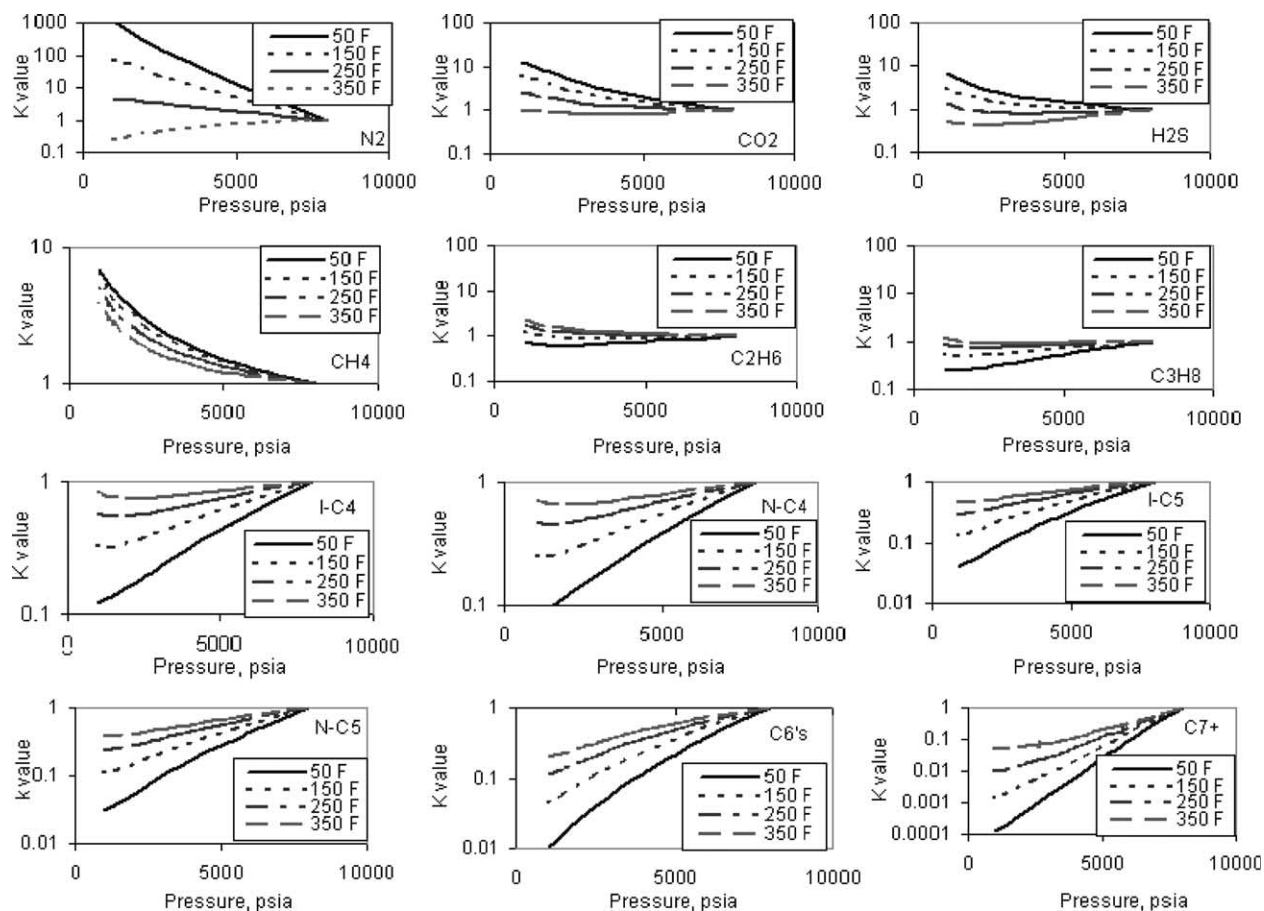


Fig. 1. *K*-values for all components from the new correlation for a typical crude oil at a convergence pressure of 8000 psi.

