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PHYSIOCHEMICAL, PSEUDOCRITICAL AND THERMODYNAMIC CHARACTERIZATIONS OF NATURAL GASES

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Abstract:
Physiochemical, pseudocritical, pseudoreduced and thermodynamic properties play an important role for determination natural gas quality and specifications. Nowadays natural gas regard as one of the importance natural source of energy supply due to its high heating value, clean source, no emissions and environmental friendly. In addition, it began to replace the oil as a fuel in various purposes and as essential feed for petrochemical industries. Consequently, the different properties of natural gas mixtures must be investigated to determine their specifications. This study was aiming to distinguish these properties using correlations and mathematical models for assessment. These properties include the physical such as molecular weight (M_w), density(ρ), specific gravity(γ), compressibility factor (z), gas viscosity (μ_g), gas formation volume factor (B_g), gas thermal compressibility (C_g) and water content as well as pseudocritical pressure (p_{pc}), pseudocritical temperature (T_{pc}), pseudoreduced pressure (p_{pr}), pseudoreduced temperature (T_{pr}). Also, the thermodynamic properties e. g. Gross heating value, thermal conductivity, and specific heat of natural gas mixtures were determined. The study has been conducted on the natural gases of Zelten, Al Ragoba, Al Hotaiba gasfields and Al Braiga terminal to predict and estimate the physical, pseudocritical and thermodynamic properties by using correlation and mathematical models methods. The obtained results revealed that

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there is a variance between these properties of the natural gas mixtures, which may be attributed to the chemical compositions of components and their behaviors. On the other hand, these characterizations can be used as guide to understand the gases behavior during the different operations and natural gases treatment processes.

Keywords: Natural gas, physiochemical, pseudocritical, pseudoreduced thermodynamic properties, and correlations.

الخصائص الفيزيائية والكيميائية الكاذبة والديناميكية الحرارية للغازات الطبيعية

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ملخص

تلعب الخواص الفيزيائية والكيميائية والحرجة الكاذبة والديناميكية الحرارية دوراً هاماً في تحديد نوعية الغاز الطبيعي ومواصفاته. يعتبر الغاز الطبيعي في الوقت الحاضر أحد أهم المصادر الطبيعية لإمدادات الطاقة نظرًا لقيمته الحرارية العالية ومصدره النظيف وعدم وجود انبعاثات وصديق للبيئة. كما بدأ يحل محل النفط كوقود في مختلف الأغراض وكعلف أساسي للصناعات البتروكيماوية. وبالتالي يجب دراسة الخصائص المختلفة لمخاليط الغاز الطبيعي لتحديد مواصفاتها. وتهدف هذه الدراسة إلى تمييز هذه الخصائص باستخدام الارتباطات والنماذج الرياضية للتقييم. تشمل هذه الخصائص الفيزيائية مثل الوزن الجزيئي (Mw)، والكثافة (ρ)، والثقل النوعي (γ)، وعامل الانضغاط (z)، ولزوجة الغاز (μg)، وعامل حجم تكوين الغاز (Bg)، والانضغاط الحراري للغاز (Cg). ومحتوى الماء وكذلك الضغط الحرج الكاذب (Ppc) ودرجة الحرارة الحرجة الكاذبة (Tpc) والضغط الكاذب (Ppr) ودرجة الحرارة المنخفضة الكاذبة (Tpr). أيضا، الخصائص الديناميكية الحرارية هـ. ز. تم تحديد القيمة الحرارية الإجمالية، التوصيل الحراري، والحرارة النوعية

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لمخاليط الغاز الطبيعي. أجريت الدراسة على الغازات الطبيعية بحقول غاز زلطن والرقوبة والحطيبة وميناء البريقة للتنبؤ وتقدير الخواص الفيزيائية والكاذبة الحرجة والديناميكية الحرارية باستخدام طرق الارتباط والنماذج الرياضية. أظهرت النتائج المتحصل عليها وجود تباين بين هذه الخواص لمخاليط الغاز الطبيعي، والذي قد يعزى إلى التركيب الكيميائي للمكونات وسلوكياتها. ومن ناحية أخرى، يمكن استخدام هذه التوصيفات كدليل لفهم سلوك الغازات أثناء العمليات المختلفة وعمليات معالجة الغازات الطبيعية.

الكلمات الدالة: الغاز الطبيعي، والكيمياء الفيزيائية، والخصائص الديناميكية الحرارية الكاذبة، والارتباطات.

1. Introduction

To understand and predict the volumetric behavior of oil and gas reservoirs as a function of pressure [1], knowledge of the physical properties of reservoir fluids must be gained. These fluid properties are usually determined by laboratory experiments performed on samples of actual reservoir fluids. In the absence of experimentally measured properties, it is necessary for the petroleum engineer to determine the properties from empirically derived correlations [2]. The objective of this study is to present several of the well-established physical property correlations for the natural gas mixtures and determined their specifications.

2. Properties of Natural Gases

A gas is defined as a homogeneous fluid of low viscosity and density that has no definite volume but expands to completely fill the vessel in which it is placed. Generally, the natural gas is a mixture of hydrocarbon and nonhydrocarbon gases. The hydrocarbon gases that are normally found in a natural gas are methanes, ethanes, propanes, butanes, pentanes, and small amounts of hexanes and heavier. The nonhydrocarbon gases (i.e., impurities) include carbon dioxide, hydrogen sulfide, and nitrogen.

