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Hydrocarbon Simulation Behavior of Wet Natural Gas Reservoirs

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Abstract

Knowing hydrocarbon dew point conditions in natural gas (HCDP) are becoming widely important in the modern marketing of liquid and gas. Without determination dew point conditions (Pressure & Temperature), the accurate description of phase changes and phase behavior cannot be achieved. Numerous models for only predicting dew point pressure of gas condensate have been proposed and other for wet natural gas reservoirs, but there is no model for predicting both dew point pressure(DPp) and dew point temperature (DPT) for wet natural gas reservoirs. Some of the published models assume knowledge the reservoir fluid composition (requiring laboratory experiments to be performed), while others only require field parameters such as reservoir temperature, stock-tank oil API, and the condensate-gas ratio (CGR). The primary objectives of this paper is to determine dew point temperature (DPT) and dew point pressure (DPp) correlations using a fluid database of nearly fifty-six wet natural gas reservoirs, that is very important for engineers to understand and manage wet natural gas reservoirs. This model was made using multiple least-squares nonlinear regression analysis methods to find hydrocarbon dew point conditions (HCDP) as a function of [CGR, Tr, API gravity, γw, $\gamma C7+$, MWw and C1, C2, CO2, N2 mole %] with a different constant value. Both statistical and graphical accuracy ensures that new models are more accurate in predicting hydrocarbon dew point conditions (HCDP) in comparison with equations of state by using limited data. Finally, thirty-four new separate set of measured data were used in testing models with an excellent agreement as compared with laboratory works.

Keywords: Wet natural gas, Dewpoint conditions, Equations of state, Nonlinear regression analysis.

I.   Introduction

Wet gas measurements are important in reservoir engineering, where a variety of data from it contributes to forecasting production and estimate reserves. Wet gas is defined as a two-phase fluids with a liquid volume fraction of up to 5 %, where the corresponding liquid mass fraction is dependent on the conditions, especially temperature [1]. In the reservoir, the wet gas exists only in the gas state throughout the reduction of pore pressure. Figure (1) shows the entire phase diagram of wet gas, where the pressure path (a line from point 1 to point 2) does not be in the phase envelope so the reservoir doesn't have any condensate liquid. Although, separator conditions are being inside the phase envelope, causing some liquid will be formed at the surface [2]. The dew point identifies the conditions at which former vapor starts to condense to liquid [3]. True wet gases have

very high producing gas-liquid ratios while producing gas-liquid ratios will remain constant throughout wet natural gas reservoir life. In petroleum engineering, a gas production extra than 50,000 SCF/STB can be treated as wet gas. Stock-tank liquid gravities of wet gas have the same liquids gravities range of retrograde gases (between 40 and 60 API). However, Stock tank liquid gravity does not change during reservoir life. The stock tank liquid is regularly water-white [2].
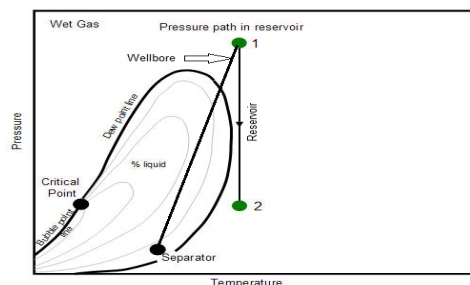

Figure (1): Phase diagram of a typical wet natural gas reservoir [2]

