INTRODUCTION

In order to reproduce the behavior of different blends using a black oil model, the model requires tuning factors for its correlations to estimate the properties of the blend. These properties include viscosity, bubble pressure and other black oil parameters, like the volume factor. In our study case, this is particularly important since the model should have the capability to reproduce different blend behavior along the different elements of the system, particularly the tubing section.

This report includes the details of the adjustment to the viscosity correlations for the black oil model, using as a reference a set of experimental values of Venezuelan crude oils and diluents. The results are extensible to other crude oils, since it just refers to physical property calculation of fluids.

For the adjustment of viscosity, the strategy was as follows:

- Taking a reference of oil and/or diluent at two experimental or measured points of the pair viscosity-temperature, at standard pressure.
- Using the blending method ASTM D7152-11 (ASTM Standard D7152, 2011)to extend the experimental data to a wider temperature span, up to 5 points within a range of 25 °C.
- Adjusting two parameters in the exponential correlation $A(R_s) \cdot {\mu_{od}}^{B(R_s)}$, where Rs is the gas in oil ratio coefficient, and μ_{od} is the dead-oil viscosity – Beggs and Robinson correlations for both dead and saturated oil.

DOCUMENT OBJECTIVE

Describing the procedure used for tuning viscosity calculation on a black oil model to represent the behavior of a crude mixture resulting from an ASTM D7152-11 blending.

DOCUMENT SCOPE

The report includes the following:

- Description of the black oil correlations for viscosity calculations
- Procedure used for adjusting the black oil correlations to calculate viscosity for oil blending.
- Results from two study cases, using high and low viscosity values.

This report will not intent to validate the accuracy of the ASTM D7152-11 standard as a method for crude oil blending.

PRELIMINARIES

BOObj class includes black oil correlations for oil property calculation. In particular, for viscosity calculation, correlations for both dead and saturated oil are used (Beggs & Robinson, J.R., 1975).

BEGGS AND ROBINSON VISCOSITY CORRELATION

For dead oil, the correlation is as follows:

$$\mu_{od} = 10^{x} - 1 \qquad \text{(eq. 01)}$$

$$x = y \cdot T^{-1{,}163} \qquad \text{(eq. 02)}$$

$$y = 10^{z} \qquad \text{(eq. 03)}$$

$$z = 3{,}3024 - 0{,}02023 \cdot \gamma_{API} \qquad \text{(eq. 04)}$$

where:

μ_{od} dead oil viscosity, for a given T at atmospheric pressure [cP]
γ_{API} oil API gravity [°API]
T temperature [°F]

For saturated oil, they proposed an exponential adjustment using the gas in oil ratio coefficient.

$$\mu_{ob} = A(R_s) \cdot \mu_{od}{}^{B(R_s)} \qquad \text{(eq. 05)}$$

$$A(R_s) = 10{,}715 \cdot (R_s + 100)^{-0{,}515} \qquad \text{(eq. 06)}$$

$$B(R_s) = 5{,}44 \cdot (R_s + 150)^{-0{,}338} \qquad \text{(eq. 07)}$$

where:

R_s gas on oil ratio [scf/stb]

TUNING PROCEDURE

Equations 05, 06 and 07 were developed using 2.073 experimental points, from 600 different samples. However, in order to represent the behavior of a particular sample, the model requires tuning factors for equations 06 and 07.

Considering this fact, equation 05 is changed to the following expression:

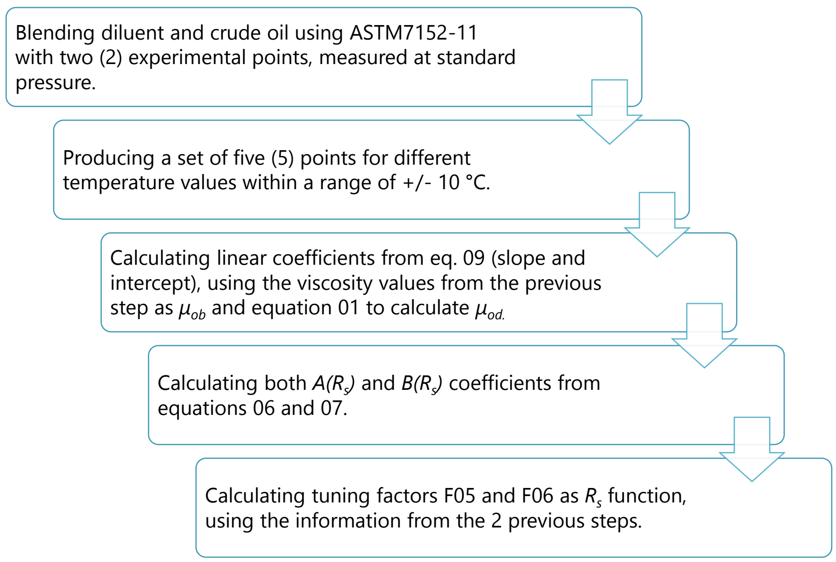
$$\mu_{ob} = A(R_s) \cdot F05(R_s) \cdot \mu_{od}{}^{F06(R_s) \cdot B(R_s)} \qquad \text{(eq. 08)}$$

