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Empirical Equations For The Surface Gas Gravity of Nigerian Associated Gas

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Abstract

The surface gas gravity is a quantity that is usually experimentally measured. This study presents a set of equations that can be used to estimate this parameter. The data used, came from the experimental pressure volume temperature (PVT) data of the gas gravity of gas associated with Niger Delta crude oil. The crude oil is subdivided into 3 broad groups in order of ascending order of American Petroleum Institute (API) gravity.

The accuracy of the calculated surface gravity is determined through statistical error analysis. Absolute errors range between 0.423 and 11.643 percent. The standard deviation is 5.291

1.0 Introduction

The specific gravity of a Natural gas is used in several aspects of petroleum engineering calculations. From estimation of other reservoir fluid properties to the transportation of gas and gas and crude oil mixtures. The specific gravity of a gas is defined as the ratio of the density of a gas to the density of air at the same condition of pressure and temperature.

The density of a gas is obtained from the general gas law. The general gas law is a combination of the equations of Boyle, Charles and Avogrado [4]. The general gas law is:

$$PV = znRT \tag{1.1}$$

Where:

P = Pressure in absolute unit
T = Temperature in absolute unit
V = Volume where gas is enclosed
n = Number of moles
R = Universal gas constant
z = Gas deviation factor (z-factor)

The gas deviation factor, commonly called z-factor is widely obtained from a chart of Standing and Katz (1942) and by calculation. Several equations for the calculation of the z-factor are available in the literature. A simple and efficient equation is that of ([1] and [2]) has derived an equation for the weight density (specific weight) of a gas. The equation is

$$\gamma = \frac{pM}{zRT} \tag{1.2}$$

Where M = Molecular weight of the gas

Then, specific gravity of a gas (r_g) becomes

$$r_g = \frac{PM_{gas}}{z_{gas}RT} \times \frac{z_{air}RT}{PM_{air}} \tag{1.3}$$

The specific gravity of a gas at atmospheric pressure (14.7 psia) and atmospheric temperature, arbitrarily set at a standard value of 60 ^oF is called the surface gas gravity. The surface gas gravity (r_{gs}) is the target of this study.
At atmospheric condition, the gas deviation factor (z) equals unity for all gases. Then from equation (1.2),

$$r_{gs} = \frac{M_{gas}}{M_{air}} \tag{1.4}$$

where r_{gs} = Surface gravity

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The type of gas used to develop the equations in this study is called associated gas. An associated gas is liberated from a crude oil during its production from a petroleum reservoir. The associated gas in this study is divided into 3 broad groups, in ascending value of the API gravity of the crude oil with which the gas is associated.

The groups are:

1. Gas associated with crude oil that has ^{o}API < 27.3
2. Gas associated with crude oil that has an ^{o}API range: 27.3 – 34.
3. Gas associated with crude oil that has an ^{o}API range: 34 – 40.

The range of data in of this study is as follows:

Temperature (^{o}F) : 130 – 220
^{O} API of Crude Oil: 17.2 – 40.4
Specific gravity of Crude Oil : 0.833 – 0.952

EMPIRICAL EQUATIONS OF SURFACE GAS GRAVITY

The equations for the surface gas gravity (r_{gs}) are functions of temperature (T) and specific gravity of gas free crude oil (r_{os}). That is:

$r_{gs} = f(T, r_{os})$

The relationship between r_{os} and ^{o}API is $r_{os} = (141.5)/(^{o}API + 131.5)$

A single equation is empirically suggested for each of the first 2 groups and 2 equations for the last group.

Equation for the group with ^{o}API < 27.3

The empirical equation for the surface gas gravity of gas associated with crude oil that has ^{O}API less than or equal to 27.3 is:

$$r_{gs} = a + b \log X + c (\log X)^2 \quad (1.5)$$

Where

r_{gs} = specific gravity of gas at 14.7 psia and 60 ^{o}F
X = $r_{os} T^2$
T = temperature ^{o}F
r_{os} = specific gravity of gas free crude oil at 14.7 psia and 60 ^{o}F.
a = 22.629070
b = -10.596475
c = 1.272947

Example 1

Calculate the surface gravity (air = 1) of a Niger Delta Natural Gas that is associated with a crude oil that has a reservoir temperature of 170 ^{o}F and an ^{o}API = 21.1

Solution

$$r_{OS} = 141.5/(^{O}API + 131.5) = 141.5/(21.1 + 131.5) = 0.928$$

$$X = r_{OS}T^2 = 0.928 \times 171^2 = 26817$$

$$r_{gs} = 22.629070 - 10.599996475 \log 26817 + 1.272941 \text{ x } (\log 26817)^2 = 0.667$$

Equation for the group with ^{o}API range 27.3 - 34

The empirical equation for this group is:

$$r_{gs} = \frac{(T + 460)}{2000\, r_{OS}} - 3.93421 + 9.19087\, r_{OS} - 4.91488\, r_{OS}^2 \quad (1.6)$$

Example 2

Find the surface gravity (air = 1) of a Niger Delta gas that is produced with a crude oil that has a reservoir temperature of 165^{0}F and an ^{0}API = 33.9.

