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## ESTIMATION OF VISCOSITY OF AZERBAIJAN CRUDE OIL

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### ABSTRACT

In this study, the prediction issue of oil viscosity, on oil samples taken from Guneshli oil field of Azerbaijan has been viewed applying empirical correlations as Beggs-Robinson, Labedi, modified Kartoatmodjo, Elsharkawy and Alikhan, Al-Khafaji. The correlation models used in the evaluation of viscosity of Azerbaijan oil have been implemented in the Python software environment. The obtained values on empirical correlations have been compared to experimental data obtained from Guneshli oil field. The result of prediction has been evaluated using statistic functions as absolute average deviation (AAD), mean absolute error (MAE), correlation coefficient, root mean square error (RMSE). According to statistical analysis, it has been known that the Beggs-Robinson model has shown the lowest value on AAD (10.5614%), MAE (12.4427 %), RMSE (20.0853 %). The Labedi model has presented the worst result on every four criterions. Even though the Elsharkawy-Alikhan model has presented the highest result (99.9272%) on correlation coefficient, in the evaluation of viscosity of Azerbaijan crude oil, the Beggs-Robinson model can be considered more acceptable.

## 1. INTRODUCTION

In oil fields, the accurate knowledge about pressure-volume-temperature (PVT) properties of reservoir fluid are considered primary data for engineer-oilmen in the projection of oil fields, development and exploitation, calculation of well debit, projection of surface devices, as well as, calculation of hydrocarbon reserves. Viscosity is one of the most important parameters of PVT properties. Especially, viscosity is important in the modeling of oil gas fields, projection of pipelines or compressor stations, increasing oil extraction and storing natural gas [1-13]. It plays a major role in the management of oil in porous environment and pipes, and determines the internal resistance of the liquid flow. Oil viscosity is a function of physical properties of saturated oil-gas as pressure, temperature, the specific gravity of oil, the specific gravity of gas, bubble point pressure:  $\mu_o = f(T, \gamma_o, \gamma_g, R_s)$  [8, 10, 11, 14].

The oil viscosity directly affects to the flow of oil into the bottom of the well during the operation of the oil reservoirs. How much oil viscosity is little, its flow rate increases so much. In atmosphere, the viscosity of gas free oil (dead oil) can range from 0.1 to 1000 cp. The viscosity of the oil in the laying conditions varies depending on the pressure and temperature of the layer and the amount of gas that solved in oil. That's why with the increase of temperature the viscosity of the oil decreases, and when gas solves in oil, the oil viscosity is significantly reduced. Therefore, the viscosity of the oil in the atmosphere and laying conditions is different. In one of Azerbaijan oilfields the oil viscosity is 1,23 cp in layer condition ( $P_1=119$  atm,  $t_1=24^\circ\text{C}$   $\forall Q_1=100$  m<sup>3</sup>/T), but its viscosity in atmosphere

condition is 5. However, experiments show that the oil's viscosity increases poorly with pressure increasing starts from saturation pressure. The smallest value of oil viscosity exists in the saturation pressure when oil and gas create touch surface [14-16].

**Bubble point pressure**  $P_b$  – is the maximum pressure that gas begins to separate from the oil during the isothermal expansion of the oil under the thermodynamic balance condition. Saturation pressure is high when the temperature is high.

**Solution Gas Oil Ratio (GOR)**,  $R_s$  – is the ratio of the volume of measured gas under normal condition (on the surface) to the volume of the remaining oil.

Generally, in the standard PVT analyses increased pressure to cause increase in viscosity when increased pressure is higher than saturation pressure. Ideally, viscosity is defined by laboratory experiments using samples taken from bottom of well at reservoir pressure and temperature conditions. When laboratory information are not satisfactory, engineers use empiric correlations, which usually differ by the complexity and accuracy, according to exist information of crude oil. Correlation means regression equations based on experimental data acquired in laboratory studies. The accuracy of these correlations largely depends on primary data used in the calculations and composition of fluids of various geographic places.

Over the last 70 years, in the prediction of oil viscosity, numerous correlation equations, which characterize these or other oils of the world have been proposed by authors as Beal [1]; Chew and Connally [5]; Vazquez and Beggs [6]; Beggs and Robinson [2]; Khan, et al. [8]; Labedi [3]; Glaso [7]; Kartoatmodjo and Schmidt [4]; Al-Marhoun [11]; Abdulmajeed [17]. The summary of used correlations in this study has been given in appendix-1.