Knowledge of pressure-volume-temperature (PVT) relationships and other physical and chemical properties of gases is essential for solving problems in natural gas reservoir engineering [3]. These properties include:

1. Apparent molecular weight, M_w.
2. Specific gravity, γ_g.
3. Compressibility factor, z.
4. Density, ρ_g.
5. Isothermal gas compressibility coefficient, C_g.
6. Gas formation volume factor, B_g.
7. Gas expansion factor, E_g
8. Viscosity, μ_g.

The above gas properties may be obtained from direct laboratory measurements or by prediction from generalized mathematical expressions. This section reviews laws that describe the volumetric behavior of gases in terms of pressure and temperature and documents the mathematical correlations that are widely used in determining the physical properties of natural gases [4].

Petroleum engineers are usually interested in the behavior of mixtures and rarely deal with pure component gases. Because natural gas is a mixture of hydrocarbon components, the overall physical and chemical properties can be determined from the physical properties of the individual components in the mixture by using appropriate mixing rules [5].

The basic properties of gases are commonly expressed in terms of the apparent molecular weight, standard volume, density, specific volume, and specific gravity.

3. Materials and Methods

3.1. Location of Study

This study has been carried out on four natural gas fields located at Sirte Basin that belonging to Sirte Company for oil and gas industry. These fields are Zelten, Al Ragoba, Al Hotaiba gasfields and Al Braiga terminal (Figure 1).

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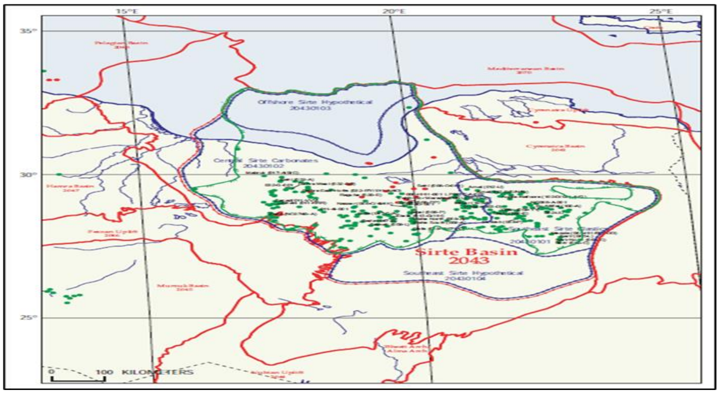

Fig. 1 Oil and gas fields in Sirte Basin

3.2. Objective of Study

The main target of this study is to predict and estimate the properties and characterizations of natural gases because of the importance of these properties for natural gases operations and processing.

On the other hand, the natural gases regard as one of the important natural resources for energy and the petrochemical industry, hence their specification must be known.

4. Physical and Critical Properties

The calculated physical and critical properties of natural gases including molecular weight, specific gravity, viscosity compressibility factor, thermal compressibility factor and formation volume factor.

Tables 1 through 4 show the chemical composition, physical and critical properties, in addition to the actual measurements of gas line data for the investigated natural gases.

4.1. Molecular Weight

The molecular weight of gas mixtures has been calculated by knowing their chemical constituents. The calculated values show variance between gas fields, whereas, the highest value was

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recorded in Al Braiga terminal (27.87) comparing with the other gas fields (Figure 2).

Table 1 Chemical composition and critical properties of Zelten gas field

Components	Mol. fraction y_i	Critical press. p_{ci} (psi)	Critical temp. T_{ci} (°R)	Mol. weight M_i	y_ip_{ci}	y_iT_{ci}	y_iM_i
CH_4	0.690	673.1	343.0	16.043	464.44	236.67	11.07
C_2H_6	0.111	708.3	549.6	30.070	78.62	61.01	3.43
C_3H_8	0.074	617.4	665.6	44.097	45.69	49.25	3.26
C_4H_{10}	0.012	550.7	765.3	58.123	6.61	9.18	0.70
C_5H_{12}	0.024	489.0	845.6	72.150	11.74	20.29	1.73
C_6H_{14}	0.001	439.7	914.2	86.177	0.44	0.914	0.086
$C_7H_{16}^+$	-	-	-	-	-	-	-
CO_2	0.061	1071.1	547.6	44.010	65.34	33.40	2.68
N_2	0.013	187.5	227.2	28.013	2.44	2.95	0.36
H_2S	0.011	493.1	672.4	34.08	5.43	7.40	0.37
$\sum$	1.090				p_{pc}= 680.74	T_{pc}= 421.06	Mw = 23.69
Specific gravity			SG = Mw/29 = 23.69/29 = 0.82				
Pseudoreduced pressure (p_{pr})			$p_{pr}=\frac{p}{p_{pc}}=\frac{430}{680.74}=0.63$				
Pseudoreduced temp. (T_{pr})			$T_{pr}=\frac{T+460}{T_{pc}}=\frac{570}{421.06}=1.35$				
Compressibility factor (z)			0.84				
Corrected compressibility factor (z)			0.87				
Actual measurements of gas line data							

Pipe efficiency (E)	Pipe diameter (D) (in)	Pipe length (L) (mile)	Stand. press. (P_s) (psia)	Stand. Temp. (T_s) (R)	Temp. (T) (R)	Gas flow rate Q (MMSCF/D)
0.92	36	5.625	14.7	520	570	50

