Predicting Model of Density for Crude Oil Blends at (Al-Wafa& Al-Feal)Field of Mellita Compound-Libya

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■ **Abstract:**

Density is considerable importance trait for evaluating transfer and treatment properties in crude oils processing. Information about density plays a very important role to a solve engineering problems concern fluid flow phenomena and momentum transfer. In the current study, Five were prepared with different sample crude oils blends from a very light crude oil Al-Wafa (W) and a light crude oil Al-Feal (F) as follows: Blend1 (20%W , 80% F); Blend2 (35%W , 65%F) ; Blend3 (55%W, 45% F); Blend4 (70% W, 30% F) and Blend5 (85%W, 15% F) at different temperatures (20, 25, and30°C) to obtain the experimental density; to develop the reliable mathematical expression for the most important physical properties using non-linear regression and to analyze the predictive model results using standard statistical techniques. The predicted density results have been validated with the experimental density data gathered in the laboratory. High precision results between the predicted and experimental values have been noticed with overall average absolute deviation (AAD %) of 0.48%. From the predicted results in this study , it can be concluded that the performance of the developed model are excellent.

● **Key-words:** ρ density, W very light crude oil, F light crude oil, (a, b) coefficients the developed model,(x) percentage of blends , AAD Absolute Average Deviations.

■ المستخلص:

تعتبر الكثافة خاصية ذات أهمية كبيرة لتقييم الخصائص الانتقالية في عمليات نقل و معالجة النفط الخام . ومعرفة المعلومات حول الكثافة تلعب دورا مهماً جداً في حل المشاكل

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الهندسية المتعلقة بتدفق السوائل وانتقال الزخم . وفي الدراسة الحالية ، تم تحضير خمسة عينات مختلفة الزيت الخام الممزوجة من زيت خام الوفاء الخفيف جداً (W) و زيت خام الفيل الخفيف (F) وكانت على النحو التالي -:خليط 1 ; (20 ٪W, 80 ٪F) خليط 2 (35 ٪ F 65٪ , W) ; خليط 3 (55 ٪ ,F 45 ٪ W) ; خليط 4 (70 ٪ , 30٪W F) ; خليط 5 (85 ٪,F 15 ٪ W) عند درجة حرارة (25 ,30 20°C) للحصول على الكثافة التجريبية ؛ ومن تم تطوير صيغة رياضية يمكن الاعتماد عليها للتنبؤ بالخصائص الفيزيائية وذلك باستخدام طرق الانحدار غير الخطية ، وتحليل نتائج النموذج المتحصل عليها باستخدام الطرق الإحصائية القياسية. وقد تم التحقق من صحة النتائج المتوقعة لقيم الكثافة بمقارنتها مع البيانات التجريبية التي تم قياسها في المختبر . ولوحظت نتائج عالية الدقة بين القيم المتوقعة والتجريبية بمتوسط الانحراف المطلق الكلي (٪ AAD) حوالي (0.48٪). ومن النتائج المتوقعة في هذه الدراسة، يمكن الاستنتاج أن أداء النموذج المطور كان ممتازًا.

● **الكلمات المفتاحية :** ρالكثافة، W النفط الخام الخفيف جدا، Fالنفط الخام الخفيف، (a ،b) معاملات النموذج المطور، (x) النسبة المئوية للخليط، AADمتوسط الانحرافات المطلقة.

1. Introduction

1.1-Density of Crude Oils

Density is the property of a fluid that causes it to resist flow. The importance of density as an input in the design of equipment processing and handling petroleum crude oils and their fractions and in solving the associated fluid flow and momentum transfer problems needs no fresh emphasis. Density is the most significant property for establishing the thickness , pressure and temperature of an oil film in lubrication , Density is also significant factor in predicting the performance and fatigue life of rolling element bearings and gears . Density is important in equations for calculating many properties such as density of oil film , shear stress, fluid friction forces [1]

The density is useful property in petroleum production, refining, and transportation. It is used in reservoir simulators to estimate the rate of oil or gas flow and their production. It is needed in calculation of power required in mixers or to transfer a fluid, the amount of pressure drop in a pipe or column, flow measurement devices, and design and operation of oil/water separators.

Oil density is a crucial property not only in crude oil but in all fluids. For instance, as the density of a crude oil increases, the fluid becomes thicker. This leads to an increase in the amount of time it takes for particles to settle out of suspension.

The density is also known as the specific mass, is its mass per unit volume. Mathematically, density is defined as mass divided by volume.

The formula for density is ***ρ= M/V***, where ***ρ*** is density, ***M*** is mass, and ***V*** is volume.