The purpose of the study is to explore the possibility of applying the widely spread correlations in scientific literature in the evaluation of the Azerbaijani oils' viscosity for prediction of viscosity, which is one of the main parameters of PVT properties of reservoir fluid.

## 2. VISCOSITY DATA

Oil samples published in Huseynov, et al. [14] of Azerbaijan Guneshli oil field have been used to conduct experiment (table 1). For Azerbaijan oil, the relative density (specific gravity) of gas has been taken 0.8, the relative density (specific gravity) of oil has been taken 0.8644, API gravity has been taken 32.1974 [14].

Table-1. Data of Guneshli oil field

$R_s$ (SCF/STB)	$T(^{\circ}F)$	$P_b(PSIA)$	$\mu_{ob}(CP)$	$P(MPa)$	$\mu_{od}(CP)$
1100.46	123.710	4312.84	0.570	40	6.6966
954.48	123.843	3826.52	0.630	35	6.6770
816.02	126.801	3372.075	0.717	30	6.2648
756.00	129.576	3178.404	0.762	28	5.9153
640.01	132.024	2774.911	0.869	24	5.6333
582.01	134.386	2572.685	0.932	22	5.3820
525.97	136.639	2372.122	1.004	20	5.1594
470.00	138.767	2166.011	1.084	18	4.9632
361.02	140.644	1740.236	1.277	14	4.8003
308.02	142.464	1527.347	1.391	12	4.6510
255.01	144.102	1306.496	1.520	10	4.5232
203.98	145.540	1085.236	1.663	8	4.4159
154.01	146.709	858.242	1.820	6	4.3318
104.99	149.884	649.931	1.990	4	4.1168
55.02	150.467	362.969	2.174	2	4.0793

Source: Huseynov, et al. [14]

For Azerbaijan oil, the relative density (specific gravity) of gas has been taken 0.8, the relative density (specific gravity) of oil has been taken 0.8644, API gravity has been taken 32.1974 [14].

Beggs-Robinson, Labedi, modified Kartoatmodjo, Al-Khafiji and Elsharkawy-Alikhan correlations have been used which are come across mainly in the literature, for calculating oil viscosity [2-4, 9, 10].

Experiments were conducted using Python programming language (jupyter notebook) on Linux OS (Ubuntu Desktop 16.04) with 1.7GB RAM, Intel(R) Core(TM) i5-2400, 64bit processor, 3.10GHz CPU properties. And Matlab are used for visualize of results.

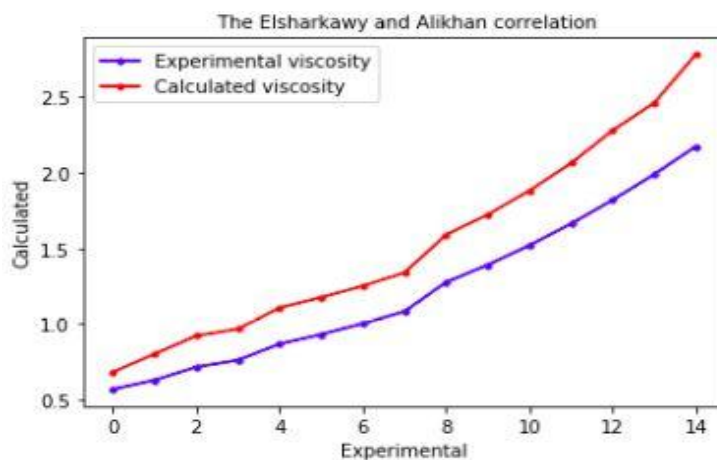
### 3. RESULTS AND DISCUSSIONS

The viscosity of crude oil has been calculated by Beggs-Robinson, modified Kartoatmodjo, Labedi, Elsharkawy-Alikhan and Al-Khafiji correlations. The comparison of calculated results to viscosity of oil samples taken from Guneshli oil field has been shown in Table 2. One sample of pseudo code of program is presented in appendix 2.

