API Gravity And Viscosity Determine Crude Oil Sulfur Concentration

Two recently developed correlations allow the effect of sulfate-reducing bacteria on biodegradation of crude oils to be quantified and can be used to forecast future measurements within an average relative error of 0.672%.

Laboratory studies show the existence of sulfate-reducing bacteria in some Arabian crude oils. The effect of sulfate-reducing bacterial activities on the biodegradation of Arabian crude oils has been quantified by correlating the API gravity and viscosity to the sulfur content and initial reservoir temperature and pressure.

Field data from 156 crude oil samples obtained from the major producing areas of Arabian reservoirs have been analyzed statistically to check normal distributions around the means. The accuracy of the developed correlations was determined using statistical error analysis. The validity of the API gravity correlation for future measurements was verified by constructing the confidence area. The developed correlations are valid for any other crude oils falling within the range of data used.

Sulfur Content

Crude oil viscosity and API gravity determine how an oil well will be produced.

Crude oil sulfur content depends on the depositional environment of the source rock.[1] Oil from source rocks such as carbonates tends to be high in sulfur, which supports sulfate-reducing bacteria. The Alberta bitumen deposits were derived by microbial modification of crude oils.[2]

Previous research revealed sulfur heterocycles, which are eluted in the aromatic fraction, are used without nutrient supplementation.[3] Research also showed lower molecular weight sulfur heterocycles are removed from crude oil by microbial action. Sulfur content loss was attributed to the metabolism of sulfur compounds. Properties such as power point, viscosity, gravity, and the physical state of the oil can be affected by microbial activity.[4]

Oils recovered from deep reservoirs had a normal n-alkane content, high API gravity, and lower viscosities than oils recovered from shallow reservoirs.[5] These shallow reservoir oils were assumed to be derived from bacterial degradation.

TABLE 1. PROBABILITY AND CONFIDENCE LEVELS OF NORMALLY DISTRIBUTED RESERVOIR PARAMETERS.

Parameter	Number of data points	Mean	Standard deviation	Maximum value (z_1)	Minimum value (z_2)	Probability p(z)	Confidence level (α)
Sulfur content wt, %	156	2.381	1.142	1.91	-1.997	0.9749	0.9498
API gravity	156	31.19	6.82	2.64	-3.47	0.9956	0.9912
Viscosity, mPa-s	156	6.9	255.0	7.724	-0.272	0.8980	0.796
Pressure, 10^5 Pa	156	3,780	1,296	5.61	-2.62	0.9956	0.912
Temperature, °F	156	197.3	32.4	3.17	3.28	0.9987	0.9974

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Maturity Concept

Mature oils come from a source rock in the main phase of oil generation by breaking carbon-oxygen and highly substituted carbon bonds.[1] They have a high API gravity and potentially high economic value.

Immature oils are bitumen-like products expelled at low levels of maturation and have high viscosity and low API gravity.

Correlations Development

In the two correlations developed, statistical error analyses were used to check the normality of the oil reservoir parameters distribution and determine the adequacy of the fitted correlations. In terms of standard normal variate, the probability of a normally distributed variable around its mean is expressed by the following probability density equation.[6]

$$P(z) = \frac{1}{\sqrt{2\pi}} \int_{z1}^{z2} e^{-z^2/2} dz \qquad (1)$$

Eq. 1 was used to check the normality of the obtained field data. Table 1 shows the probabilities and confidence levels of the given reservoir parameters range from 0.989 to 0.9987 and from 0.796 to 0.9974 respectively. This ensures the studied parameters are well distributed around their means and can be tested statistically for correlation.

API Correlation

A linear relationship between API gravity and sulfur content is obtained using:

$$API = 43.079 - 4.9334S \qquad (2)$$

The correlation coefficient was calculated at 0.911. This value, along with the number of data points (n) and number of independent variables (k), was used to find the calculated f-test (f_c) from the following equation:

$$f_c = \frac{f^2(n-k-1)}{(1-r^2)\,k} \qquad (3)$$

The f_c value of 751.88 from Eq. 3 exceeds the tabulated f-test value (f_t=3.84) for 1 and 154 degrees of freedom at a confidence level of 0.99. This indicates an excellent linear relationship between API gravity and sulfur content.