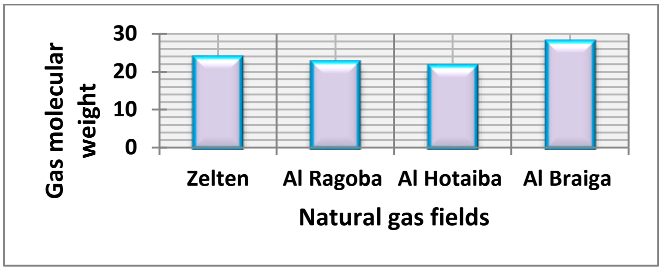

Fig. 2 Molecular weight of natural gas mixtures

Table 2 Chemical composition and critical properties of Al Ragoba gas field

Components	Mol. fraction y_i	Critical press. p_{ci} (psi)	Critical temp. T_{ci} (°R)	Mol. weight M_i	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
CH_4	0.679	673.1	343.0	16.043	469.15	232.90	10.89
C_2H_6	0.116	708.3	549.6	30.070	82.16	63.75	3.49
C_3H_8	0.085	617.4	665.6	44.097	52.50	56.58	3.75
C_4H_{10}	0.015	550.7	765.3	58.123	8.26	11.48	0.87
C_5H_{12}	0.005	489.0	845.6	72.150	2.45	4.23	0.36
C_6H_{14}	0.0004	439.7	914.2	86.177	0.18	0.37	0.034
$C_7H_{16}^+$	-	-	-	-	-	-	-
CO_2	0.047	1071.1	547.6	44.010	50.34	25.74	2.09
N_2	0.019	187.5	227.2	28.013	3.56	4.32	0.53
H_2S	0.013	493.1	672.4	34.08	6.41	8.74	0.44
$\sum$	0.979				p_{pc} = 675.01	T_{pc} = 408.11	Mw = 22.45
Specific gravity			SG = Mw/29 = 22.45/29 = 0.77				
Pseudoreduced pressure (p_{pr})			$p_{pr}=\frac{p}{p_{pc}}=\frac{430}{675.01}=0.64$				
Pseudoreduced temp. (T_{pr})			$T_{pr}=\frac{T+460}{T_{pc}}=\frac{570}{408.11}=1.40$				
Compressibility factor (z)			0.85				
Corrected compressibility factor (z)			0.88				
Actual measurements of gas line data							

Pipe efficiency (E)	Pipe diameter (D) (in)	Pipe length (L) (mile)	Stand. press. (P_s) (psia)	Stand. Temp. (T_s) (R)	Temp. (T) (R)	Gas flow rate Q (MMSCF/D)
0.92	20	54.625	689.38	520	570	20

4.2. Density of Natural Gases

This property depends on the chemical composition of hydrocarbons, also it is related to the number of carbon atoms in hydrocarbon compound and hence of molecular weight of gas mixture. The calculated values of density for investigated gas mixtures are running as Equation [1] and presented in Table 5.

$$\rho_g = \frac{pM_w}{zRT} \quad [1]$$

The calculated density of natural gas mixtures revealed that the highest value was recorded in Zelten gas field (1.98 lb/cu ft). Figure 3 depicted the density of natural gas mixtures.

Table 3 Chemical composition and critical properties of Al Hotaiba gas field

Components	Mol. fraction y_i	Critical press. p_{ci} (psi)	Critical temp. T_{ci} (°R)	Mol. weight M_i	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
CH_4	0.785	673.1	343.0	16.043	528.38	269.26	12.59
C_2H_6	0.044	708.3	549.6	30.070	31.16	24.18	1.32
C_3H_8	0.014	617.4	665.6	44.097	8.64	9.32	0.62
C_4H_{10}	0.009	550.7	765.3	58.123	4.96	6.89	0.52
C_5H_{12}	0.005	489.0	845.6	72.150	2.45	4.23	0.36
C_6H_{14}	0.003	439.7	914.2	86.177	1.32	2.74	0.26
$C_7H_{16}^+$	0.002	-	-	-	0.79	1.94	0.20
CO_2	0.104	1071.1	547.6	44.010	111.39	56.95	4.57
N_2	0.015	187.5	227.2	28.013	2.81	0.34	0.42
H_2S	0.016	493.1	672.4	34.08	7.89	10.76	0.55

∑	0.997				p_{pc} = 699.79	T_{pc} = 386.61	Mw = 21.41
Specific gravity			SG = Mw/29 = 21.41/29 = 0.74				
Pseudoreduced pressure (p_{pr})			$p_{pr}=\frac{p}{p_{pc}}=\frac{400}{699.79}=0.57$				
Pseudoreduced temp. (T_{pr})			$T_{pr}=\frac{T+460}{T_{pc}}=\frac{570}{386.61}=1.47$				
Compressibility factor (z)			0.86				
Corrected compressibility factor (z)			0.85				
Actual measurements of gas line data							

Pipe efficiency (E)	Pipe diameter (D) (in)	Pipe length (L) (mile)	Stand. press. (P_s) (psia)	Stand. Temp. (T_s) (R)	Temp. (T) (R)	Gas flow rate Q (MMSCF/D)
0.92	30	9.06	14.7	520	570	90

Table 4 Chemical composition and critical properties of Al Braiga terminal

Components	Mol. fraction y_i	Critical press. p_{ci} (psi)	Critical temp. T_{ci} (˚R)	Mol. weight M_i	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
CH_4	0.7316	673.1	343.0	16.043	492.44	250.94	11.45
C_2H_6	0.1004	708.3	549.6	30.070	71.11	55.18	3.02
C_3H_8	0.0255	617.4	665.6	44.097	15.74	16.97	1.12
C_4H_{10}	0.1310	550.7	765.3	58.123	72.14	100.25	7.62
C_5H_{12}	0.0161	489.0	845.6	72.150	7.89	13.65	1.16
C_6H_{14}	0.0025	439.7	914.2	86.177	1.10	2.29	0.215
$C_7H_{16}^+$	0.0008	-	-	-	0.332	0.78	0.08
CO_2	0.0507	1071.1	547.6	44.010	54.30	27.76	2.23
N_2	0.020	187.5	227.2	28.013	3.75	4.54	0.56
H_2S	0.012	493.1	672.4	34.08	5.92	0.069	0.41
∑	1.090				p_{pc} = 724.72	T_{pc} = 472.43	Mw = 27.87
Specific gravity			$SG = Mw/29 = 27.87/29 = 0.96$				
Pseudoreduced pressure (p_{pr})			$p_{pr}=\frac{p}{p_{pc}}=\frac{350}{724.72}=0.48$				