K-values represent *K*-*C*₁. The figures show that the Wilson correlation significantly underestimated the *K*-values of hydrocarbon components C₄ to C₇₊ and overestimated the *K*-values of N₂, also the McWilliams correlation underestimated the *K*-values of hydrocarbon components C₄ to C₆ and overestimated the *K*-values of H₂S, while the Whitson and Torp correlation underestimated the *K*-values of C₇₊ and overestimated the *K*-values of non-hydrocarbon components. The new proposed correlation, on the other hand, matched the experimental values closely for hydrocarbon components and relatively better for non-hydrocarbon components. Table 4 is a comparison of the

statistical measures for the three correlations. It shows a significant overall improvement in the predictions of *K*-values for the proposed correlation over the Wilson correlation, Whitson and Torp correlation, and Polynomial correlation for UAE data. The following is a group-by-group comparison of individual crude components.

*C*₁–*C*₆ components. Figs. 2–5 compare *K*-values from the four correlations. The comparison shows that the three published correlations performed relatively fair for *C*₁–*C*₆ components while the new proposed correlation performed well for *C*₁–*C*₆ components. Overall for *C*₁–*C*₆ components, the new correlation reduced the %AAD to 17.03%

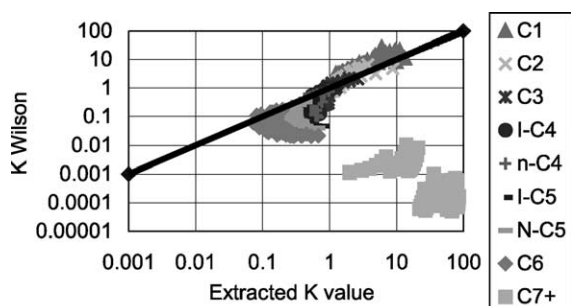


Fig. 2. *K*-values for hydrocarbons, Wilson correlation.

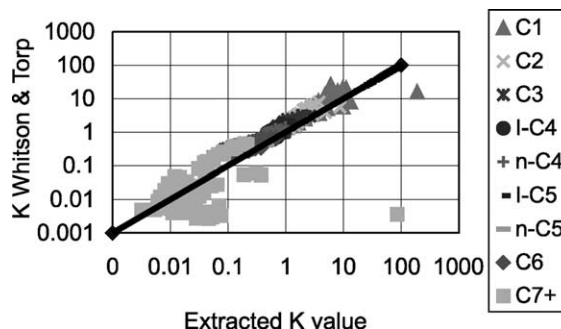


Fig. 3. *K*-values for hydrocarbons, Whitson and Torp correlation.

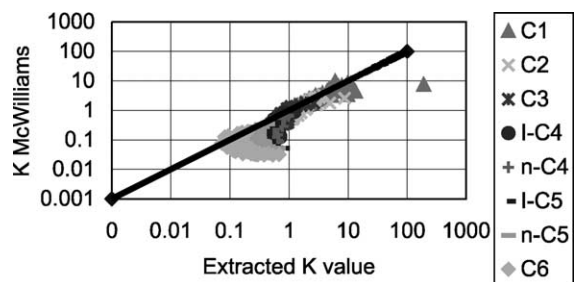


Fig. 4. *K*-values for hydrocarbons, McWilliams correlation.

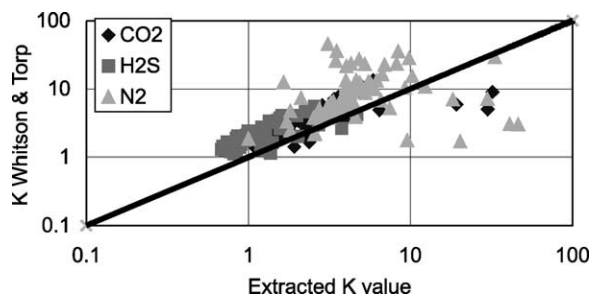


Fig. 7. *K*-values for non-hydrocarbons, Whitson and Torp correlation.