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In case of gas condensate reservoir, the condition at which reservoir is depressurized until the first liquid is formed at reservoir temperature is pressure, so it is called dew point pressure. While In case of the wet natural gas reservoir, the condition at which the first droplet of hydrocarbon liquid condenses from the vapor at defined pressure is temperature, so it is called hydrocarbon dew point conditions (HCDP). Accurately it is a critical parameter for petroleum engineer (processing, production and reservoir) in production design systems, fluid characterization, and for gas reservoir performance calculations, so we must determine it. Also, it is stipulated in contractual qualifications and enforced all over the supply chain, startle from producers to companies of transmission and distribution reached to finally end-users [4]. The risk of multiphase flow, hydrate formation and liquids accumulations along the wellbores or the flow lines increase when the gas temperature falls down its dew point temperature at system pressure. These risks and problems occur while handling the wet gas and/or rich gas which increase the cost of handling these gases, which, in turn, requires a reliable method of determining and estimating the hydrocarbon dew point. Therefore, determining hydrocarbon dew point conditions (HCDP) and comparing with the flowing temperature can afford an early aware that the stream flowing is upcoming two-phase in order to enable mitigation efforts to avoid hydrate formation, liquid accumulation and flow measurement error [5]. The traditional experimental methods to determine hydrocarbon dew point conditions (HCDP) may be by laboratory phase behavior experimental work or online site by using a chilled-mirror device that decreases the mirror temperature in a measurement chamber full natural gas till sufficient hydrocarbon haze condenses on the mirror so to be detected. Also, available other analyzer using different techniques to determine hydrocarbon dew point conditions (HCDP) but all of them dedicated hydrocarbon dew point at a single pressure only [1]. Computational methods for determining hydrocarbon dew point conditions (HCDP) using Soave Redlich Kwong [6] and Peng Robinson [7] equation of states still cheapest and time-consuming as compared with experimental work. Normally by entering the good stream composition of wet gas into the recognized equation of state, the theoretical dew point pressure and dew point temperature are calculated. Today's all the researchers in the world research by the various

laborites working group the effect of entering liquid in gas as a big issue and its impact on the measurement system is being. Therefore, the objective of this study to search for mathematical correlations for determination hydrocarbon dew point conditions (HCDP) based on regression analysis within excellent accuracy.

II. Experimental work

Fifty-six wet gas samples from different locations were utilized in this study. A wet natural gas reservoir fluid study contains a sequence of laboratory procedures designed by laboratory well-stream mathematical recombination process to provide values of the physical properties that required as an input parameter in the calculation of the equation of state and in making new correlation for estimating hydrocarbon dew point conditions (HCDP) [8].Measurement data for dew point conditions of wet gas is analyzed by studying phase behavior of wet natural gas reservoirs by laboratory test of constant mass expansion (CME) stage at a different temperature. Constant mass expansion (CME) stage at different temperature was used to study phase behavior for each one of the wet natural gas reservoir samples. A portion of the recombined reservoir fluid was charged to the automated mercury-free PVT cell (VINCI Technologies, France (2013), Applilab Macro Software) and subjected to the operating temperature and pressure above reservoir pressure. The upper limit pressure scale of this model is 12,000 psi, temperature up to 300°F, capacity=500cc and lower Volume liquid accuracy: 0.001 ml. In addition, the calibration of the PVT cell has been done periodically by VINCI technologies, France company. The pressure of the PVT cell is reduced at a predetermined level by increasing the volume of the PVT cell [9]. At each equilibrated stage, the pressure and volume of the PVT cell is measured until dew point pressure is appeared. The experimental procedure, as shown schematically as presented in figure (2) [10]. Figure (2A) shows single phase in the wet gas reservoir (before dew point), figure (2B) shows a collection of gas particles in towards to form a drop of liquid, figure (2C) shows appearing the first drop of liquid. This procedure of (CME) is repeated at different temperature for one sample of the wet natural gas reservoir until dew point pressure does not appear.
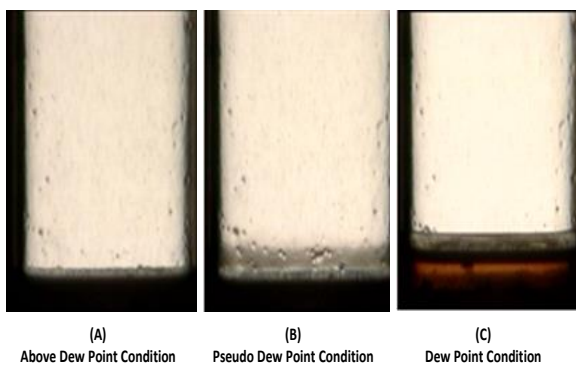
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(A)
Above Dew Point Condition

(B)
Pseudo Dew Point Condition

(C)
Dew Point Condition

Figure (2): The following photographs illustrate dew point pressure measurements at the operating temperature for one reservoir

also show summary for all samples used.