Equation 08 can be rearranged in its linear form as follows:

$$\ln(\mu_{ob}) = \ln\big(A(R_s)\cdot F05(R_s)\big) + F06(R_s)\cdot B(R_s)\cdot \ln(\mu_{od}) \qquad \text{(eq. 09)}$$

Equation 09 was used for calculating the tuning parameters, following the procedure described in Figure 1.

Figure 1. Procedure for calculating tuning factors



STUDY CASE

The tuning procedure was tested by using data from crude oils and diluents available in Venezuela (INTEVEP, 1998). The sample viscosity values used in the tuning are reported at standard pressure.

Reference samples are listed in Table 1.

Table 1. Reference crude oils

DENOMINATION	°API	T1	V1	T2	V2
Boscan	10,3	38,0	19.800,0	60,0	6.200,0
Pilon 14,5	14,5	37,8	906,0	50,0	329,0
Pilon – Uracoa	13,5	37,8	1.660,0	50,0	631,0
Tia Juana pesado	11,0	60,0	1.215,0	82,2	287,6
Laguna	10,9	60,0	1.425,0	98,8	144,0

NOTE: temperature in C, viscosity in cP.

Table 2. Reference diluents

DENOMINATION	°API	T1	V1	T2	V2
Forties	36,9	21,0	7,7	28,0	3,4
Bass River	42,9	21,0	2,1	38,0	1,5
Iranian Heavy	30,8	38,0	9,8	54,0	7,5
Fosterton	24,2	10,0	139,0	38,0	30,0
Kerosina	40,2	10,0	3,3	40,0	1,8

NOTE: temperature in C, viscosity in cP.

TUNING TEST

In order to validate the procedure, different reference crude oils and diluents were blended at different proportions. For purpose of this report, two different volumetric fraction of the diluent were used: 23,1% and 76,9%. The purpose was to study the behavior of the tuning within a wide of span of diluent injection rate.