Pseudoreduced temp. (T_{pr})	$T_{pr}=\frac{T+460}{T_{pc}}=\frac{570}{472.43}=1.21$					
Compressibility factor (z)	0.87					
Corrected compressibility factor (z)	0.89					
Actual measurements of gas line data						
Pipe efficiency (E)	Pipe diameter (D) (in)	Pipe length (L) (mile)	Stand. press. (P_s) (psia)	Stand. Temp. (T_s) (R)	Temp. (T) (*R*)	Gas flow rate Q (MMSCF/D)
0.95	36	50.625	14.7	520	570	160

Table 5 Natural gases density

Gas density (ρ_g)				
Gas field	Zelten gas field	Al Ragoba gas field	Al Hotaiba gas field	Al Braiga terminal
Density (lb/cu ft)	1.98	1.88	1.63	1.63

4.3. Specific Gravity

Specific gravity regarded as important property for natural gas mixtures and it can be calculated by knowing molecular weight. Al Braiga terminal has the highest value of specific gravity (0.96) while the lowest value of Al Hotaiba gas field (Figure 4), and this may attribute to the chemical composition of light hydrocarbons, however, this is coinciding with molecular weight of these components.

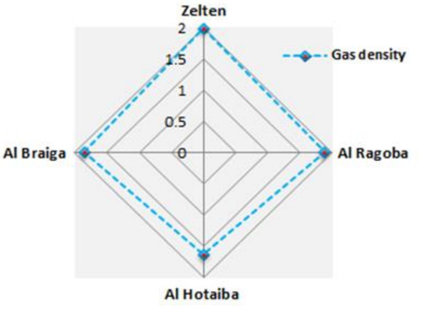

Fig. 3 Density of natural gas mixtures

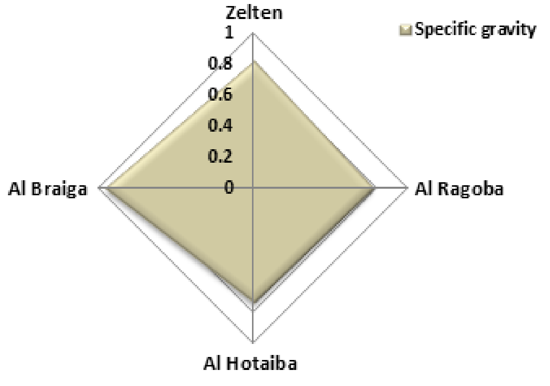

Fig. 4 Specific gravity of natural gas mixtures

4.4. Pseudocritical Properties

The critical properties of chemical components in pure state different from the state of components mixtures. So, it must be determined for hydrocarbon mixtures that known as pseudocritical properties.

The pseudocritical properties of gas mixtures were calculated for the investigated natural gases and the results are presented in Tables 1 through 4.

4.5. Compressibility Factor (z)

Compressibility factor regarded as important parameter to calculate the physical properties of natural gases and it is express about the deviation of real gas from the behavior of ideal gas.

Compressibility factor has been calculated mathematically by using Equation [2]. Due to the presence of impurities in the mixtures that represented by H_2S, N_2 and CO_2, the z factor was corrected by using Wichert-Aziz correlation [6] for these sour gases as shown in Tables 1 through 4.

$$z = 1 - \frac{p_{pr}}{T_{pr}}\left[0.36748758 - 0.04188423\left(\frac{p_{pr}}{T_{pr}}\right)\right] \qquad [2]$$

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The calculated values reflect a variance for the studied gas mixtures, which indicate the difference of chemical composition of these gases (Figure 5).

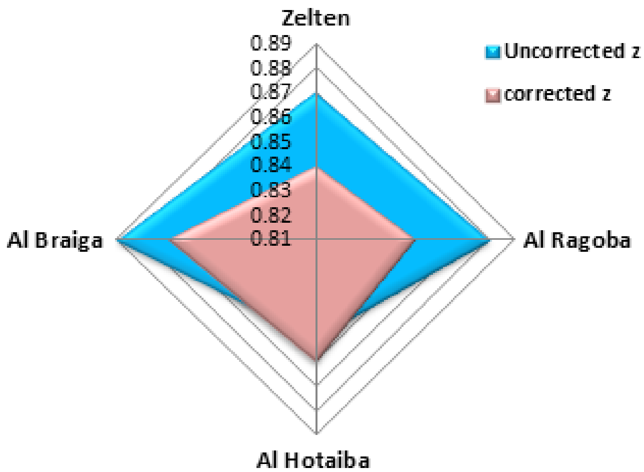

Fig. 5 Comparison between compressibility factors of natural gases

4.6. Viscosity of Sour Gases

Gas viscosity can be estimated by using graphical or mathematical correlations. Carr [7] developed a correlation, which can be applied to determine the viscosity of sour gases. This can be carried out through two steps: first viscosity estimated at atmospheric pressure and temperature using gas specific gravity; second the atmospheric pressure is adjusted at standard conditions by using Pseudoreduced pressure p_{pr} and temperature T_{pr} to determine the ratio of gas viscosity $\frac{\mu_g}{\mu_1}$. From chart and the substitution in Equation [3]. The results were presented in Table 6.

$$\mu_g = \frac{\mu_g}{\mu_1}(\mu_1) \qquad [3]$$

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Table 6 Viscosity of the natural gas mixtures

Gas field	Parameters		
	μ_1 (cp)	$\frac{\mu_g}{\mu_1}$	μ_g (cp)
Zelten gas field	0.0109	1.1	0.01199
Al Ragoba gas field	0.0108	1.09	0.01177
Al Hotaiba gas field	0.0106	1.03	0.0109
Al Braiga terminal	0.0102	1.02	0.0108

According to the above calculated viscosity the higher value recorded by Zelten gas field (0.01199 cp) comparing with the other fields (0.01177 cp, 0.0109 cp and 0.0108 cp) of Al Ragoba gas field, Al Hotaiba gas field and Al Braiga terminal respectively (Figure 6).