Table (1): Compositional analysis of good stream, in Mole %.

Components	Sample ID (1)	Sample ID (2)	Sample ID (3)	Sample ID (4)	Sample ID (5)	Sample ID (6)	Sample ID (7)	Sample ID (8)	Sample ID (9)	Sample ID (10)
Nitrogen	0.144	0.141	0.134	0.128	0.123	0.118	0.112	0.102	0.023	0.064
Carbon dioxide	0.435	0.620	1.006	1.313	1.576	1.883	2.190	2.761	0.145	4.823
Methane	97.177	96.405	94.78	93.499	92.39	91.10	89.821	87.430	84.67	78.78
Ethane	0.952	1.361	2.216	2.897	3.481	4.161	4.842	6.106	5.566	10.67
Propane	0.358	0.491	0.769	0.989	1.179	1.400	1.621	2.031	5.835	3.514
I-Butane	0.228	0.233	0.245	0.255	0.263	0.273	0.282	0.300	0.878	0.364
n-Butane	0.169	0.189	0.232	0.266	0.295	0.329	0.363	0.426	1.585	0.654
I-Pentane	0.076	0.081	0.093	0.102	0.109	0.118	0.127	0.144	0.535	0.204
n-Pentane	0.049	0.055	0.068	0.078	0.087	0.098	0.108	0.127	0.085	0.196
Hexanes	0.158	0.165	0.181	0.194	0.204	0.217	0.230	0.253	0.324	0.337
PS-1	0.254	0.259	0.270	0.279	0.287	0.295	0.304	0.321	0.349	0.381
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

III. Results and Discussion

This section shows, the results of well-stream & phase behavior and the most traditional and widely measurement techniques were applied to fifty-six wet gas samples to evaluate hydrocarbon dew point conditions (HCDP). Also, they were used to develop another new hydrocarbon dew point conditions (HCDP) empirical correlations then re-evaluating it.

III.1. Well-stream & Phase behavior

The measured compositions of the separator products using Clarus 500 Perkin Elmer gas chromatograph (GC) {ASTM D - 6730} were used in conjunction with the field gas-oil ratio and the measured shrinkage factor to recombined laboratory well-stream mathematical recombination process [11]. While C7+ is calculated from the following equation (1).

$$\%C_7^+ = \frac{GCR^{-0.8207}}{70680}$$

.....................................(1)

In this calculation, we used the standard method test of {ASTM D-4052} for measuring API gravity of stock-tank condensate by density meter [12] and the molecular weight of stack tank condensate is measured using molecular weight apparatus (CRYTTE WRTM) by freezing point depression through {ASTM D-2224}[13]. Summary of ten hydrocarbon well stream composition data in Mole % (reprehensive to fifty-six wet gas) that used in this study as shown in table (1). From experimental work for each sample by constant mass expansion stage, the dew point pressure and temperature are recorded to draw the phase behavior of each reservoir as shown in figure (3). This figures

Figure (A): Phase diagram of a wet gas reservoir (TR = 249.47°F)

Figure (B): Phase diagram of awet gas reservoir (T_R = 224.8°F)

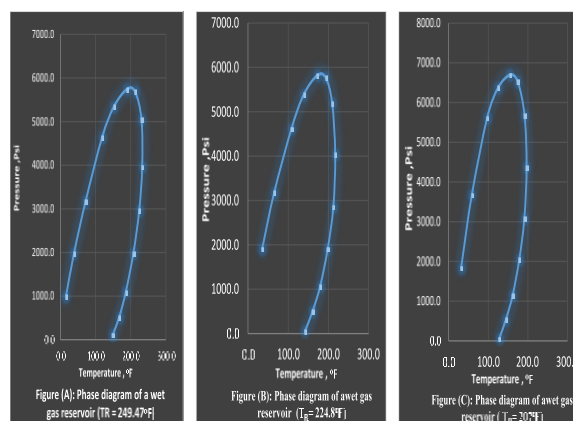**Figure (C):** Phase diagram of awet gas reservoir (T_R = 207°F)