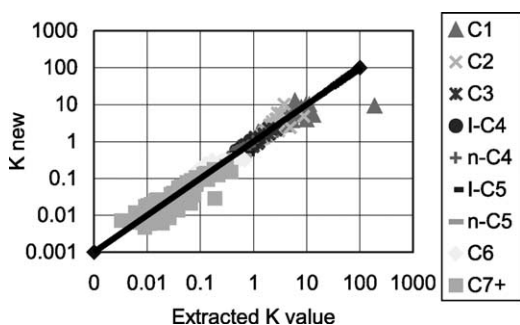


Fig. 5. *K*-values for hydrocarbons, new correlation.

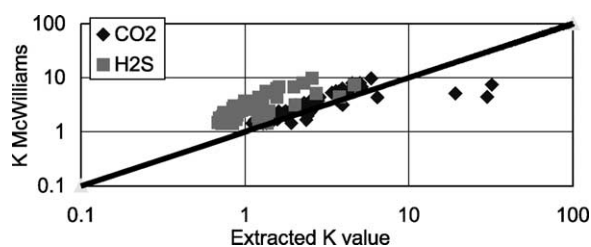


Fig. 8. *K*-values for non-hydrocarbons, McWilliams correlation.

from 63.32% for the Wilson correlation, 62.42% for the Whitson and Torp correlation, and 49.94% for the McWilliams correlation. The standard deviation for the proposed correlation also showed an improvement over the published correlations.

Non-hydrocarbon components. Figs. 6–9 show that the new correlation moderately improves the accuracy of predictions for *K*-H₂S and *K*-CO₂, which were relatively well predicted by the other correlations. The prediction of these published correlations of *K*-N₂ was, however, quite off the extracted *K*-N₂ values. The new correlation improved the accuracy of *K*-N₂ to only around 42%. This relatively high error is attributable to the relatively low accuracy of GC analysis for N₂ especially in low concentrations.

C₇₊ component. The C₇₊ component is also shown in Figs. 2–5. The comparison shows that the Wilson correlation underestimated the *K*-C₇₊ hydrocarbon pseudo-component, while the Whitson and Torp correlation

performed better. The new proposed correlation shows an improvement in the relative accuracy (%AAD) over the other correlations. Part of this improvement is attributed to the additional term in the polynomial, as a function of ω . Further improvement in the accuracy of estimating *K* for the C₇₊ fraction was, however, difficult due to the undefined nature of this fraction.

6.2. Comparison with saturation pressure measurements

As a further check on the accuracy of the new correlation, the independent measures of the bubble and dew points for the seventeen samples were calculated using the new correlation, the published correlations, and the Peng–Robinson equation of state with default values. The results of this comparison are shown graphically in Fig. 10. They show that the Wilson correlation and to a lesser extent the Whitson and Torp correlation, because they generally overestimated the *K*-values, gave smaller dew points and higher bubble points. The proposed

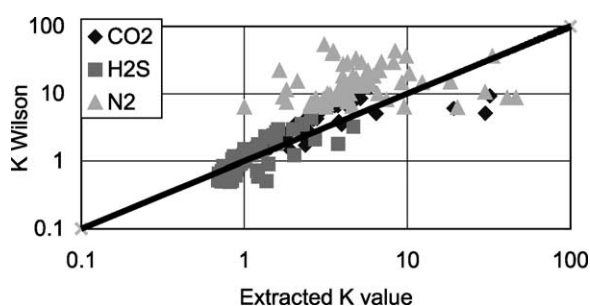


Fig. 6. *K*-values for non-hydrocarbons, Wilson correlation.

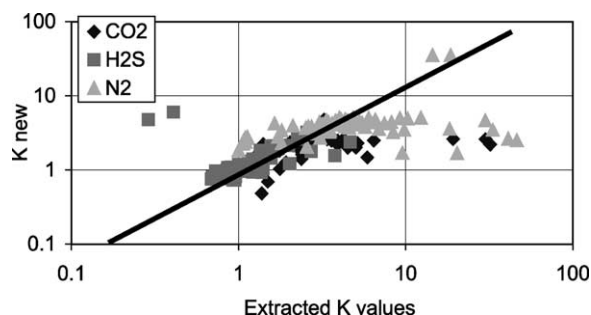


Fig. 9. *K*-values for non-hydrocarbons, new correlation.