4.7. Gas Formation Volume Factor (B_g)

Gas formation volume factor defined as the ratio between gas volumes at reservoir conditions to the gas volume at standard conditions. The hydrocarbons volumes are different in both cases due to the difference of pressure and temperature. So, it must be determined to calculate the actual surface volumes of natural gas. The calculated values of B_g are performed using Equation [4].

$$B_g = \frac{zT\,(14.65)}{(1.0)(520)P} = 0.082\,\frac{zT}{P}\,\frac{cu\,ft}{SCF} \quad [4]$$

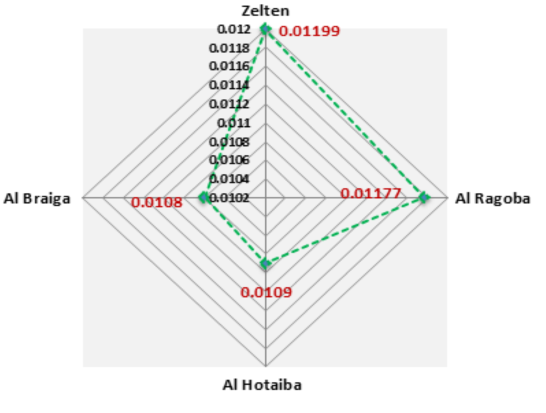

Fig. 6 .Viscosity of natural gases

And presented in Table 7 as shown below. Whereas, Al Braiga terminal displays the highest value (2.57 cu ft/SCF) (Figure 7). This variation attributed to the different conditions of both pressure and temperature of these mixtures.

Table 7 Formation volume factor for natural gas mixtures

Gas field	Zelten gas field	Al Ragoba gas field	Al Hotaiba gas field	Al Braiga terminal
B_g ($\frac{cu\ ft}{SCF}$)	2.44	2.43	2.49	2.57

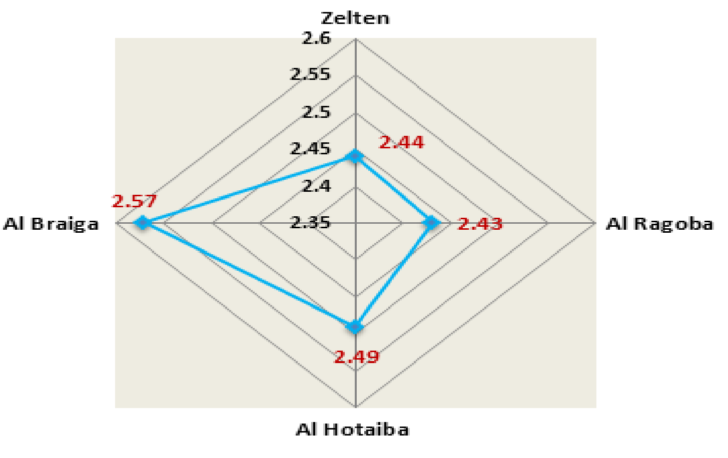

Fig. 7 Formation volume factor of natural gases

4.8. Gas Thermal Compressibility (C_g)

Gas thermal compressibility representing an important parameter for natural gases. This parameter was determined by applying Equation [5] and the data is presented in Table 8.

$$C_g = \frac{C_r}{p_{pc}} \quad [5]$$

By knowing pseudoreduced properties (p_{pr}, T_{pr}), the parameter C_rT_r can be obtain to get $C_r = C_rT_r/T_{pr}$.

Table 8 Gas thermal compressibility for natural gas mixtures

Gas field	Parameters		
	$C_r T_r$	C_r	$C_g (psia^{-1})$
Zelten gas field	2.65	1.96	$2.833 \times 10^{-3} psia^{-1}$
Al Ragoba gas field	2.21	1.58	$2.334 \times 10^{-3} psia^{-1}$
Al Hotaiba gas field	2.88	1.96	$2.80 \times 10^{-3} psia^{-1}$
Al Braiga terminal	2.75	2.27	$8.26 \times 10^{-3} psia^{-1}$

The values of gas thermal compressibility display a difference between gas mixtures which referred to their characteristics (Table 7). Figure 8 depicts the variance of gas thermal compressibility for the investigated gas mixtures.

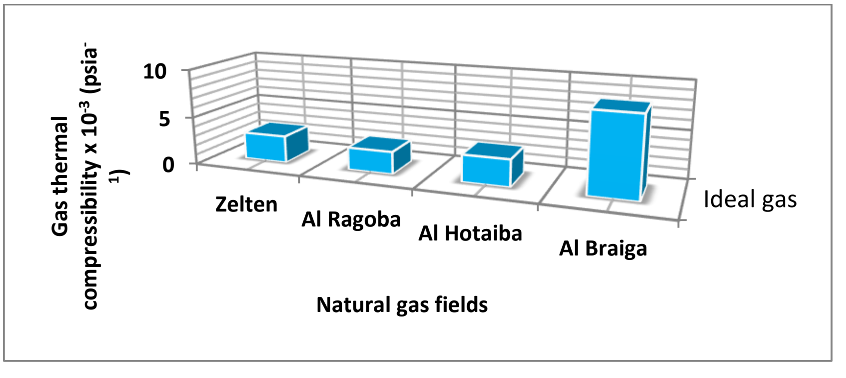

Fig. 8 Gases thermal compressibility

4.9. Water Content

The water content considered as a function of pressure, temperature, composition and salt content in free water.