Figure (3): Phase behavior (Pressure - Temperature relation) for three reservoirs
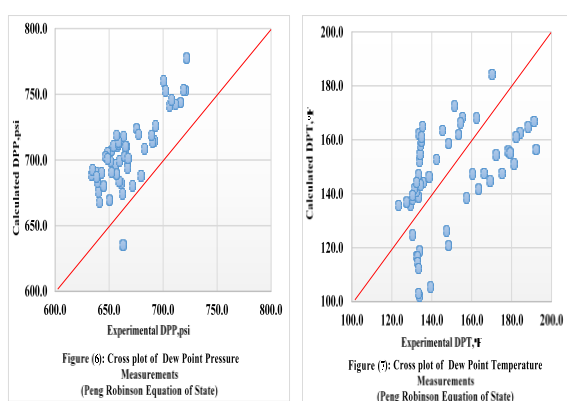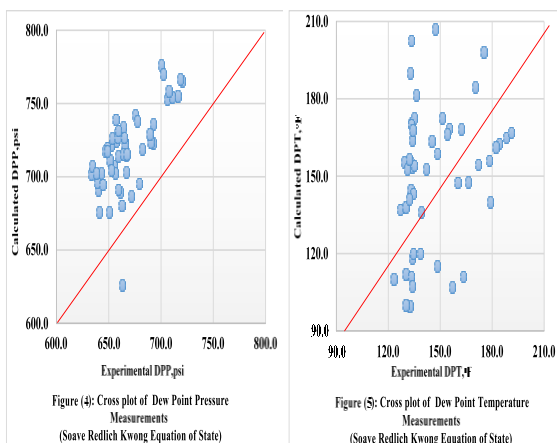
III.2. The equation of State Evaluation

The use of an equation of state calculation to derive the hydrocarbon dew point conditions (HCDP) of wet natural gas reservoir requires an extended laboratory analysis such as well stream compositional analysis and present field data such as reservoir pressure and reservoir temperature. Statistical and graphical means were used in this comparative evaluation of dew point pressure and temperature for both Soave Redlich Kwong and peng rebonsion equations of state [14]. Table (2) was reported the accuracy of the numerous methods for predicting the hydrocarbon dew point condition of the wet gas samples using in this study. peng rebonsion equation of state shows the least statistical accuracy error analysis for dew point temperature and pressure measurements as compared with Soave Redlich Kwong equations of state. But also, don't give good

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performance to estimate the hydrocarbon dew point condition (HCDP) of the wet natural gas reservoir. The cross plots of the Peng-Rebonsion equation of state for dew point pressure and the temperature is mostly closed around the 45o line as compared to Soave Redlich Kwong equations of state but still, data points of both equations of state have bad scattering as shown in figures (4) through (7).

Table (2): Statistical accuracy of hydrocarbon dew point condition for Wet Natural Gas Reservoirs (Equation of state validation)

Equations of State	$E_r,\%$	$E_a,\%$	E_{max}	E_{min}	$S,\%$	$r^2,\%$
Dew Point Temperature Measurements						
Soave Redlich Kwong	-5.54	17.82	52.30	2.18	21.05	21.04
Peng Robinson	0.61	11.90	24.03	3.80	12.96	30.26
Dew Point Pressure Measurements						
Soave Redlich Kwong	-7.77	7.98	11.10	2.36	8.38	50.83
Peng Robinson	-5.92	6.07	8.87	1.31	6.43	61.97

Figure (4): Cross plot of Dew Point Pressure Measurements (Soave Redlich Kwong Equation of State)

Figure (5): Cross plot of Dew Point Temperature Measurements (Soave Redlich Kwong Equation of State)

Figure (6): Cross plot of Dew Point Pressure Measurements (Peng Robinson Equation of State)

Figure (7): Cross plot of Dew Point Temperature Measurements (Peng Robinson Equation of State)

III.3. Hydrocarbon Dew Point Condition (HCDP) Model

According to the bad performance of the most common equation of state for estimating hydrocarbon dew point conditions (HCDP), new empirical correlations have been advanced for estimating of hydrocarbon dew point conditions (HCDP) with high accuracy. Table (3) show details of the main parameters data of fifty-six wet gas samples, that was used to develop the new empirical correlations which covering a wide range of types and natures of wet natural gas reservoirs.