Table 4
Statistical comparison of four correlations for all components using UAE data

Component	Proposed correlation		Wilson correlation		Whitson and Torp correlation		Polynomial correlation	
	AAD	SD	AAD	SD	AAD	SD	AAD	SD
All	20.50	34.04	84.27	170.43	76.12	130.99	105.83	95.59

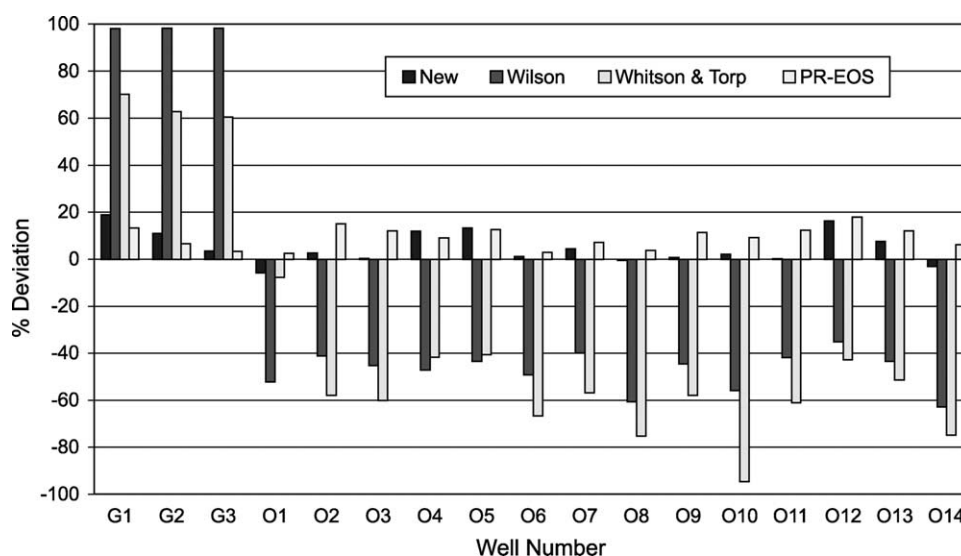


Fig. 10. Comparisons of errors associated with evaluation of saturation pressures using the different correlations.

correlation and the PR-EOS, on the other hand, can be used to obtain reliable estimates. The McWilliams correlation could not be included in this comparison because there is no description for the C_{7+} fraction. The average absolute error in saturation pressures for the proposed correlation is 6.08% compared to 56.34% for Wilson correlation, 57.84% for Whitson and Torp correlation, and 9.28% for Peng–Robinson EOS (PR-EOS).

7. Conclusions

As a result of this study, the following conclusions can be made:

1. K -values extracted from the CVD and DL experiments provided a direct comparison between experimental and correlated K -values for UAE crude oil at high pressure.
2. K -values obtained from three correlations, namely the Wilson correlation, Whitson and Torp correlation, and the polynomial correlation, compared poorly with extracted, K -values for some hydrocarbon components. They also performed poorly for all non-hydrocarbon components.

3. A new correlation is proposed, for the UAE crudes. It is based on the same general formula for the polynomial correlation. However, the parameter for the correlation are modified to fit experimental data using multi-variable regression. The statistical comparison shows that the new correlation compares favorably well with results from the other three correlations included in this study.
4. Checking the accuracy of all correlations for calculating the bubble and dew points of several samples, which provide an independent test, shows the proposed correlation to predict the saturation pressures within an average of 6.08% compared to 56.34% for the Wilson correlation and 57.84% for the Whitson and Torp correlation. The Peng–Robinson equation of state, without tuning, predicted the saturation pressures within 9.28%.

Acknowledgements

The authors would like to acknowledge the managements of Abu Dhabi National Oil Company (ADNOC) and Abu Dhabi Offshore Operating Oil Company (ADMA-OPCO) for providing the data used in this study. This work was part of a funded research project by ADNOC through the

University's Center for Externally Funded Research (eFORS).

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