SET 1 – HIGH VISCOSITY

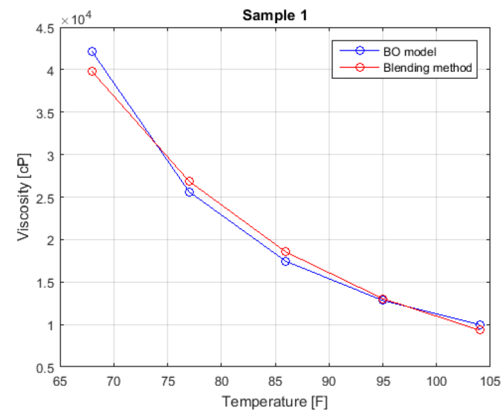
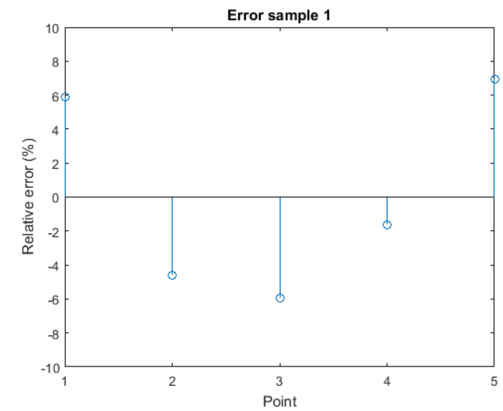
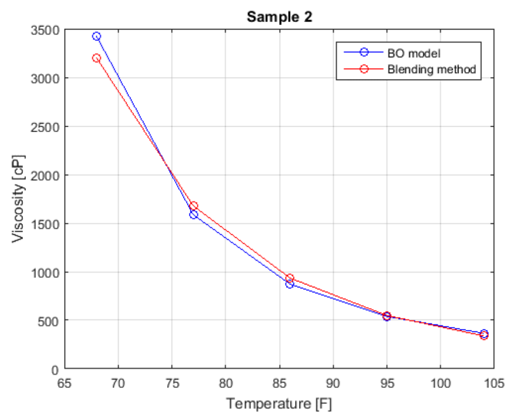
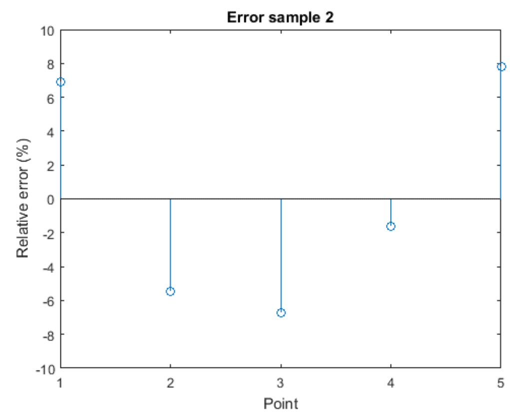
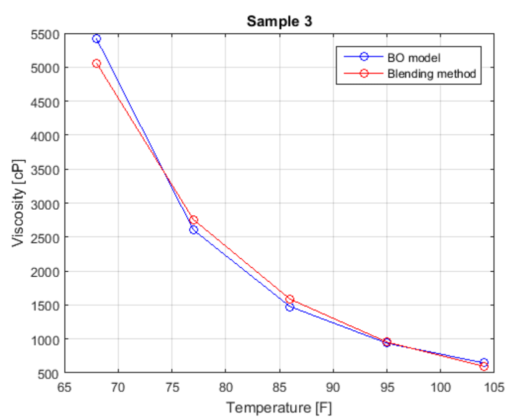
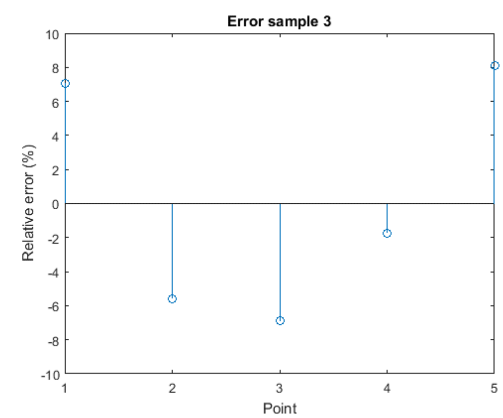
In this first set, the lowest volumetric fraction was used. In this case, the resulting blending had low °API values, which indicates high values of density. Density and viscosity are not directly related, however in Newtonian fluids as crude blending they show a proportional relationship.

Table 3. Blending parameters for the first set.

Sample	Oil	Diluent	°API(*)	% vol
1	Boscan	Forties	15,6	23,1
2	Pilon 14,5	Forties	19,1	23,1
3	Pilon – Uracoa	Forties	18,3	23,1
4	Tia Juana pesado	Forties	16,3	23,1
5	Laguna	Forties	16,2	23,1

(*)°API from blending.

Figure 2. Plotting of first set of data

PLOTTING	RELATIVE ERROR
	
	
	