Table (3): Statistical data ranges of experimental measurements for fifty-six samples.

Property	Maximum Value	Minimum Value	Average Value
Res. T, $_{\circ F}$	249.47	207	224.8
CGR, bbL/MM SCF =	7.2	3.5	5.2
$^{\circ}$API =	75.0	60.2	67.6
γ_w =	0.7301	0.5880	0.6626
γ_{C7+}=	0.7997	0.7647	0.7816
MWw =	21.1	17.0	19.20
C_1 mole % =	97.2	78.8	87.80
C_2 mole % =	0.952	10.67	5.749
CO_2 mole % =	0.145	4.823	2.391
N_2 mole % =	0.144	0.023	0.097

The hydrocarbon dew point condition (HCDP) model is based on two steps. As a first step to creating hydrocarbon dew point condition (HCDP) model for wet natural gas reservoirs, chose the best effective input parameter on estimating dew point pressure and temperature. There is data from field based on the condensate gas ratio (CGR) and reservoir temperature (T_r) while there are anther data from experimental work like molecular weight of good stream (MW_w), light components (C_1, C_2, CO_2, N_2 mole%), well stream heptanes plus specific gravity (γ_{C7+}), Stock-tank gravity (API) and well stream specific gravity (γ_w).

Non-linear regression is selected for the least error values of modelling dew point pressure (DP_P) and dew point temperature (DP_T). The best regression analysis results were obtained using the following function, is given by Eq. (2)[15]:

$$DP_p \ \& \ DP_T = f\left(T_r, CGR, \gamma_{C7+}, \gamma_w, API, C_1, C_2, CO_2, N_2, MW_w\right) \qquad \ldots$$

Binary interaction parameters of dew point temperature and dew point pressure correlation are calculated and generalized in tables (4) and (5) to calibrate the extent of non-ideality of a given binary mixture. When these parameters for all possible

binary mixtures are obtained in a given system, the dew point temperature and dew point pressure can be predicted with satisfied accuracy.

Table (4): Binary interaction parameters for dew point temperature correlation

Parameters	DP_T	CGR/T_r	$1/API$	$MW_w^{(\gamma_{c7+}/\gamma_w)}$	$C_1+C_2+CO_2 +N_2$
DP_T	1				
CGR/T_r	0.919136	1			
$1/API$	0.909291	0.978669	1		
$MW_w^{(\gamma_{c7+}/\gamma_w)}$	-0.970251	-0.950209	-0.932987	1	
$C_1+C_2+CO_2 +N_2$	-0.925954	-0.790179	-0.752136	0.926041	1

Table (5): Binary interaction parameters for dew point pressure correlation

Parameters	DP_P	CGR/T_r	$1/API$	$MW_w^{(\gamma_{c7+}/\gamma_w)}$	$C_1+C_2+CO_2 +N_2$
DP_P	1				
CGR/T_r	0.745263	1			
$1/API$	0.840658	0.978669	1		
$MW_w^{(\gamma_{c7+}/\gamma_w)}$	-0.669051	-0.950209	-0.932987	1	
$C_1+C_2+CO_2 +N_2$	-0.454570	-0.790179	-0.752136	0.926041	1

In the second step, different forms of relationships were mathematically formulated with different input data sets till reached to the best formulas with strong a strong relationship by using matrix form as shown in the Eq. (3) [16, 17].

$$\begin{bmatrix} (CGR, T_r, \gamma_w, \gamma_{C7+}, API, C_1, C_2, \\ CO_2, N_2, MW_w) \\ 5 \times 56 \\ \downarrow \\ 5 \times 5 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} Exp. \\ DPT \\ 1 \times 56 \\ \downarrow \\ 1 \times 5 \end{bmatrix} \quad ...(3)$$