**Table-2.** The calculated values of viscosity with Beggs-Robinson, Modified Kartoatmodjo, Labedi, Elsharkawy-Alikhan and Al-Khafiji

Oils samples	Experimental correlation	Calculated correlations				
		Beggs-Robinson	Labedi	Modified Kartoatmodjo	Elsharkawy - Alikhan	Al-Khafaji
1	0.570	0.7039	1.5402	0.7252	0.6836	0.8764
2	0.630	0.7819	1.6177	0.8359	0.8034	1.0049
3	0.717	0.8498	1.6385	0.9558	0.9224	1.1225
4	0.762	0.8714	1.6193	1.0065	0.9678	1.1621
5	0.869	0.9563	1.6625	1.1657	1.1083	1.3043
6	0.932	0.9964	1.6672	1.2500	1.1769	1.3706
7	1.004	1.0429	1.6795	1.3449	1.2522	1.4450
8	1.084	1.1002	1.7027	1.4568	1.3396	1.5335
9	1.277	1.2836	1.8294	1.7750	1.5909	1.8026
10	1.391	1.3910	1.8949	1.9501	1.7234	1.9476
11	1.520	1.5319	1.9892	2.1588	1.8816	2.1270
12	1.663	1.7138	2.1197	2.3978	2.0632	2.3422
13	1.820	1.9635	2.3137	2.6798	2.2794	2.6116
14	1.990	2.2553	2.5205	2.9252	2.4620	2.8596
15	2.174	2.8277	3.2115	3.3294	2.7818	3.2632

Saturated oil viscosity is predicted by Beggs-Robinson, Modified Kartoatmodjo, Labedi, Elsharkawy-Alikhan and Al-Khafiji correlations. The accuracy has been checked with experimental data for calculation of saturated oil viscosity.



**Figure-1.** The comparison of experimental viscosity with calculated viscosity by Elsharkawy and Alikhan correlation.

Labedi correlation [3] has been applied to calculate oil viscosities of obtained Azerbaijan oil samples. The comparison of calculated values with predicted values has been shown in figure 2. In this correlation model, AAD is 73.4591%, is 91.4944%, MAE is 70.6893%, RMSE is 73.4825%.

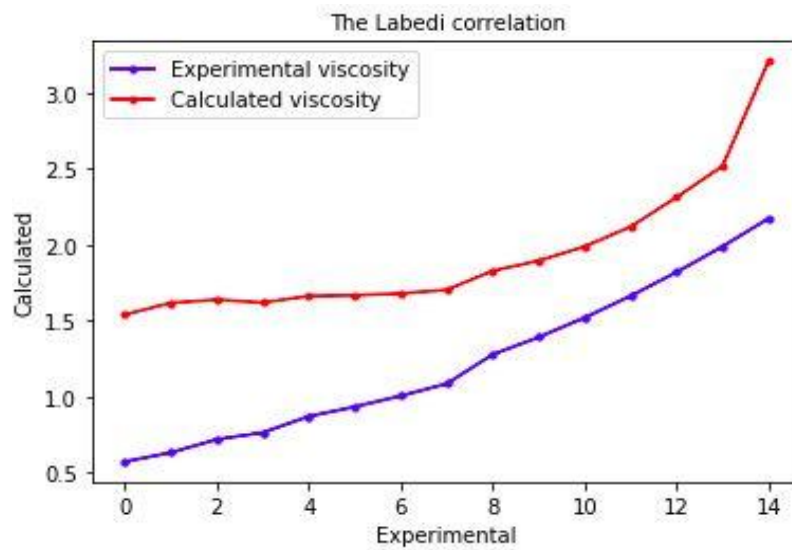


Figure-2. The comparison of experimental viscosity with calculated viscosity by Labedi correlation

The modified Kartoatmodjo correlation [4] is has been checked over Azerbaijan crude oil samples, and obtained result has been presented graphically in figure 3. AAD is 38.3125%, is 99.8744%, MAE is 50.3589%, RMSE is 58.2237%.