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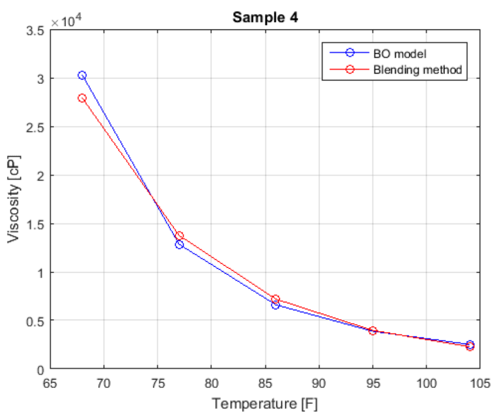
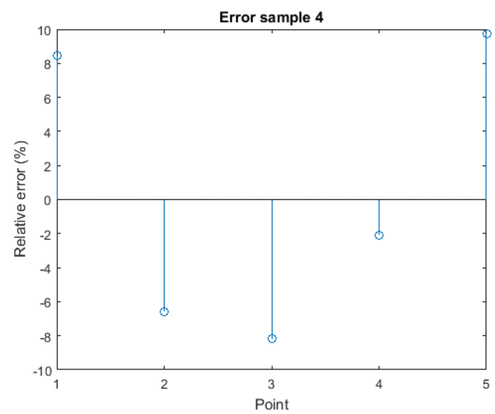
<tr><td>
</td><td>
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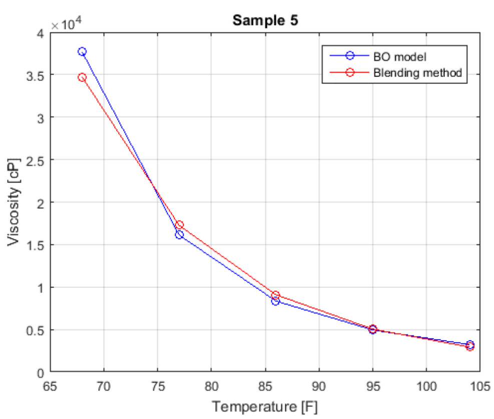
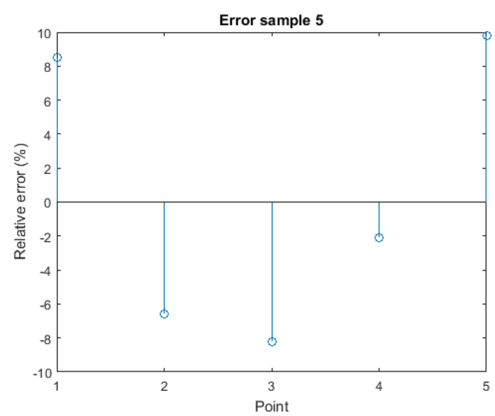
<tr><td>
</td><td>
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The resulting blending in each sample of this set shows a viscosity within the range 450-4.500 cP as depicted in Figure 2. The relative error between the blend extension using the ASTM D7152-11 standard (ASTM Standard D7152, 2011) and the tuned black oil model are given on Table 4.

Table 4. Relative error between BO model and blending method, first set.

Temperature (°F)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
68	5,9%	6,9%	7,1%	8,5%	8,5%
77	-4,6%	-5,5%	-5,6%	-6,6%	-6,6%
86	-5,9%	-6,9%	-6,9%	-8,2%	-8,2%
95	-1,6%	-1,6%	-1,7%	-2,1%	-2,1%
104	6,9%	7,9%	8,1%	9,7%	9,8%

In order to have an idea of the mean error of the tuning, we used a mean relative value defined by using the following equation:

$$\varepsilon_{\%,abs} = \frac{\sum_{i=1}^{n} \left| \frac{\mu_{e,i} - \mu_{c.i}}{\mu_{e,i}} \right| \cdot 100\%}{n} \quad \text{(eq. 10)}$$

For this set, this mean relative error was 6,1%.

SET 2 – LOW VISCOSITY

For this set, the viscous oil was fixed and the diluent oil was changed using the different types available. The purpose was to create a low viscosity set of data.

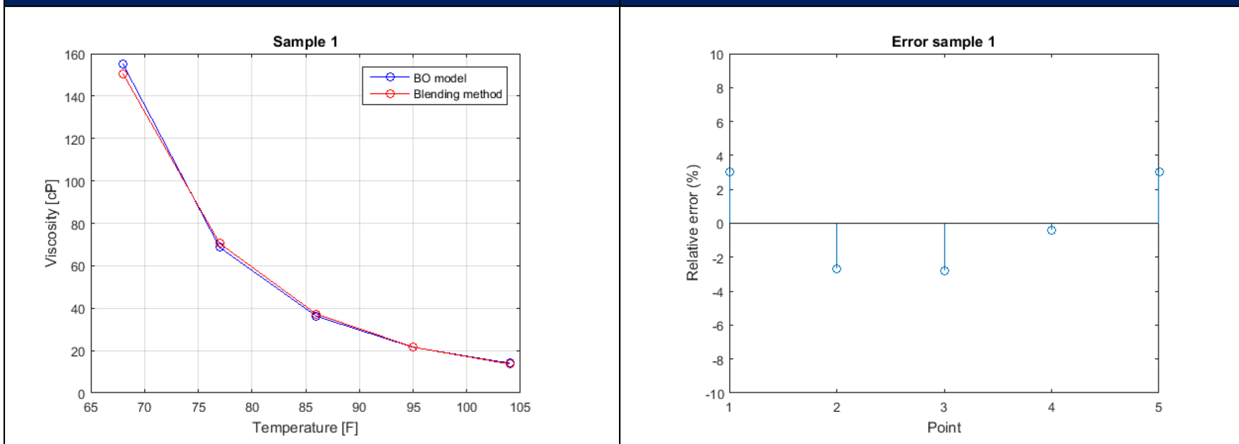
Table 5. Blending parameters for the second set.