Density offers a convenient means of obtaining the mass of a body from its volume or vice versa; the mass is equal to the volume multiplied by the density **(*M = V ρ*) ,** while the volume is equal to the mass divided by the density **(*V = M/ρ*).** The weight of a body. [2]

1.2-Measuring Density of Crude Oil:

Density plays a critical role in how crude oil and how machines perform. Most systems are designed to pump a fluid of a specific density, so as the density begins to change, the pump's efficiency begins to change as well.

The density of most oils will range between 700 and 950 (kg/m3). In oils, it is usually indicated in the temperature of +15°C or +20°C, in units kg/m3. Water has a density of 1,000 kg/m3. This means that most oils will float on water as they are lighter by volume. This is not always the case, as some Group IV base oils can have a higher density than water, effectively causing the oil to sink in the water. [3]

1.3-Density Temperature Relation

Density depends on temperature, even though the dependency is relatively small compared to crude oil viscosity . Here is an empirical formula that can be used to calculate the change of density with temperature:

$$\rho = \rho_{T1} + \alpha_p (T1 - T)$$

Where:

$\alpha_P = 0.65$ for

$380\ Kg/m^3 < \rho < 950\ Kg/m^3$

and

$\alpha_P = 0.60$ for

$950\ Kg/m^3 < \rho < 1000\ Kg/m^3$

As it can be seen, this empirical relation applies only for the oils having the densities in a specified range, however, this range covers most commonly used crude oils (860-980) Kg/m³. [4]

1.4-

Density Pressure Relation.

When the crude oil is compressed, density of the oil increases. This increase starts to be noticeable at relatively high pressures (>0.1GPa), which is however quite common for .The most widely used formulate to describe the change of oil density with pressure is known as Dowson an Higginson density equation: [5]

$$\rho=\rho o\frac{0.59\times10^{9}+1.34p}{0.59\times10^{9}+p}$$

1.5-Density Test Standard

ASTM D5002-19: Standard Test Method for Density, Relative Density, and API Gravity Of Crude Oils By Digital Density Analyses. This test method covers the determination of the density, relative density, and API gravity of crude oils that may be handled generally as liquids at test temperatures between 15 °C and 35 °C utilizing either manual or automated sample injection equipment. This test method applies to crude oils with high vapor pressures, provided appropriate precautions are taken to prevent vapor loss during the transfer of the sample to the density analyses.

This test method was evaluated in inter laboratory study testing using crude oils in the range of 0.75 g/cm^3 to 0.95 g/cm^3. Lighter crude oil may require special handling to prevent vapor losses.

ASTM D1298-12: Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method. This test method covers the laboratory determination using a glass hydrometer in conjunction with a series of calculations of the density, relative density, or API gravity of crude petroleum, petroleum products, or mixtures of oil. [6].

1.6- Classifications or Grades

Crude oil is classified as light, medium, or heavy according to its measured density as shown in Table (1).

Table 1-Type of crude oil

Type of crude oil	Densité (kg/m^3)
Light crude oil	< 830
Medium oil	830 – 950
Heavy crude oil	950 – 1000
Extra heavy oil	> 1000

1.7-Mellita Compound

The company of Mellta for oil and is one of the largest oil companies in Libya . It is daily production nearly (600,000) barrels (crude oil , natural gas , condensate gas for propane , Butane and naphtha) .

The company runs a number offshore and onshore oil fields located in different regions of Libya . The most important onshore field operated by . the company is AL-Wafa field and AL-Feal field ,who are heading to array crude oil to Mellitah oil compound . the crude oil AL-Wafa is very low densities while the crude oil AL-Fealis low densities , therefore their crude oil is mixed in the compound to obtain medium density.

1.8- Objectives of the Study

The present study is concerned with the measuring and predicting of the densities of crude oils, where published data are relatively scarce. The objectives can be highlighted as follows:

- To obtain the experimental density data of crude oils and their blends at different temperatures.
- To develop the reliable mathematical expression for the most important physical properties using non-linear regression technique.
- To analyze the predictive model results using standard statistical techniques.

1.9-Benefits

- Experimental correlations to determine the physical properties of crude oil blends would be positive in both cost and time.
- To determine the density of crude oils using very accurate models.

2.Experimental Procedures

Materials and Preparation Predation Data Samples

Two types of crude oils provided by Libyan oil companies were used. denoted as very light crude oil (**W**)at **Al-Wafa** oil field and light crude oil **(F**) at **Al-Feal** oil field. From the base crude oils, Five binary mixtures were prepared with different sample compositions as shown in Figure (1). These are named as follows **:**

Blend 1 (20% W , 80%F)

Blend 2 (35% W , 65%F)

Blend 3 (55% W , 45%F)

Blend 4 (70% W , 30%F)

Blend 5 (85% W , 15%F)

Figure 1. Different samples preparation

The density of crude oils pure and crude oils blends were measured. The experiments were carried at atmospheric presume and temperature ranges(20,25,30^{o}C), the results will be presented in the next section .