Eq. (4) represent the best regression analysis form for dew point pressure (DP_P) and dew point temperature (DP_T) empirical correlations with a different constant value.
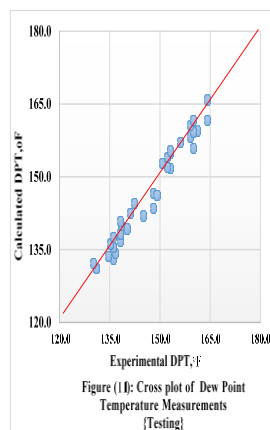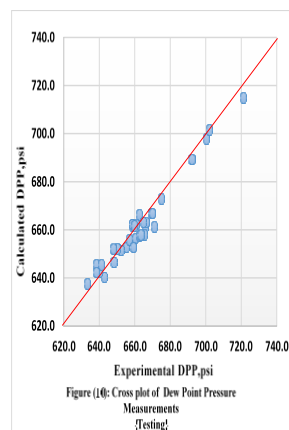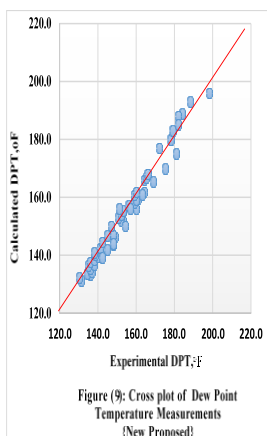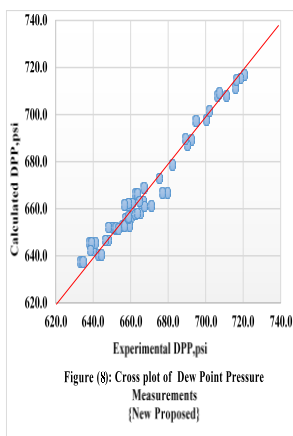
By applying a logarithmic transformation, the final linear empirical correlation for dew point temperature (DP_T) was linearized, as shown in Eq. (5).

$$\ln(DP_T) = 21.16 + 0.033\ln\frac{CGR}{T_r} + 0.894\ln\frac{1}{API} + 0.43\ln MW_w^{\gamma_{c7+}/\gamma_w} \\ - 3.017\ln(C_1+C_2+CO_2+N_2) \quad ......(5)$$

While Eq. (6) shows the final linear empirical correlation for dew point pressure (DPp).

$$\ln(DP_p) = 20.055 - 0.419\ln\frac{CGR}{T_r} + 1.951\ln\frac{1}{API} + 0.387\ln MW_w^{\gamma_{c7+}/\gamma_w} \\ - 1.812\ln(C_1+C_2+CO_2+N_2) \quad ......(6)$$

The next step after creating the modeling correlations for predicting dew point temperature (DPT) and dew point pressure (DPp) of the fifty-six wet gas samples in the reference dataset, is evaluating the truth of it. However, the accuracy of these models depended on both statistical and graphical techniques in comparison with other equation of state [18,19]. Recall that the goal of this research is to develop methods for predicting hydrocarbon dew point condition (HCDP) that is accurate to within the established accuracy experimental work. The statistical accuracy selected using Eq. (3) meet this target accuracy with an average relative error (E_r) of -0.01428%, average absolute relative error (E_a) of 1.5039 %, standard deviation (S) of 1.73%, minimum relative error (E_{min}) of 0.0043%, the maximum relative error (E_{max}) of 3.0495%, and coefficient of determination (r^2) of 97.18 %. For Eq. (4), a correlation was obtained with an acceptable (r^2) of 97.02 %, (S) of 0.6403 %,(E_r) of 0.1312 %,(E_a) of 0.5271 %,(E_{min}) of 0.0568% and (E_{max}) of 1.8201% [20,21]. The graphical plots of the newly developed correlations, presented in figures (8) and (9) show the best overall accuracy data points which are well scattered closely around the 45o line as compared with experimental work [6].