Sample	Oil	Diluent	°API(*)	% vol
1	Pilon 14,5	Forties	31,2	76,9
2	Pilon 14,5	Bass River	35,5	76,9
3	Pilon 14,5	Iranian Heavy	26,7	76,9
4	Pilon 14,5	Fosterton	21,8	76,9
5	Pilon 14,5	Kerosina	33,5	76,9

(*) Blending °API.

Figure 3. Plotting of second set of data.

PLOTTING	RELATIVE ERROR



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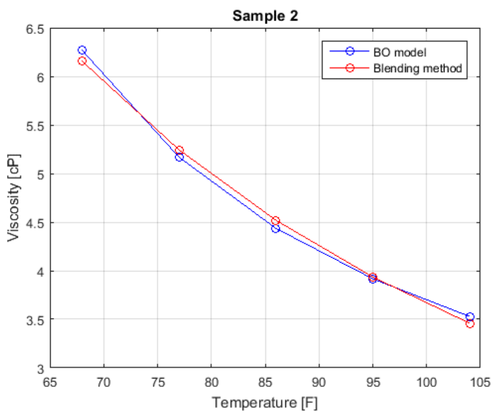	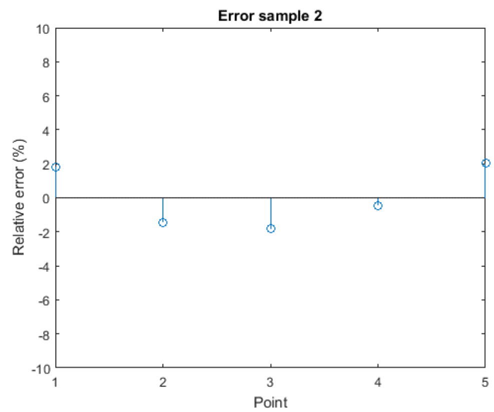
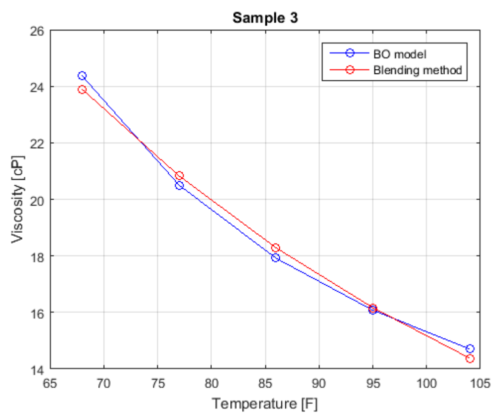	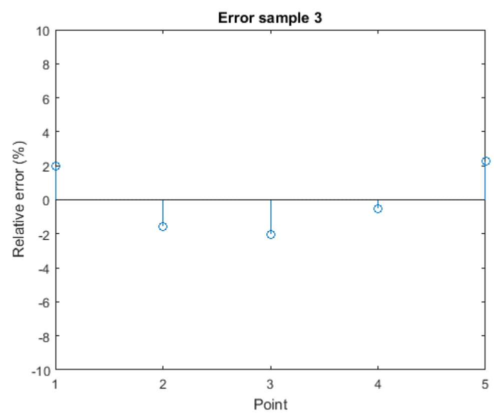
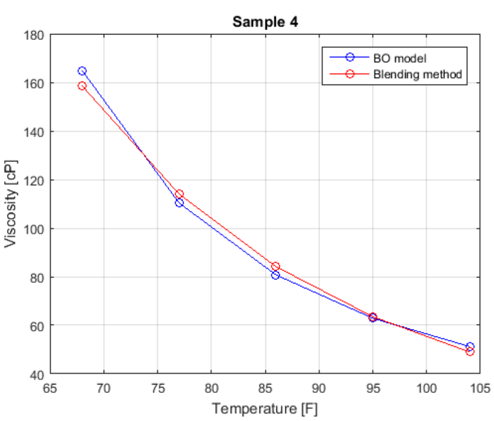	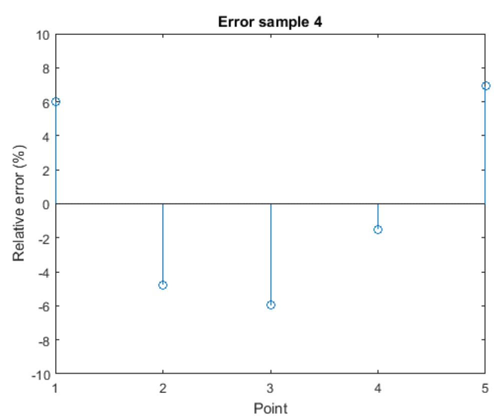