The apparatus used in the experiments was **hydrometer**as shown in Figure (2). Density of the samples (Blends) were determined according to ASTM D1298-12.It can be noticed that all apparatus used in this work existed in Mellita Industrial Compound and the experimental work was carried out in their labs[6].

Figure 2. Hydrometer of density.

3.Experimental Result and Developed Model

Density Experimental.

The densities of pure and crude oils blends were measured at various temperatures (20, 25 and 30°C) as shown in Table (2).

Table 2. Experimental density (g/cm³) of pure crude oils and investigated blends at various temperatures (°C)

Type of Blend	Percent of blends		Density(g/cm3)		
	(W)%	(F)%	20 °C	25°C	30 °C
Pure (W)	0	100	0.7623	0.7612	0.7603
Blend 1	20	80	0.7704	0.7682	0.7663

Blend 2	**35**	**65**	**0.7787**	**0.7752**	**0.7725**
Blend 3	**55**	**45**	**0.7948**	**0.7890**	**0.7849**
Blend 4	**70**	**30**	**0.8090**	**0.8023**	**0.7964**
Blend 5	**85**	**15**	**0.8240**	**0.8172**	**0.8102**
Pure (F)	**100**	**0**	**0.8476**	**0.8378**	**0.8267**

Predicted of Density by New Developed Model.

The crude oil is highly refined oil that consists of paraffinic and naphthenic hydrocarbons. In the more conventional oil reservoirs, It have complex mixture whose physical and chemical properties vary considerably with their composition. The present model has been extended by comparing the predicted values of the density for some crude oils considered with the experimental data obtained in the laboratory at different temperature.[7]

In this work, nonlinear regression technique is used to determine the developed model parameters (**a** and **b**) for some oil blends considered. The general form of the density model in terms of composition (x) and temperature (T) can be expressed as:

$$\rho = a\, e^{bx} \qquad (1)$$

Where

ρ: density

a ,b : coefficients which will be determined by the regression technique

x : one of the blend component fraction and value as (w) fraction, x=f (w) It may be noted that (**a**) is only a function of temperature (T)and can be expressed as :

$$a = a'' \, T^{b''} \qquad (2)$$

where **a”** and **b”** are constant which will be determined

From Table (2) can be drawn in terms of a graph Figure. (3) showing relationship between density at different temperatures and percentage of blends by using the Excel software and Nonlinear Regression Technique.