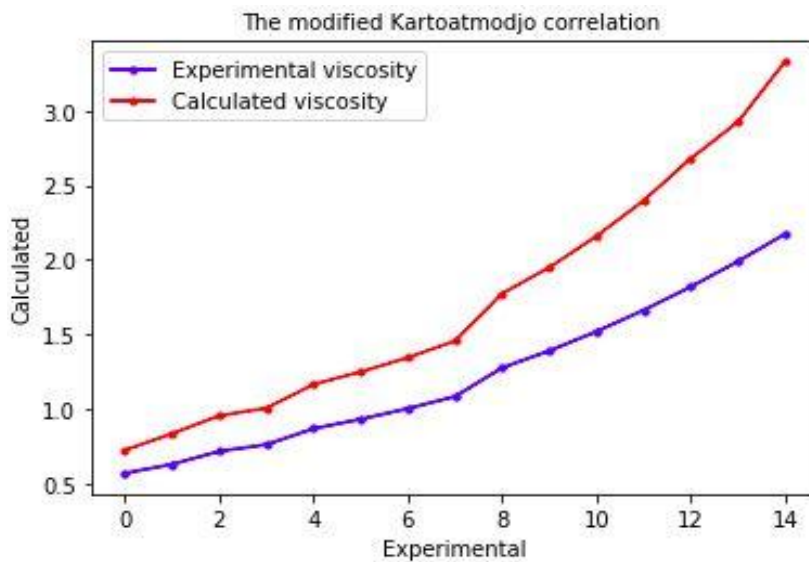


Figure-3. The comparison of experimental viscosity with calculated viscosity by modified Kartoatmodjo correlation

Beggs-Robinson correlation [2] has been tested with viscosity of oil samples taken from Guneshli oil reservoir and comparative result has been shown in figure 4. For this model, AAD is 10.5614%, is 97.2405%, MAE is 12.4427%, RMSE is 20.0853%.

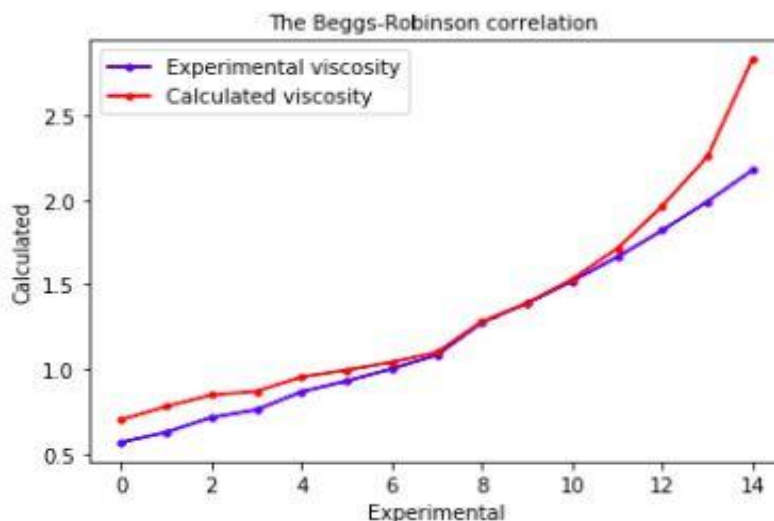


Fig-4. The comparison of experimental viscosity with calculated viscosity by Beggs-Robinson correlation

Al-Khafaji correlation [9] has been applied to calculate viscosity of Azerbaijan oil samples. The comparison predicted value with experimental value has been shown in figure 5. AAD is 46.9403%, is 99.6687%, MAE is 55.7998%, and RMSE is 59.5658%.

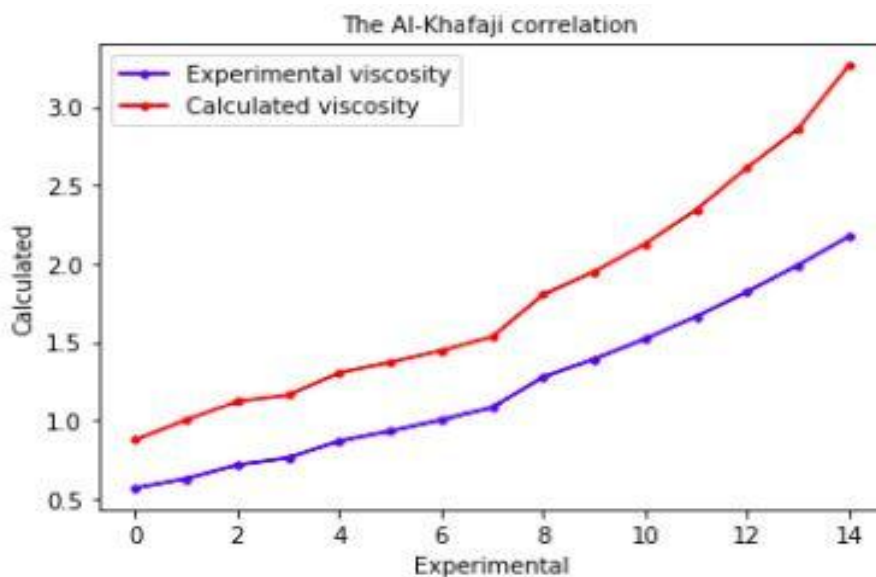


Figure-5. The comparison of experimental viscosity with calculated viscosity by Al-Khafaji correlation