It can be obtained the vapor water content in gas mixtures [8]. The obtained results are graphically represented as shown in Figure 9.

The values are higher than the permissible limits of standard natural gas specifications. The water content of Al Hotaiba gas field shows the highest one (180 lb/MMCF), while the lowest value was recorded in Zelten gas field (160 lb/MMCF).

Consequently, these gases should be treated by dehydration to eliminate the water content to avoid any problems in pipelines and to meet natural gas specifications.

5. Thermodynamic Properties

Thermodynamic properties regarded as ones of the important properties of natural gases that must be studied e. g. heat of combustion, heating value, thermal conductivity and specific heat.

5.1. Heat of Combustion

This property related to heating value or heat of combustion. Whereas, the heating value of natural gas is the produced heat due to the full combustion of gas into carbon dioxide and water. It is expressed by British thermal units, Btu/scf.

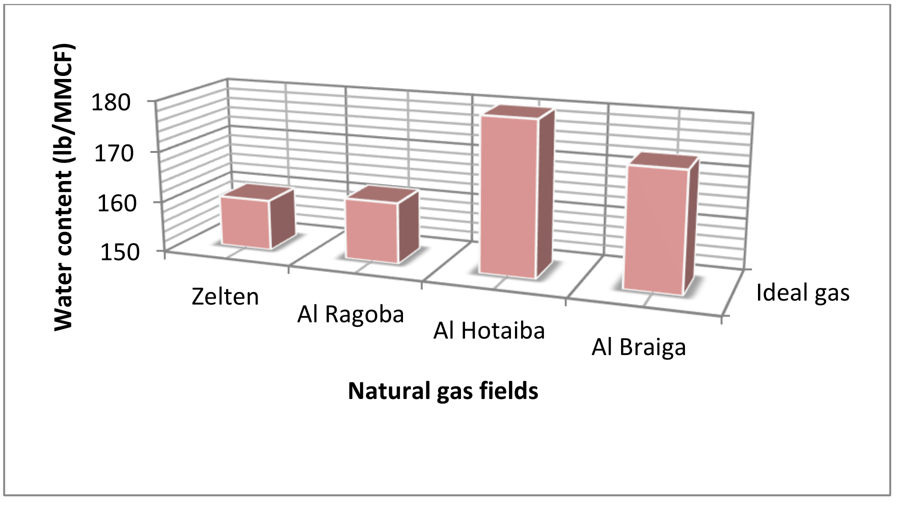

Fig. 9 Water content in natural gas mixtures

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5.2. Gross Heating Value for Natural Gases

The heating value of natural gas can be calculated for ideal gas according to Equation [6] [9]:

$$L_{c\,ideal} = \sum_i y_i L_{ci} \qquad [6]$$

The above Equation can be used to calculate the gross heating value, and in many cases the units must be converted from ideal gas to real gas at standard conditions by dividing the ideal value on compressibility factor (z) at standard conditions according to Equation [7]:

$$L_c = \frac{L_{c\,ideal}}{z} \qquad [7]$$

The compressibility factor (z) can be estimated at standard conditions by applying Equation [8]:

$$z = 1 - \left(\sum_i y_i \sqrt{1 - z_i}\right)^2 \qquad [8]$$

The heating values of natural gases are calculated for the investigated gas fields and presented in Tables 9 through 12.

Table 9 Gross heating value for Zelten gas field

Components	Mole fraction y_i	Gross heating value (Btu/scf) L_{ci}	$y_i L_{ci}$	Compressibility factor (z) Standard conditions	
				z_i	$y_i\sqrt{1-z_i}$
CH_4	0.690	1009.7	696.69	0.9980	0.0309
C_2H_6	0.111	1768.8	196.34	0.9919	0.0099
C_3H_8	0.074	2517.5	186.30	0.9825	0.0098
C_4H_{10}	0.012	3262.1	39.15	0.00354	0.0119
C_5H_{12}	0.024	4009.6	96.23	0.00065	0.0240
C_6H_{14}	0.001	4756.2	4.76	0.00081	0.0010
$C_7H_{16}^+$	0.0002	5502.8	1.10	0.00012	0.0002
CO_2	0.061	0.0	0.0	0.9943	0.0046
N_2	0.013	0.0	0.0	0.9997	0.0002

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H_2S	0.011	0.0	0.0	-	-
$\sum$	0.997		1220.57 Btu/scf		0.0925
Gross heating value for ideal gas and compressibility factor at standard conditions			$z = 1- (\sum_i y_i\sqrt{1-z_i})^2 = 1-(0.0925)^2 = 0.9914$		
Gross heating value as real gas			$L_c = \frac{L_{c\,ideal}}{z} = \frac{1220.57\ BTU/scf}{0.9914} = 1231.16$ Btu/scf		