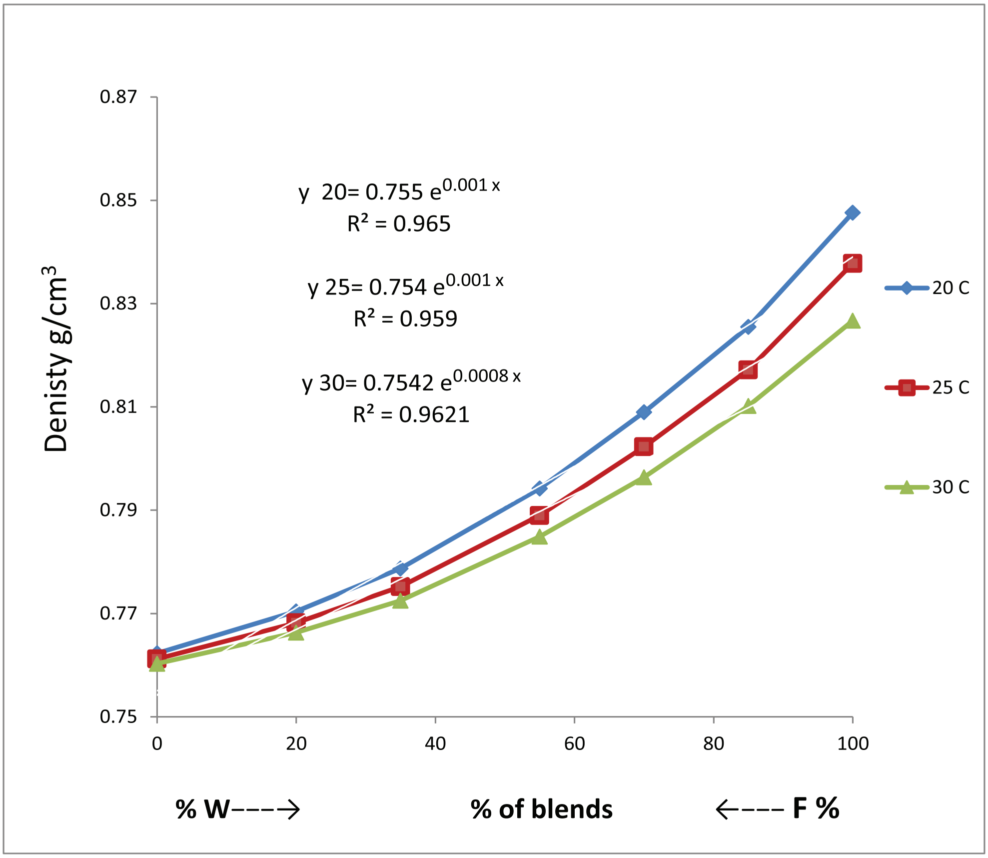

Figure 3.Density at different temperatures vs percentage of blends.

Figure (3)shows the best three curves (nonlinear) at different temperatures according to Equation (1). The parameters of (**a** and **b**) determined and presented in Table (3).

Table 2.(a and b) parameters at different temperatures

T	a	b
20	**0.7550**	**0.001**
25	**0.7540**	**0.001**
30	**0.7542**	**0.0008**

From the Table (3)It can draw the relationship between the(a) parameter and (T) temperature as shown in Figure (4).

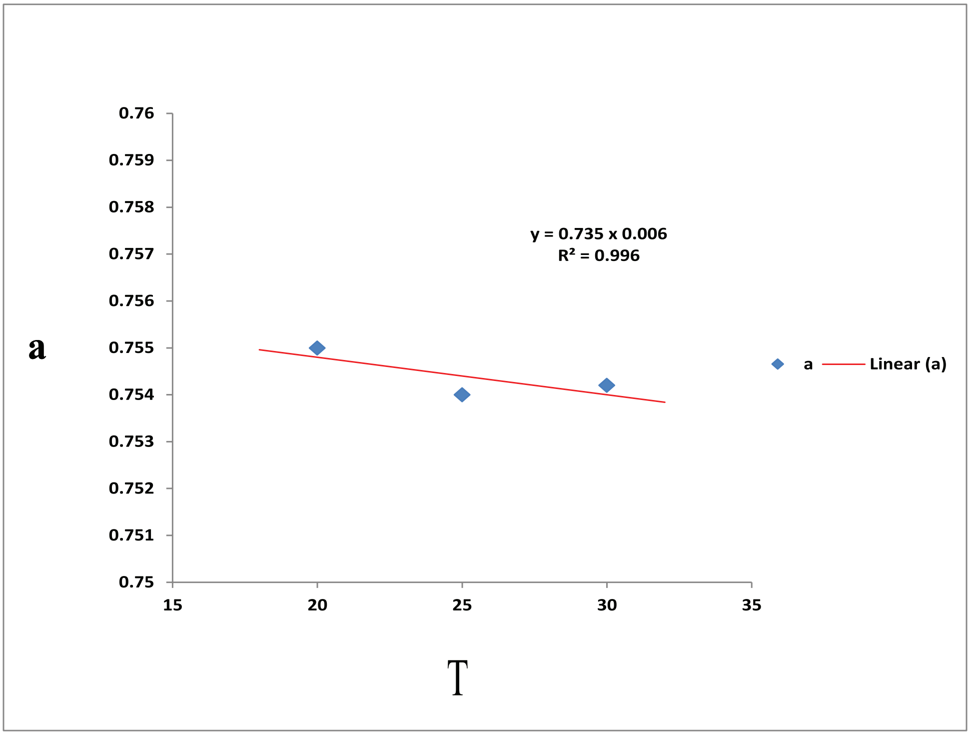

Figure 4. (a) parameter vs (T) temperature.

Figure(4) , shown the linear relationship between parameter (a) and temperature (T).From this relationship it can determine (**a" and b"**) parameters , these values are constant for all blends at different temperatures .

(a" = 0.735) , (b"= 0.006)

Equation (2) can be rewritten as:

$$\mathbf{a = 0.735\ T^{(0.006)}} \qquad (3)$$

By substituting the value of **(a**) in the Equation(1) when can be expressed in terms of composition as general rule for any blend:

$$\rho = \mathbf{0.735\ T^{(0.006)}\ e^{bx}} \qquad (4)$$

From this equation the density can be calculated for different blends at different temperatures. It can be noticed that the constant (b) is ranged as :(**0.001**,**0.001** and**0.0008)** for temperatures(20,25 and 30) receptivity.[8]

Table 3. Calculated density(g/cm3) of blends at various temperatures.

