بسم الله الرحمن الرحيم

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About:

A new correlation for viscosity of heavy crude oil in Sudanese oil fields

ابتكار معادلة المضاهاة لحساب لزوجة الخام النفطي الثقيل في الحقول السودانية

Prepared by:

1. Ayman Merghane Ahmed Mohammed.

2. Gihad Abdul-basietMahgoub.

3. Rashid Abdul-Mahmoud Nour Allah.

4. Mohanad Omer Eshag Mohammed .

Supervisor:

Mr. *YahyaSharfi*October 2017

الاستهلال

قال تعالى:

﴿هُوَ الَّذِي أَنزَلَ عَلَيْكَ الْكِتَابَ مِنْهُ آيَاتٌ مُّحْكَمَاتٌ هُنَّ أُمُّ الْكِتَابِ وَأُخَرُ مُتَشَابِهَاتٌ ۖ فَأَمَّا الَّذِينَ فِي قلوبِهِم زَيْغٌ فَيَتَّبِعُونَ مَا تَشَابَهَ مِنْهُ ابْتِغَاءَ الْفِتْنَةِ وَابْتِغَاءَ تَأْوِيلِهِ ۗ وَمَا يَعْلَمُ تَأْوِيلَهُ إِلَّا اللَّهُ ۗ وَالرَّاسِخُونَ فِي الْعِلْمِ يَقُولُونَ آمَنَّا بِهِ كُلٌّ مِّنْ عِندِ رَبِّنَا ۗ وَمَا يَذَّكَّرُ إِلَّا أُولو الْأَلْبَابِ (7)﴾

سورة آل عمران

Dedication

This study is dedicated to all our Fathers, Mothers, Brothers, Sisters, Friends, Teachers and Every person that **support** us during our long journey in this **research** .

May Allah (Subhanhu WaTa’ala) bless you and give you what you want.

Acknowledgments

After the Lord Allah (Subhanhu WaTa'ala), we would like to express our sincere gratitude to our Advisors Mr. Yahya Boshra (supervisor) and Mr. Hamza Ahmed (co-supervisor) for their continuous support during our research.

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Abstract

Oil viscosity is veryimportant property in oil industry, it’s very important in the designing of production equipment, testing wells, EOR methods selection and pipelines.

And for that a new correlation has been developed to measure viscosity at different temperatures for a set of heavy oils from the Sudanese oil fields (FNE and FN) using least approximation method (logarithmic form) using excel , covering a viscosity range from 3000 to 39412 mPa.s. A good relationship emerges between temperature and viscosity for a corresponding viscosity temperature correlation with a high confident was obtained for every oil sample. Detailed investigations showed that μ_T (viscosity values at temperature T°C) shows a strong function of μ_{29}(viscosity value at 29°C).

Therefore, this correlation is used for predicting oil viscosity with only two input parameters: temperature and viscosity at 29°C and it can be used to provide an alternative method to predict the viscosity for heavy oils in Sudanese oil fields.

التجريد

لزوجة النفط من احدي الخواص المهمة جدا في الصناعة النفطية , حيث تظهر اهميتها في تصميم معدات الانتاج , اختبارات الابار , اختيار الطريقة المثلي في عمليات تحسين انتاج النفط و في تصميم خطوط نقل النفط.

ولذلك تم تطوير معادلة لحساب اللزوجة عند درجات حرارة مختلفة وذلك للخام الثقيل في الحقول السودانية . تغطي هذه المعادلة مدى بين 3000 الى 39412 مللي باسكال .ثانية باستخدام التحليل العددي طريقة التقريب الاقل باستخدام برنامج الاكسل ,هذا وقد نتج علاقة قوية بين درجة الحرارة واللزوجة لحساب اللزوجة للمراجعة

الحسابات المفصله نتج عنها ان اللزوجة عند اي درجة حرارة اظهرت ارتباطا قويا بقيمة اللزوجة عند درجة حرارة 29 درجة مئوية وبالتالي هذه المعادلة يمكن ان تستخدم للتنبؤ بقيم اللزوجة باستخدام عاملين فقط هما الحرارة وقيمة اللزوجة عند 29درجة مئوية.ويمكن استخدامها كطريقة بديلة لحساب اللزوجة للخام الثقيل في الحقولالسودانية.