Table 10 Gross heating value for Al Ragoba gas field

Components	Mole fraction y_i	Gross heating value (Btu/scf) L_{ci}	y_iL_{ci}	Compressibility factor (z) Standard conditions	
				z_i	$y_i\sqrt{1-z_i}$
CH_4	0.679	1009.7	685.59	0.9980	0.0304
C_2H_6	0.116	1768.8	205.18	0.9919	0.0104
C_3H_8	0.085	2517.5	213.99	0.9825	0.0112
C_4H_{10}	0.015	3262.1	48.93	0.00354	0.0150
C_5H_{12}	0.005	4009.6	20.05	0.00065	0.0050
C_6H_{14}	0.0004	4756.2	1.90	0.00081	0.0004
$C_7H_{16}^+$	0.0001	5502.8	0.55	0.00012	0.0001
CO_2	0.047	0.0	0.0	0.9943	0.0035
N_2	0.019	0.0	0.0	0.9997	0.0003
H_2S	0.013	0.0	0.0	-	-
$\sum$	0.967		1176.19 Btu/scf		0.0763
Gross heating value for ideal gas and compressibility factor at standard conditions			$z = 1- (\sum_i y_i\sqrt{1-z_i})^2 = 1-(0.0763)^2 = 0.9941$		
Gross heating value as real gas			$L_c = \frac{L_{c\,ideal}}{z} = \frac{1176.19\ BTU/scf}{0.9941} = 1183.08$ Btu/scf		

Table 11 Gross heating value for Al Hotaiba gas field

Components	Mole fraction y_i	Gross heating value (Btu/scf) L_{ci}	$y_i L_{ci}$	Compressibility factor (z) Standard conditions	
				z_i	$y_i\sqrt{1-z_i}$
CH_4	0.785	1009.7	792.61	0.9980	0.0351
C_2H_6	0.044	1768.8	77.83	0.9919	0.0040
C_3H_8	0.014	2517.5	35.25	0.9825	0.0019
C_4H_{10}	0.009	3262.1	29.36	0.00354	0.0090
C_5H_{12}	0.005	4009.6	20.05	0.00065	0.0050
C_6H_{14}	0.003	4756.2	14.27	0.00081	0.0030
$C_7H_{16}^+$	0.002	5502.8	11.01	0.00012	0.0020
CO_2	0.104	0.0	0.0	0.9943	0.0079
N_2	0.015	0.0	0.0	0.9997	0.0003
H_2S	0.016	0.0	0.0	-	-
$\sum$	0.981		980.38 Btu/scf		0.0682
Gross heating value for ideal gas and compressibility factor at standard conditions			$z = 1-(\sum_i y_i\sqrt{1-z_i})^2 = 1-(0.0682)^2 = 0.9953$		
Gross heating value as real gas			$L_c = \frac{L_{c\,ideal}}{z} = \frac{980.38\ BTU/scf}{0.9953} = 985.01$ Btu/scf		

Table 12 Gross heating value for Al Braiga terminal

Components	Mole fraction y_i	Gross heating value (Btu/scf) L_{ci}	$y_i L_{ci}$	Compressibility factor (z) Standard conditions	
				z_i	$y_i\sqrt{1-z_i}$
CH_4	0.7316	1009.7	738.70	0.9980	0.0327
C_2H_6	0.1004	1768.8	177.59	0.9919	0.0090
C_3H_8	0.0255	2517.5	64.20	0.9825	0.0034
C_4H_{10}	0.1310	3262.1	427.34	0.00354	0.1308
C_5H_{12}	0.0161	4009.6	64.55	0.00065	0.0161
C_6H_{14}	0.0025	4756.2	11.89	0.00081	0.0025

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$C_7H_{16}^+$	0.0008	5502.8	4.40	0.00012	0.0080
CO_2	0.0507	0.0	0.0	0.9943	0.0038
N_2	0.020	0.0	0.0	0.9997	0.0004
H_2S	0.012	0.0	0.0	-	-
$\sum$	1.078		1488.67 Btu/scf		0.2067
Gross heating value for ideal gas and compressibility factor at standard conditions			$z = 1- (\sum_i y_i\sqrt{1-z_i})^2 = 1- (0.2067)^2 = 0.9573$		
Gross heating value as real gas			$L_c = \frac{L_{c\,ideal}}{z} = \frac{1488.67\ BTU/scf}{0.9573} = 1555.07$ Btu/scf		

The change of heating value for ideal gas to real gas generally less than 0.5% and can be neglected. It be regarded as important property for natural gases. The calculated values of gas mixtures are increasing than the standard value (1000/scf). The of heating value of Zelten, Al Ragoba and Al Braiga are 123.16, 1183.08 and 1555.07 Btu/scf respectively (Figure 10).

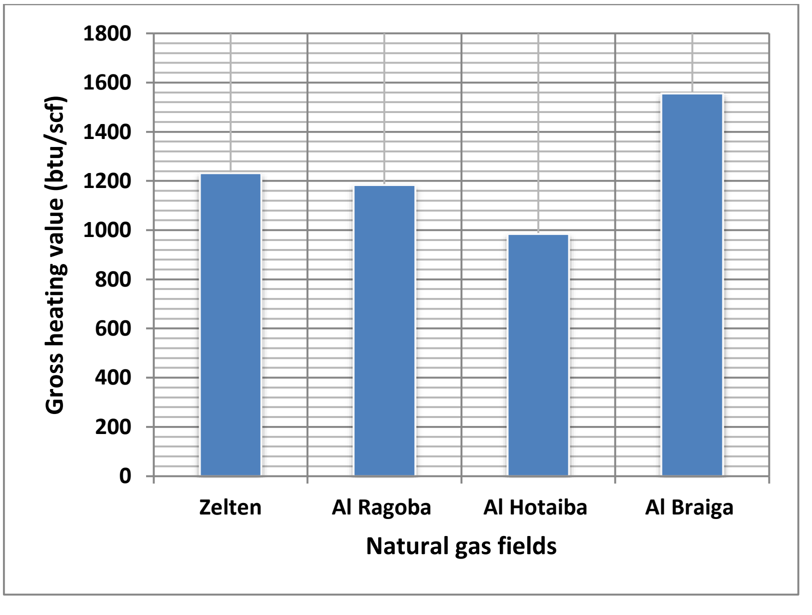

Fig. 10 Gross heating value of natural gases

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5.3. Thermal Conductivity

Thermal conductivity can be calculated for gas mixtures at high pressure and low pressures by using graphical correlations that developed by Published data [1].