Type of Blend	Density(g/cm3)		
	20 °C	25°C	30 °C
Blend 1	0.7634	0.7645	0.7623
Blend 2	0.7750	0.7760	0.7715
Blend 3	0.7906	0.7917	0.7839
Blend 4	0.8026	0.8037	0.7934
Blend 5	0.8147	0.8158	0.8029

4. Discussion of Results

Statistical Error Analysis

The accuracy of correlations relative to the observed values (experimental values) is determined by using various statistical means. The following criteria are used in this study:

% Average Deviations (% AD)

It is defined as describe by (Riazi, 2005; Nhaesi and Asfour, , 2000):

$$\% \text{ AD} = \frac{|\rho^{\exp} - \rho^{cal}|}{\rho^{\exp}} \times 100 \qquad (5)$$

Where: $\rho^{\exp}$ and ρ^{cal} represented the experimental and calculated density values respectively. The % AD indicates how close the calculated values are to experimental values.

% Absolute Average Deviations (% AAD)

The experimental data obtained in this study Table (1) have been used to subject various models for predicting the density of crude oil blends. The percentage absolute an average deviation (% AAD) described by (Riazi, 2005; Nhaesi and Asfour, 2000) is applied and can be defined as:

$$\% AAD = \frac{1}{n} \sum_{i=1}^{n} \frac{\rho^{\exp} - \rho^{cal}}{\rho^{\exp}} \times 100 \qquad (6)$$

Where: n is the total number of data points and ρ^{exp} and ρ^{cal} representing the experimental and calculated density values, respectively.

Graphical Error Analysis

Graphical means help in visualizing the accuracy of a correlation between the experimental and calculated density values. This relationship are drawn by a cross plot type.

Cross Plot Type

In this technique, all estimated values are plotted against the observed values and thus a cross plot is formed. A 45° straight line $\rho^{exp} = \rho^{cal}$, is drawn on the cross plot which indicate the perfect data points to this line, good results gat when both of the density are very close. (Riazi, 2005; Nhaesi and Asfour, , 2000)[9] , [10]

Application of the Developed Model for Prediction Density of Crude Oil Blends

The experimental and the predicted density data of the investigated crude oils are listed in Tables (2) and (4), respectively. Then, It can make a comparison between both results can be observed .

Table 5. AAD% Of developed model:

.Blend NO	(T (°C	(ϱ(Calc	(ϱ(Exp	% AD	% AAD
Blend 1	20	0.7634	0.7704	0.9024	0.64
	25	0.7645	0.7682	0.4855	
	30	0.7623	0.7663	0.5282	
Blend 2	20	0.7750	0.7787	0.4770	0.24
	25	0.7760	0.7752	0.1063	
	30	0.7715	0.7725	0.1353	

.Blend NO	(T (°C	(ϱ(Calc	(ϱ(Exp	% AD	% AAD
Blend 3	02	0.7906	0.7948	0.5232	0.33
	25	0.7917	0.7890	0.3423	
	30	0.7839	0.7849	0.1278	
Blend 4	20	0.8026	0.809	0.7922	0.45
	25	0.8037	0.8023	0.1703	
	30	0.7934	0.7964	0.3817	
Blend 5	20	0.8147	0.824	1.1262	0.73
	25	0.8158	0.8172	0.1699	
	30	0.8029	0.8102	0.8963	

Over all AAD % = 0.48 %

The developed model was given an overall average absolute deviation of0.48% between experimental and predicted data. From the previous results ,it can be concluded that the model equation can predict accuracy values as good as those from experimental measurements

Comparison of Experimental and Calculated from Developed Model

The accuracy and ability of present model for predicting density of crude oil was checked with experimental data. Figure (5) depicts the comparison of experimental values of density for different blends at temperature (20 , 25 and 30°C). It was noticed from Figure (5) that the model provides a good result with experimental data , using this method the overall average absolute deviation (AAD %) between experimental and predicted data was 0.48 % .