#### 4. STATISTICAL ANALYSIS

The accuracy of applied correlations – expressed by (1)-(5) formulas – has been calculated based on statistical parameters [18, 19] as absolute average deviation, mean absolute error, correlation coefficient.

$$\%AD = \frac{|\mu_{exp} - \mu_{cal}|}{\mu_{exp}} \times 100 \tag{1}$$

$$\%AAD = \frac{1}{n} \sum_{i=1}^n \frac{|\mu_{exp} - \mu_{cal}|}{\mu_{exp}} \times 100 \tag{2}$$

$$\%MAE = \frac{1}{n} \sum_{i=1}^n |\mu_{cal} - \mu_{exp}| \times 100 \tag{3}$$

$$\%R^2 = \frac{n(\mu_{cal}\mu_{exp}) - (\sum \mu_{exp})(\sum \mu_{cal})}{\sqrt{[n\sum \mu_{exp}^2 - (\sum \mu_{exp})^2][n\sum \mu_{cal}^2 - (\sum \mu_{cal})^2]}} \times 100 \tag{4}$$

$$\%RMSE = \sqrt{\frac{\sum_{i=1}^n (\mu_{cal} - \mu_{exp})^2}{n}} \times 100 \tag{5}$$

Where, n is the number of experimental points, is experimental viscosity, is calculated viscosity. AAD% shows how to be near the calculated values are to experimental values.

The results of calculations have been presented in table 3, and graphically in figure 6.

Table-3. The results of statistical analysis

Correlations	Statistical analysis			
	AAD(%)	R <sup>2</sup> (%)	MAE (%)	RMSE (%)
Beggs - Robinson	10.5614	97.2405	12.4427	20.0853
Labedi	73.4591	91.4944	70.6893	73.4825
Modified Kartoatmodjo	38.3125	99.8744	50.3589	58.2237
Elsharkawy - Alikhan	25.2323	99.9272	30.8906	33.4159
Al-Khafaji	46.9403	99.6687	55.7998	59.5658

As seen from Figure 6, the %AAD value is respectively 10.5614, 73.4591, 38.3125, 25.2323, and 46.9403%, and % is 97.2405, 91.4944, 99.8744, 99.9272 and 99.6687 for Beggs-Robinson, Labedi, modified Kartoatmodjo, Elsharkawy-Alikhan and Al-Khafaji corrections.