Solution

Here, ^{o}API = 33.9 and r_{OS} = 0.855. Given, T ^{O}F = 165. Then ,

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$$r_{gs} = \frac{(165+460)}{2000\times 0.855} - 3.93421 + 9.19087\times 0.855 - 4.91488\times 0.855^2 = 0.697$$

Equations for group with ^{0}API range: 34-40

Gas that is associated with crude oil that has ^{O}API in the range 34-40 is further divided into two groups. The criterion of demarcation is the quantity Bo1×T; where , Bo1 is the formation volume factor of gas free crude oil at reservoir temperature and T is reservoir temperature in degrees Rankine. [3] has developed an equation for Bo1 given by

$$B_{O1} = 0.004203\left(\frac{T^oF}{r_{os}}\right) + 0.968065 \tag{1.7}$$

The two equations for the gas gravity associated with a crude oil that has an ^{0}API range 34 – 40 are

$$r_{gs} = 60.32981Y^2 - 85.89440Y + 31.25313 \tag{1.8}$$

if $B_{OI}\times T \le 693$ and $r_{gs} = -80.27392Y^2 + 127.76356Y - 49.94628$ (1.9)

if $B_{o1\times}T > 693$, where ,Y = $\frac{(T^oF+460)}{1000\, r_{OS}}$

Example 3

What is the surface gas gravity of a Nigerian Natural Gas that is associated with a 39.3^{0}API crude Oil, if the reservoir temperature is 175^{0}F.

Solution

Here, r_{os} = 141.5/(39.3 + 131.5) = 0.829, $B_{O1} = 0.0004203\left[\frac{175}{0.829}\right] + 0.96805 = 1.057$

$B_{O1}\times T^0R = B_{OI}(T^0F+460) = 1.057(175+460) = 671$

Since 671 < 693, equation 8 is applicable

$Y = \frac{175+460}{1000\times 0.829} = 0.766$, $r_{gs} = 60.32981\times 0.766^2 - 85.89440x0.766 + 31.253129 = 0.857$

Table 1 shows values of surface properties of crude oil samples of this study, reservoir temperature, calculated surface gas gravity, and experimentally determined surface gravity and of this study.

STATISTICAL ERROR ANALYSIS

The accuracy of the equation of this study are obtained through statistical analysis. The measures used are: percent error, average percent error, average absolute error, minimum/maximum absolute error and standard deviation. The definition of there measures by [5] follow:

(a) Percent error (Di) = $\frac{(X_{est} - X_{exp})\times 100}{X\exp}$ (1.10)

Where: Xest = Surface gravity from this study , Xexp = Surface gravity from PVT study

(b) Average percent error (M.D.) = $\frac{\sum Di}{N}$ (1.11)

(c) Average percent absolute error (A.M.D.) = $\frac{\sum Ei}{N}$ (1.12)

Where, Ei = $\frac{|X_{est} - X_{exp}|}{X_{exp}}$ (1.13)

(b) Standard deviation (SD) = $\sqrt{\frac{(\sum Ei^2)}{N-1} - \frac{(\sum Ei)^2}{N}}$ (1.14)

The values obtained for these statistical measures of accuracy from this study are shown in table 2.

Where, N = total number of samples

Table 1: Surface crude oil properties, Temperature and surface gas gravity of this study

SERIAL NO.	^{O}API	r_{go}	T^{0}F	$r_{gs}^{(exp)}$	$r_{gs}^{(calc.)}$
1	17.2	0.952	130	0.565	0.579
2	17.4	0.950	146	0.631	0.603
3	18.7	0.942	139	0.565	0.589

Table 2: Surface Gas Gravity form this Study

Data value true value estimaied value error absolute error

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4	19.8	0.935	144	0.566	0.597
5	20.0	0.928	130	0.568	0.579
6	21.1	0.928	170	0.634	0.667
7	21.8	0.923	180	0.723	0.702
8	22.2	0.921	140	0.617	0.588
9	23.0	0.916	135	0.578	0.582
10	24.8	0.905	142	0.616	0.589
11	26.8	0.894	150	0.579	0.602
12	27.1	0.892	171	0.655	0.659
13	28.5	0.884	170	0.709	0.706
14	29.6	0.879	150	0.747	0.694
15	29.9	0.877	161	0.627	0.700
16	30.1	0.876	144	0.623	0.690
17	33.9	0.855	165	0.672	0.697
18	37.8	0.836	220	0.879	0.866
19	38.6	0.836	211	0.959	0.887
20	39.1	0.839	166	0.844	0.793
21	40.4	0.833	183	0.981	0.898

1	.565	.579	-2.478	2.478
2	.631	.603	4.437	4.437
3	.565	.589	-4.248	4.248
4	.566	.597	-5.477	5.477
5	.568	.579	-1.937	1.937
6	.634	.667	-5.205	5.205
7	.723	.702	2.905	2.905
8	.617	.588	4.700	4.700
9	.578	.582	-.692	.692
10	.616	.589	4.383	4.383
11	.579	.602	-3.972	3.972
12	.655	.659	-.611	.611
13	.709	.706	.423	.423
14	.747	.694	7.095	7.095
15	.627	.700	-11.643	11.643
16	.623	.690	-10.754	10.754
17	.672	.697	-3.720	3.720
18	.879	.866	1.479	1.479
19	.959	.887	7.508	7.508
20	.844	.793	6.043	6.043
21	.981	.898	8.461	8.461

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AVERAGE PERCENT ERROR = -.157

AVERABE ABSOLUTE PERCENT ERROR = 4.675

STANDARD DEVIATION = 5.291

Conclusion

Equations for the surface gas gravity of Nigerian Associated gas have been developed. Error analysis shows that the equations can be used in the absence of experimental pressure volume Temperature (PVT) data.

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