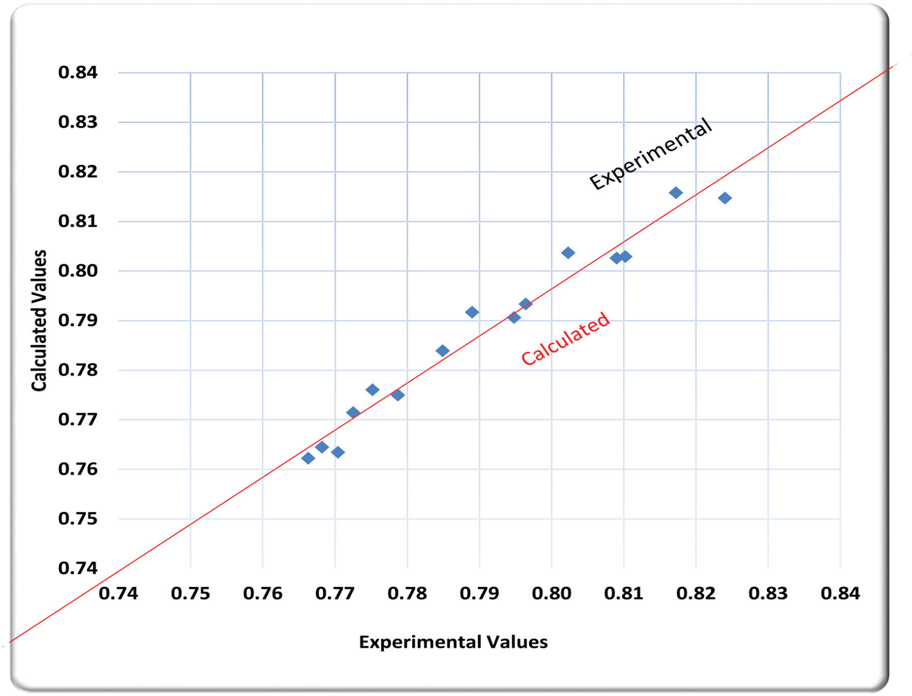

Figure5. Compared of experimental values with calculated values from developed model .

Results of AD% For Each ail Blend at Different Temperatures

Absolute Deviation percentage (AD %) was calculated for each blend at different temperature. As observed from the results in Table (6)

Table 6. AD % For each blend at different temperature.

Temp.(°C)	AD %				
	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
20	0.9024	0.4770	0.5232	0.7922	1.1262
25	0.4855	0.1063	0.3423	0.1703	0.1699
30	0.5282	0.1353	0.1278	0.3817	0.8963

The values for AD % were given as a logical results (statistical histogram). This deference in the result can be clearly seen in Figure (6).

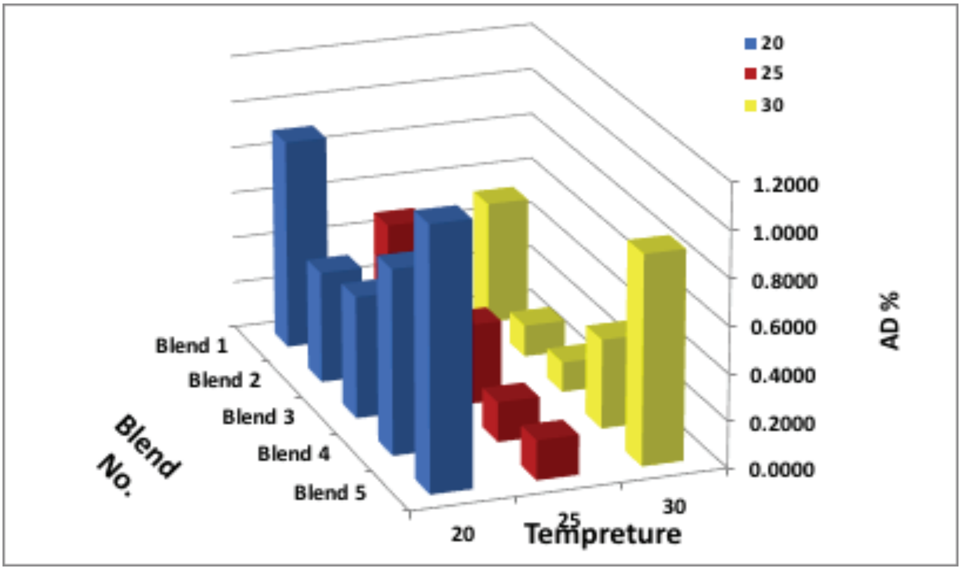

Figure 6. Results of AD% for each blend at different temperatures.

Results of AD and AAD% For Each ail Blend at Variable Temperatures

The results of AD % and AAD % for each blend of mineral oils at different temperatures are shown in Table (7).

Table 7. AD and AAD % for each blend at different temperatures.

Temp.(°C)	% AD				
	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
20	0.9024	0.4770	0.5232	0.7922	1.1262
25	0.4855	0.1063	0.3423	0.1703	0.1699
30	0.5282	0.1353	0.1278	0.3817	0.8963
%AAD	0.64	0.24	0.33	0.45	0.73

The lowest (the best) %AAD value (**0.24**%) of the predicted density was obtained **blend 2** (35%W,65% F) was used. On the other hand , the highest AAD % value (0.73 %) of the prediction was obtained **blend 5**(85% W , 15% F). The other %AAD blends came in between , and this deference in the result can be clearly seen in Figure (7).