Consequently, the thermal conductivity was calculated for gas mixtures by knowing molecular weight and pseudocritical properties (p_{pc}, T_{pc}) as shown in Table 13. Figure 11 shows the little variation between thermal conductivity of natural gases.

Table 13 Thermal conductivity for natural gas mixtures

Gas field	Parameters		
	k_A Btu/[hr ft^2 °F)/ft]	$\frac{k}{k_A}$	K Btu/[(hr ft^2 °F)/ft]
Zelten gas field	0.0163	1.24	0.0202
Al Ragoba gas field	0.0169	1.26	0.0213
Al Hotaiba gas field	0.0177	1.25	0.0222
Al Braiga terminal	0.0144	1.22	0.0176

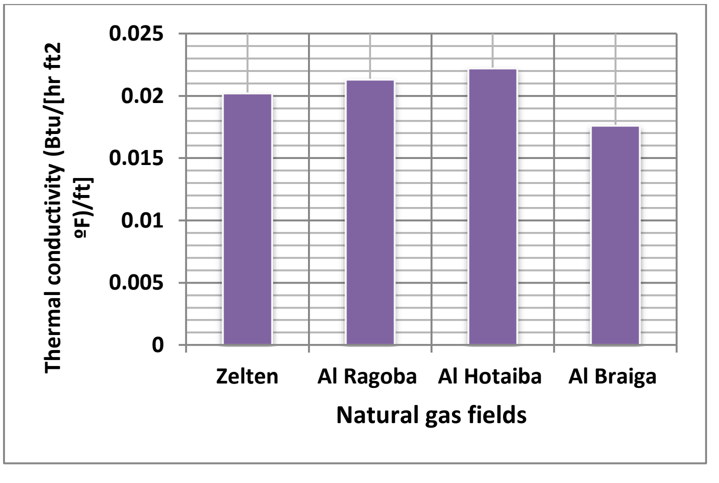

Fig. 11 Gross heating value of natural gases

5.4. Specific Heat

Specific heat can be determined by knowing both pressure and temperature. Figure illustrates the variation of specific heat for gas mixtures, whereas, Zelten has the highest value (0.76 J/kg.℃) while Al Braiga the lowest one (0.72 J/kg.℃) (Figure 12).

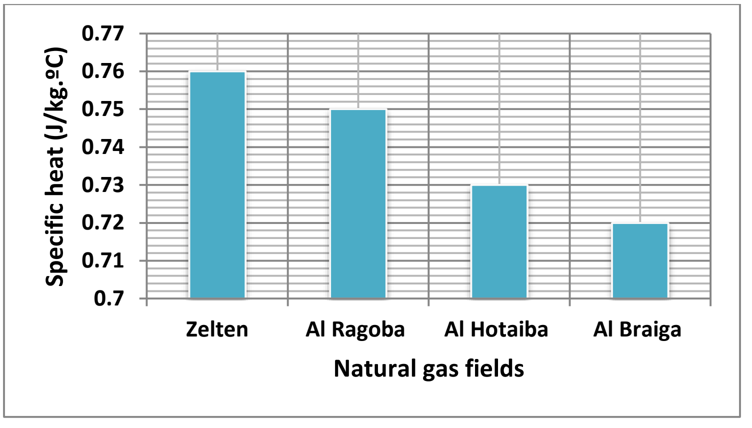

Fig. 12 Specific heat of natural gases

6. Conclusion

The following conclusions were drawn from the results obtained in this study:

1. The physical properties of natural gas mixtures such as molecular weight (M_w), density(ρ), specific gravity(γ), compressibility factor (z), gas viscosity (μ_g), gas formation volume factor (B_g), gas thermal compressibility (C_g) and water content as well as pseudocritical pressure (p_{pc}), pseudocritical temperature (T_{pc}), pseudoreduced pressure (p_{pr}), pseudoreduced temperature (T_{pr}), must be investigated to determine their specifications.
2. The examined properties of natural gas mixtures display some variations between the studied different gases, which may attribute to their chemical composition of constituents.

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3. Thermodynamic properties e. g. gross heating value, thermal conductivity, and specific heat of natural gas mixtures were determined. Also, exhibit a variance between the calculated values owing to their major constituents.
4. The gases contain high content of water vapor and required to be treated by dehydration to eliminate the water content to avoid any problems in pipelines and to meet natural gas specifications.
5. From the obtained results it is found that the majority of characterization of properties of natural gases coinciding with the required standard specifications.

Nomenclature

M_w= molecular weight of gas mixture.
M_a = molecular weight of air.
PVT = pressure-volume-temperature.
p = pressure, psia.
p_c = critical pressure, psia.
p_{pc} = pseudocritical pressure.
p_{pr} = pseudoreduced pressure.
T = temperature, ˚R.
T_c = critical temperature, ˚R.
T_{pc} = pseudocritical temperature.
T_{pr} = pseudoreduced temperature.
y_i = mole fraction of the i-th component.
γ_g= Specific gravity of gas mixture.
ρ = Gas density, lb/cu ft.

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