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Chapter 1

1.1 Introduction

Despite the high viscosity, heavy oil is becoming a more and more important part of the energy supply in the world with the petroleum demand growing and conventional oil depleting. It's very important to determine the viscosity accurately, because it's very important in the designing of production equipment, testing wells and pipelines.

Crude Oil**:** Petroleum (an equivalent term is crude oil) is a complex mixture consisting hydrocarbon and non-hydrocarbon, predominantly of hydrocarbons and containing sulfur, nitrogen, oxygen, and helium as minor constituents.

Properties of crude oil: The physical and chemical properties of crude oil vary considerably and are dependent on the concentration of the various types of hydrocarbons present. An accurate description of physical properties of crude oils is of a considerable importance in the fields of both applied and theoretical science and especially in the solution of petroleum reservoir engineering problems.

Physical properties of primary interest in petroleum engineering studies include:

- Fluid gravity
- Specific gravity of the solution gas
- Gas solubility
- Bubble-point pressure
- Oil formation volume factor
- Isothermal compressibility coefficient of under saturated crude oils
- Oil density
- Total formation volume factor
- Crude oil viscosity
- Surface tension

The above properties are usually determined by laboratory experiments performed on samples of actual reservoir fluids. In the absence of experimentally measured properties of crude oils, it is necessary for the petroleum engineer to determine the properties from empirically derived correlations. (Ahmed, Tared H., 1946)

Depending on the concentration of hydrocarbon the crude oil divided into

1- light crude oil
2- heavy crude oil

The oil viscosity, in general, is defined as the internal resistance of the fluid to flow. Crude oil viscosity is an important physical property that controls and influences the flow of oil through porous media and pipes.

The oil viscosity is a strong function of the temperature, pressure, oil gravity, gas gravity, and gas solubility. Whenever possible, oil viscosity should be determined by laboratory measurements at reservoir temperature and pressure. The viscosity is usually reported in standard PVT analyses. If such laboratory data are not available, engineers may refer to published correlations, which usually vary in complexity and accuracy depending upon the available data on the crude oil.

According to the pressure, the viscosity of crude oils can be classified into three categories:

1- Dead-Oil Viscosity.
2- Saturated-Oil Viscosity.
3- Under saturated-Oil Viscosity.

Methods of calculating viscosity of crude oil:

1- Laboratory
2- Empirical correlation

Laboratory calculation: Laboratory measure of a crude oil often provides viscosity information at a fixed temperature. However, oil viscosities at other temperatures are often required. Therefore, viscosity prediction for crude oils at a desired temperature by a common laboratory measure will be very useful.(B.C.Craft and M.F.Hawkins)

In the Laboratory, the measurement of oil viscosity will be done by viscometer device, and there are many devices can be used as (capillary viscometer and rotational viscometer) depending on the type of oil and there viscosity ranges. Only rotational viscometer is mentioned.

Rotational viscometer: though gravity is available everywhere for free, it is sometimes not strong enough as a driving force. For highly viscous fluids such as heavy crude oils a measurement based on gravity would take far too long. Therefore, rotational viscometers use a motor drive. Unlike capillary viscometers, rotational viscometers provide dynamic or shear viscosity results. A rotational viscometer consists of a sample-filled cup and a measuring bob that is immersed into the sample

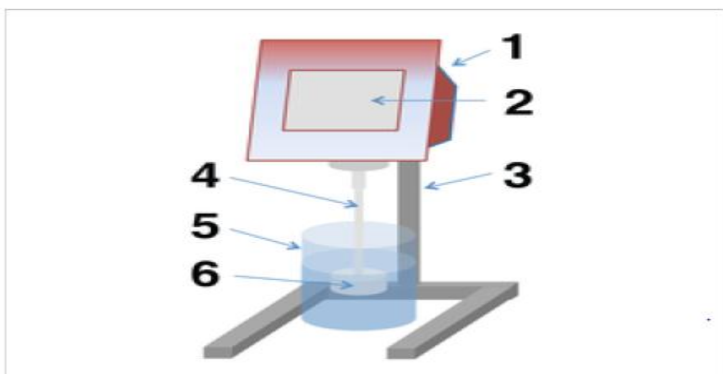


Fig.(1-1): Rotational Viscometer.