The validity of the correlation for predicting API gravity for future field data can be verified by constructing the confidence area. The equations of the upper and lower limits of the confidence area are given by:

$$\Delta y = t_{\alpha/2} S \sqrt{1 + \frac{1}{n} + \frac{(x_i - \bar{x})^2}{\sum_{i=1}^{n} (x_i - \bar{x})}} \qquad (4)$$

$$\text{upper limit} = y_c + \Delta y \quad (5)$$

$$\text{lower limit} = y_c + \Delta y \quad (6)$$

Fig. 1 shows the field data of API gravity and sulfur content overlays the confidence area where the upper and lower limits are calculated from Eqs. 4-6. The sulfur content in the studied Arabian oils ranges from 0% to 6%. It is inversely proportional to API gravity, emphasizing the existence of sulfate-reducing bacteria. It also reveals 66.7% of the Arabian crude oils have API gravity and sulfur content greater than 30° and less than 3% respectively. Therefore, these crude oils can be categorized as "mature oils."

The immature oils are characterized by low API gravity and high sulfur content. The tank oil specific gravity can be expressed in terms of sulfur content:

$$\gamma_o = \frac{141.5}{174.579 - 4.9334S} \quad (7)$$

The correlated data were checked by comparing the API gravity calculated from Eq. 2 with the field data.

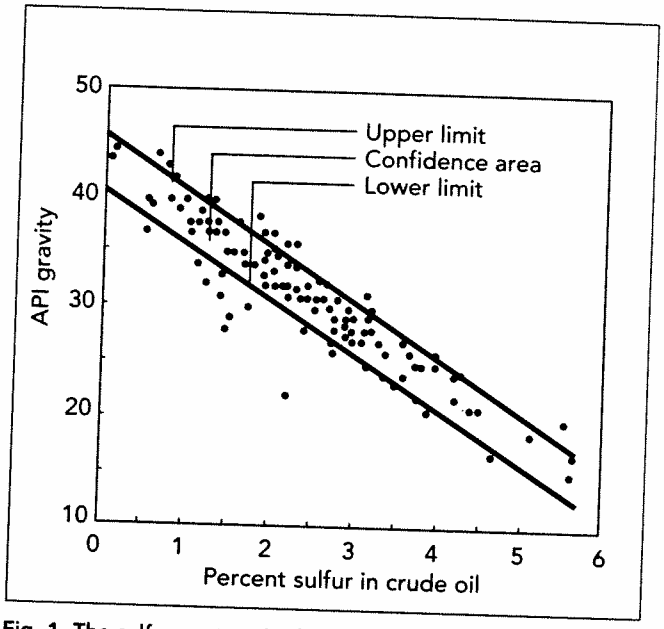

Fig. 1. The sulfur content in the studied Arabian oils is inversely proportional to API gravity, emphasizing the existence of sulfate-reducing bacteria.

TABLE 2. CORRELATION VALIDITY

Sulfur in crude oil, %	API gravity (measured)	API gravity (calculated)
2	33.5	33.2
3	28.0	28.3
5	18.0	18.4
6	14.0	13.5

TABLE 3. VISCOSITY VALUE COMPARISON

Correlation	Average relative error, %
Comparison 1[7]	32.073
Comparison 2[8]	-82.557
Calculated (Eq. 8)	-13.584

Viscosity Correlation

Several trials have been attempted to correlate the viscosity of crude oil to sulfur content, temperature, and pressure. The equation obtained is:

$$\mu = \frac{8.06 \times 10^5 e^{77 \times 10^{-4} P - 7.496 + 0.855}}{T^{1.49}} \quad (8)$$

The correlation coefficient equals 0.926. The value of f_c calculated from Eq. 3 equals 926.01, which is greater than that obtained from statistical tables (f_t=2.6). This emphasizes the strength of the correlation between μ and p, S and T.

To determine the validity of the API gravity correlation to the other crude oils within the range of data used, data observed for Adriatic Basin crude oil in Italy and Yugoslavia were compared with the calculated data using Eq. 2.[1] The developed equation has an excellent validity in relation to the other crude oils (Table 2).

Table 3 shows a comparison between previously published, measured viscosity of Arabian oils and those calculated from Eq. 8. The developed correlation (Eq. 8) reveals the least average relative error. Therefore, Eq. 8 should be valid for Arabian oils or other crude oils falling within the range of data used in the study. ●

Nomenclature

API = $141.5/\gamma_o - 131.5$, °API

f_c, f_t	=	values of calculated and tabulated f-test
K	=	number of independent variables
n	=	number of data points
P	=	initial reservoir pressure, psi
P(z)	=	probability
r	=	correlation coefficient
S	=	sulfur content, %
SD	=	standard deviation
T	=	initial reservoir temperature, °F
$t_{\alpha/2}$	=	value of t-test at $\alpha/2$
x_i	=	measured value of viscosity or API
$\bar{x}$	=	mean value of viscosity or API data
y_c	=	calculated value of viscosity or API
z_1, z_2	=	higher and lower values of standard variate
μ	=	viscosity, cp
γ_o	=	specific gravity of crude oil
α	=	confidence level

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