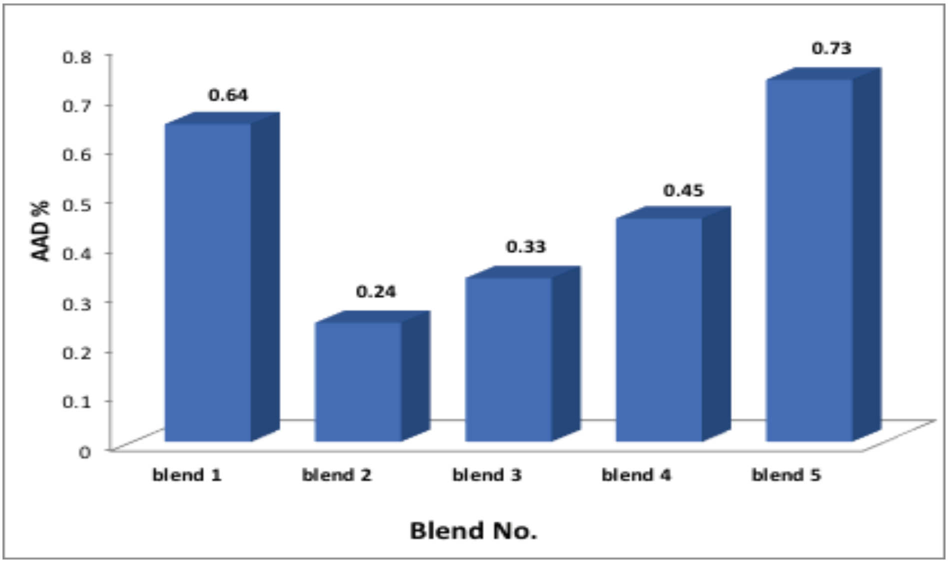

Figure 7. Results of AAD% for each blend at different temperatures.

According to the obtained results , it is highly recommended to use the **blend 2** mixture for crude oils , because it give us the lowest error in comparison between the experimental and calculated data.

Results of AD and AAD% at Constant Temperatures For Each Oil Blend

The results of AD and AAD % at different temperature for each blend are shown in Table (7).

Table 8. AD and AAD % the results of various temperatures for each blend.

Type of Blend NO	AD %		
	20°C	25 °C	30 °C
Blend 1	0.9024	0.4855	0.5282
Blend 2	0.4770	0.1063	0.1353
Blend 3	0.5232	0.3423	0.1278
Blend 4	0.7922	0.1703	0.3817
Blend 5	1.1262	0.1699	0.8963
AAD %	0.76	0.25	0.41

The lowest AAD % value of (**0.25**%) of the predicted density was considered the best result obtained at temperature **25 °C** , followed by the value of (0.41%) at 30 °C and the last one was (0.76%) at 20°C. The deference in the result can be clearly shown in Figure (8).

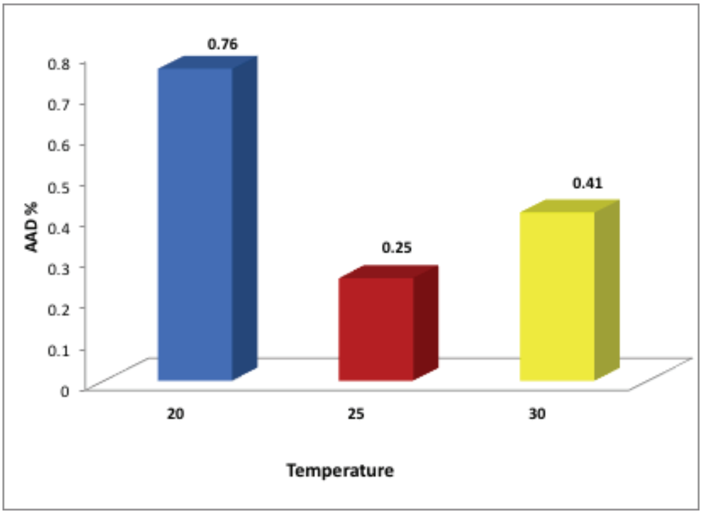

Figure 8. Results of AAD% at different temperature for each blend.