1- Motor and measuring unit

2 -User interface

3 -Stand

4 -Spindle/bob axis

5- Sample-filled cup

6- Measuring spindle/bob (rotor)

A number of empirical viscosity correlations or prediction models based on some specific parameters have been developed to measure the viscosity of crude oil. Many correlations for predicting viscosity of dead oil were reported by Beggs and Robinson, Glaso, Kartoatmodjo and Schmidt, Elsharkawy and Alikhan, and Naseri etal. All the prediction models have expressed the dead oil viscosity as a function of oil API gravity and temperature and mainly focused on conventional oils. Limited methods have been reported for viscosity prediction for heavy oils, even less for oils with viscosity higher than 20,000 mPa•s.

1.2 Problem Statement:

Viscosity measurements usually are done only on laboratories, sometimes these measurements are not available and cost a lot of time and money, also the fluid sample may be hard to be gained for testing , for this purpose in this research a temperature based correlation will be developed to predict the viscosity and this saves the times and reduce the cost.

1.3 Objectives:

1. Developed a simple viscosity correlation based on the temperature.
2. Comparison between published temperature viscosity correlation and this work

Chapter 2

Literature Review and Theoretical Background

2.1 Literature Review

Literature search introduced numbers of correlation to predict the viscosity of oil , and these correlations are divided according to the three types of crude oil – as mentioned before : dead oil viscosity , bubble or saturated oil viscosity , and under saturated oil viscosity.

Beal presented dead oil viscosity correlation as a function in API gravity and temperature in rang of 100-229 ºF. 655 data points were collected from different USA's oil fields at and above 100ºF. Also he developed an under saturated oil viscosity correlation based on 52 data points from 26 crude samples. Beal's viscosity correlation has an average error of 24.2%, (Beal.C ,1946)

Beggs and Robinson developed 2 correlations for dead and saturated oil. The first one (dead oil viscosity correlation) was developed using 460 data points from 93 different oil samples. It showed an average error of -0.64% with 13.53% standard deviation. On the other hand , the second viscosity correlation was developed from 2073 data points with an average error and standard deviation of 1.83% and 27.25% respectively.(Beggs H.D. and Robinson J.R, 1975)

Glaso published a dead oil viscosity correlation using 26 data points and analyzing it from six North Sea crudes.(Glaso O, 1980)

Al-Khafaji et al. developed viscosity correlations for dead oil , saturated and under saturated live oil based on 1270 data points from various oil with different.(Al-khafaji H.A, 1987)

Hossain published a dead oil viscosity correlation using fourteen dead, eight saturated and nine under saturated live oil viscosity correlations against a databank consisting of heavy oil data from various parts of the world with wide ranges of temperature, pressure and fluid compositions. The existing empirical viscosity correlations were mostly devolved for significantly lighter oils. Most of them cannot reasonably predict the heavy oil viscosity at low temperatures. Three new empirical correlations for dead saturated and under saturated oils are developed that are applicable for the heavy oils with API gravity ranging from 10 to 22.3. When compared with the databanks, the new dead oil saturated and under saturated oil viscosity correlations showed 3 to 50%.3 to 13% and 22 to 27 % improvement over the existing best correlations respectively. Saturated, aromatics, resin and asphaltenes (SARA) data of some heavy oils were also analyzed to understand the role of the asphaltene and resins in heavy oil viscosity. (Hossain M.S, 2005)

C. ZHANG, et al, have published new correlation for Viscosity values (μ) were measured at different temperatures (40, 50, 60, 70, 80 and 90°C) for a set of dead oils from the Liaohe basin, NE China, covering a viscosity range from 76 to 34,590 mPa.s at 50°C. A good relationship emerges between temperature and viscosity and a corresponding viscosity temperature correlation with a high coefficient was obtained for every oil sample. Detailed investigations revealed that μ_T (viscosity values at temperature T = 60, 70, 80 and 90°C) shows a strong function of μ_{50} (viscosity value at 50°C) in the form of μ_T = aμ_{50} b, in which the parameters a and b show a function of temperature [a = f(T) and b = f1(T)] with high coefficients.