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Figure (8): Cross plot of Dew Point Pressure
Measurements
{New Proposed}

Figure (9): Cross plot of Dew Point
Temperature Measurements
{New Proposed}

Figure (10): Cross plot of Dew Point Pressure
Measurements
{Testing}

Figure (11): Cross plot of Dew Point
Temperature Measurements
{Testing}

To be most useful, the correlations must be able to test on thirty-four a separate set of measured dew points pressure and temperature, where this dew points for validation not used to create the correlations of dew point temperature (DP$_T$) and dew point pressure (DP$_p$). The accuracy and validity of the new models have been confirmed statistically by comparing the obtained results of these developed correlations with experimental data gas samples. As before, the procedure used in the section of evolution was used with different input data to predict dew points for thirty-four validation gas samples. Dew point temperature (DP$_T$) model have an (r^2) of 96.11 %, (S) of 1.39 %,(E$_r$) of 0.032%, (E$_a$) of 1.2302 %, (E$_{max}$) of 2.0884%, and (E$_{min}$) of 0.2306%. While dew point pressure (DP$_p$) model produce the same accurate as the following: (r2) of 96.14 %, (S) of 0.6073 %,(E$_r$) of 0.1282%, (E$_a$) of 0.5183 %, (E$_{max}$) of 1.1890 %, and (E$_{min}$) of 0.0568%. Figures (10) and (11) show test values of dew points for dew point pressure (DP$_p$) and dew point temperature (DP$_T$) that consistently produce dew points ensure worthy agreement with experimental values [22].

Conclusions

1-This study evaluated the accuracy of common equations of state methods with a bad agreement with experimental work in predicting hydrocarbon dew points condition (HCDP).

2-A primary goal was to identify new empirical formulas that could predict accurate hydrocarbon dew point condition (HCDP) predictions from the fifty-six real data of wet gas samples.

3-The new hydrocarbon dew point condition (HCDP) models most closely predicts the observed dew points, wherein case dew point temperature (DP$_T$) model have an (r^2) of 97.18 %, (S) of 1.73 %,(E$_r$) of -0.01428%, (E$_a$) of 1.5039 %, (E$_{max}$) of 3.0495%, and (E$_{min}$) of 0.0043%. While in dew point pressure (DP$_p$) model produce the same effect accurate of the following: (r^2) of 97.02 %, (S) of 0.6403 %,(E$_r$) of 0.1312 %,(E$_a$) of 0.5271 %,(E$_{min}$) of 0.0568% and (E$_{max}$) of 1.8201%. So they have better sufficient accuracy as compared with Soave Redlich Kwong and Peng Rebonsion equations of state.

4-It has also confirmed during this study that sensitivity of new formulas has an excellent agreement with experimental work by testing thirty-four samples that were not used in the development of new correlations.

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Appendix A

Sample No.	1	2	3	4	5
Comp					
Nitrogen	0.144	0.136	0.132	0.126	0.112
Carbon dioxide	0.435	0.874	1.137	1.444	2.190
Methane	97.177	95.338	94.235	92.947	89.821
Ethane	0.952	1.925	2.508	3.189	4.842
Propane	0.358	0.674	0.863	1.084	1.621
I-Butane	0.228	0.241	0.249	0.259	0.282
n-Butane	0.169	0.217	0.246	0.280	0.363
I-Pentane	0.076	0.089	0.096	0.105	0.127
n-Pentane	0.049	0.064	0.072	0.083	0.108
Hexanes	0.158	0.176	0.186	0.199	0.230
PS-1	0.254	0.266	0.274	0.283	0.304
Total	100	100	100	100	100

Nomenclature

API :   American Petroleum Institute, degree.

C_1 :   Ethan, mole %

C_2 :   Methan, mole %

C_7^+ Heptan Plus

CGR: Gas condensate ratio, bbl/mmSCF

CO_2:   Carbon Dioxide, mole %

DP_P dew point temperature

DP_T :   dew point temperature

E_a average absolute relative error

E_{max} maximum relative error

E_{min} minimum relative error

E_r average absolute relative error

MW_w :   The molecular weight of stock tank liquid.

N_2:   Nitrogen, mole %

r^2 coefficient of determination

S   standard deviation.

T_{re}:   Reservoir temperature, ^oF.

γc^{7+}:   well stream heptanes plus specific gravity

γ_w well stream specific gravity

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