According to the obtained results it is highly recommended to prepare and use blends of crude oils at temperature **25 °C** . Because, it gives a best result in comparison between the experimental values and calculated data as shown in Figure (9)

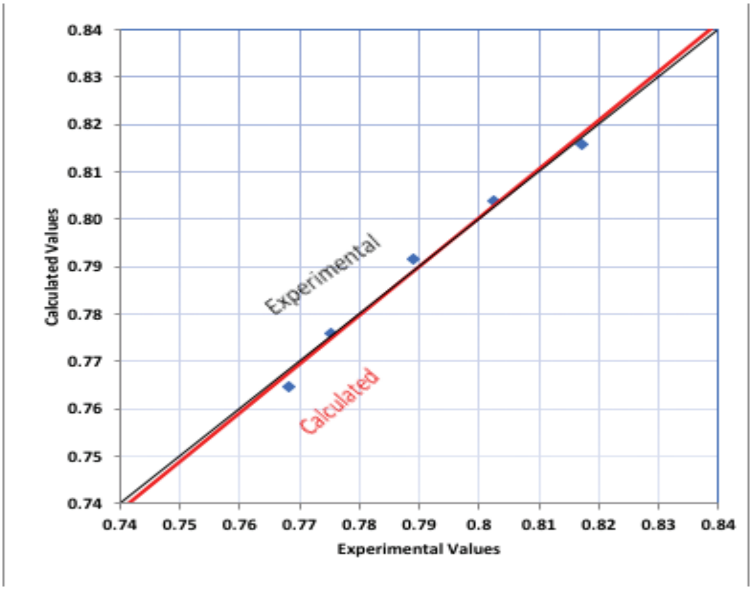

Figure 9. Compared of experimental values vs calculated values at 25 °C.

CONCLUSION

In present study, experimental data - base consists of five different crude oils blends from very light crude oil (**W**) at **Al-Wafa** oil field and a light crude oil **(F**) at **Al-Feal (F**) oil field at different temperatures (20, 25, and 30°C) to obtain the experimental density, as discussed before analysis of the predictive model results using standard statistical techniques. The predicting results which is validated with the experimental Mellita compound data gathered in the laboratory, a lower discrepancy between experimental and calculated values. The high precision results have been observed with the overall percentage average absolute deviation (AAD %) of **(0.48%).** According to the obtained results, it is highly recommended for oil Engineers at Mellita Compound to use the **blend 2** mixture for crude oils, because it give us the lowest **(AD%)** error in comparison between the experimental and calculated data. As well as from the obtained results it is highly recommended for oil Engineers to prepare and use blends of crude oils at temperature **25ºC**,because it give us best result when a comparison made between the experimental and calculated data. The predict developed model have high sobriety to be used with any blend of two oil fields mentioned **(W&F)** at the Mellita Compound. From the economic point of view the predicted formula offer more time and lower cost analysis.

■ References

1. Gascoin G N.. Fauand Gillard P. Novel density determination method Validation and application to fuel flow / Flow Measurement and Instrumentation vol. 22, (2011) ,pp 529–536.

2. Guillermo Centeno, Gabriela Sánchez-Reyna, Jorge Ancheyta , José A.D. Muñoz, Nayeli Cardona: Testing various mixing rules for calculation of density of petroleum blends, Fuel 90.(2011) , pp661–670.

3. Serway, Raymond A. Physics for Scientists & Engineer (4th ed.).Saunders College Publishing.(1996), PP. 108- 123.

4. Andrade , Edward. generalized density correlation for undefined fractions, Chemical Eng. Journal, 27, (2004) , pp. 112 - 123.

5. Allan, J. M. and Teja, A. S. Correlation and prediction of the density and undefined hydrocarbon liquids .Can. J. Chem . Eng. (1991), PP.69 - 86.

6. ASTM – IP Petroleum, Report on the Development, Construction, Calculation and Preparation ofthe Measurement Tables (ASTM

D1298-12; IP 200), (1990),PP.203-207.

7. Edreder E., Nhaesi A., and Elgarni M., "density Modelling of Some Libyan Fuels at Different Temperatures", the first international conference and exhibition on Chemical and Process Engineering, University, Tripoli-Libya. (2009), PP. 14**-** 19.

8. Abdel-Latif, A. and Hassan, M. M.. A generalized density correlation for undefined petroleum fractions. *Chemical Engineering Journal* 72 (1999), PP. 253- 256.

9. Riazi, M. R. Characterization and Properties of Petroleum Fractions, irstedition, (ASTM manual series: MNL50), Printed in the U.S.A. (2005), PP.116-125.

10. Nhaesi, A. &Asfour, A.A**.** Prediction of the density of multi- component liquid mixtures: a generalized McAllister three-body interaction model .*Chemical Engineering science*.55, (2000), PP. 462-473.