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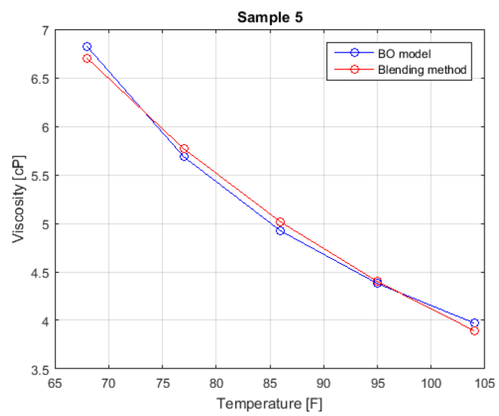	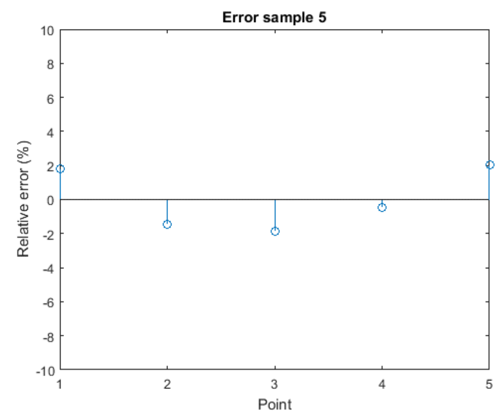

The resulting blending in each sample of this set shows a viscosity within the range 3,5-160,0 cP as depicted in Figure 3. The relative error between the blend extension using the ASTM D7152-11 standard and the tuned black oil model are given on Table 6.

Table 6. Relative error between BO model and blending method, second set.

Temperature (°F)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
68	3,0%	1,8%	1,9%	4,0%	1,8%
77	-2,7%	-1,4%	-1,6%	-3,2%	-1,4%
86	-2,8%	-1,8%	-2,0%	-4,0%	-1,8%
95	-0,4%	-0,5%	-0,5%	-1,0%	-0,5%
104	3,0%	2,0%	2,2%	4,6%	2,0%

For this set, the mean relative error defined by eq. 10 was 2,1%. The error in this set is 3 times lower than for the high viscosity set.

REMARKS

- In all adjustments, the extrema points always provide a positive deviation, an overestimation, in respect to the ASTM D7152-11 predicted values. On the other hand, the middle values the model provide a negative deviation, a sub estimation, in respect to this set.
- In respect to the first set of data, the difference between the diluent and crude oil viscosity values is between two and four magnitude orders. In terms of error between the black oil

fitting and the prediction given by the blending procedure ASTM D7152-11, the mean relative error was 6,1%.

- For the second set of data, the maximum difference between the diluent and crude oil viscosity values is two magnitude orders. The mean relative error between the black oil fitting and the prediction given by the blending procedure ASTM D7152-11 was 2,1%.
- According to this calculation, the tuned black oil model would perform similarly as the ASTM D7152-11 blending method. Furthermore, the lower the difference between the diluent and crude oil viscosity, the better the performance of the tuned black oil viscosity calculation.

REFERENCES

ASTM Standard D7152. (2011). Standard Practice for Calculating Viscosity of a Blend of Petroleum Products. West Conshohocken, PA: ASTM International. doi:10.1520/D7152-11

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