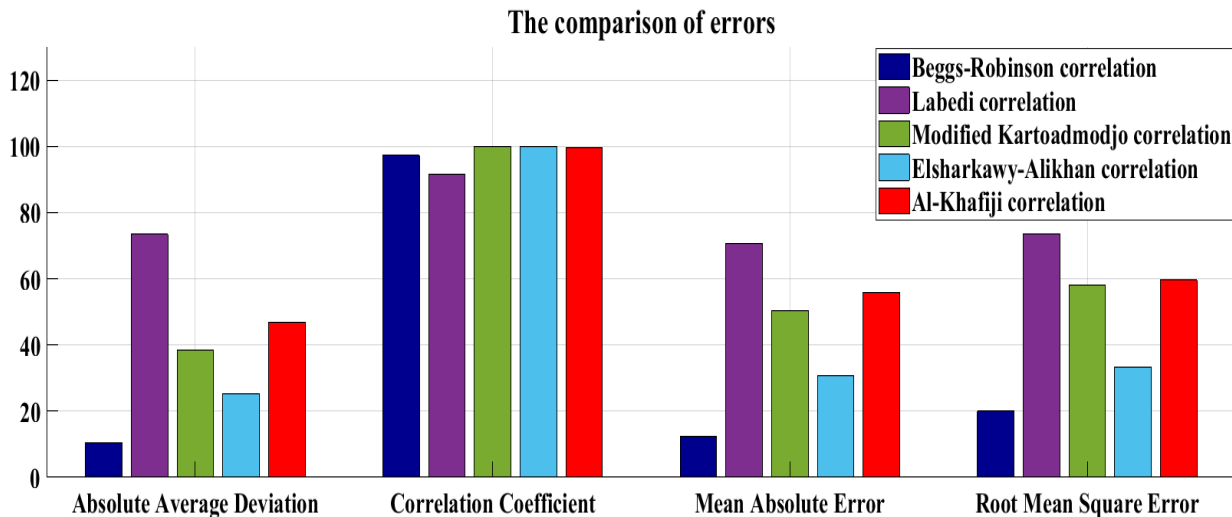


Figure-6. The result of statistical analysis

### 5. CONCLUSION

Five empiric models have been applied to evaluate viscosity of crude oil on the basis of Azerbaijan Guneshli oil field. At the end of the analysis, it was became clear that the Beggs and Robinson model had the lowest %AAD (10.5614%) value and the Labedi model had the highest %AAD value (73.4591 %) for Azerbaijani oil compared to other correlation models. Elsharkawy-Alikhan model have showed the highest result for correlation coefficient (99.9272%). According to the results of statistical analysis, we can say that Beggs-Robinson model compared to other used correlation models can be considered more acceptable in the evaluation of viscosity of Azerbaijan crude oil. Experiments show that, in the prediction of viscosity, partial compline is observed to offer traditional empiric

correlations according to different regions for oil which differ sharply each other by PVT properties between predicted and experimental values. That's why none of these correlations can be considered universal correlation. More compatible empiric correlations must be applied to calculate and to predict accurately viscosity of Azerbaijan crude oil. In future studies, it is planned to develop more accurate correlation models for the evaluation of the viscosity of Azerbaijan crude oil. The development of model based on machine learning methods is also intended to evaluate more accurately viscosity.

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**Contributors/Acknowledgement:** All authors contributed equally to the conception and design of the study.

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**Appendix-1.** Summary of used viscosity correlation

$$API = \frac{141.5}{\gamma_o} - 131.5$$

**Beggs – Robinson correlation [2]:**

$$\mu_{cal} = a \times \mu_{od}^b$$

where

$$\mu_{od} = 10^x - 1$$

$$x = T^{-1.163} \times (10^{3.0324 - 0.02023 \times API})$$

$$a = 10.715(R_s + 100)^{-0.515}$$

$$b = 5.44(R_s + 150)^{-0.338}$$

**Labedi correlation [3]:**

$$\mu_{cal} = (10^{2.344 - 0.03542 \times API}) \times \frac{\mu_{od}^{0.6447}}{P_b^{0.426}}$$

**Modified Kartoatmodjo correlation [4]:**

$$\mu_{cal} = 0.0132 + 0.9821 * F - 0.005215 * F^2$$

where

$$F = (0.2038 + 0.8591 * 10^{(-0.000845 * R_s)}) * \mu_{od}^{0.385 + 0.5664 * y}$$

$$y = 10^{(-0.0008 * R_s)}$$

**Elsharkawy – Alikhan correlation [10]:**

$$\mu_{cal} = a \times \mu_{od}^b$$

where

$$a = 1241.932(R_s + 641.026)^{-1.12410}$$

$$b = 1768.841(R_s + 1180.335)^{-1.06622}$$

**Al-Khafaji correlation [9]:**

$$\mu_{cal} = a \times \mu_{od}^b$$



where

$$a = 0.247 + 0.2824X + 0.5657X^2 - 0.4065X^3 + 0.0631X^4$$

$$b = 0.894 + 0.0546X + 0.07667X^2 - 0.0736X^3 + 0.01008X^4$$

$$X = \log R_s$$

#### Appendix-2. Pseudo code of the Beggs-Robinson correlation

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
#input data
P=np.array(#value of pressure)
Rs=np.array(#value of solution gas-oil ratio)
exp_vis=np.array(#value of experimental viscosity)
T=np.array(#value of oil reservoir temperature)
Pb=np.array(#value of bubble point pressure)
sg_o=0.8644
sg_g=0.8
API=141.5/sg_o-131.5
x=pow(T,-1.163)*pow(10,(3.0324-0.02023*API))
do_vis=pow(10,x)-1
a=10.715*pow((Rs+100),(-0.515))
b=5.44*pow((Rs+150),(-0.338))
cal_vis=a*pow(do_vis,b)
#visualization
plt.plot(exp_vis,color='blue',marker=".")
plt.plot(cal_vis,color='red',marker=".")
plt.legend(('Experimental viscosity', 'Calculated viscosity'), loc='upper left')
plt.xlabel('Experimental')
plt.ylabel('Calculated')
plt.title('The Beggs-Robinson correlation ')
plt.show()
```

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