Therefore, a new simple correlation for predicting oil viscosity has been deduced as a function of temperature and μ_{50} In the form of μ_T = f (T) μ_{50} f1(T) with only two input parameters: temperature and viscosity at 50°C. The validity of the model for Liaohe heavy oils has been tentatively confirmed by a set of experimental data from the laboratory of the Liaohe Oil Field with most errors less than 10% for the viscosity prediction at 100°C. The correlation reported in this paper may provide an alternative method to predict the viscosity for dead oils, especially for heavy oils with μ_{50} even up to 160,000 mPa.s in the Liaohe basin.(C. ZHANG, H. ZHAO, M. HU, Q. XIAO, J. LI, C. CAI, 2007)

Table (2.1): equations have been used to determine dead oil viscosity

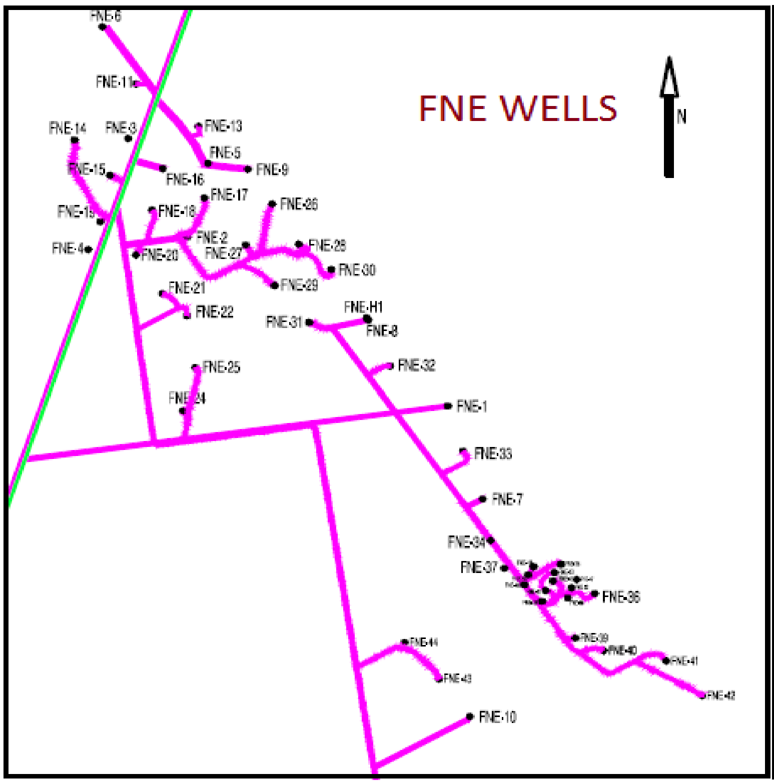
Developer	Equation
Beal (1946)	$\mu_{od} = \left(0.32 + \frac{1.8(10^7)}{API^{4.53}}\right)\left(\frac{360}{T-460}\right)^a$ $a = 10^{\left(0.43+\frac{8.33}{API}\right)}$
Beggs and Robinson (1975)	$\mu_{od} = 10^x - 1$ $x = y(T-460)^{-1.163}$ $y = 10^z$ $z = 3.0324 - 0.02023(API)$
Glaso (1980)	$\mu_{od} = [3.141(10^{10})]((T-460)^{-3.444}[log(API)]^a$ $a = 10.313[log(T-460)] - 36.447$
Khafji Ghasson (1987)	$\mu_{od} = \frac{10^{(4.9563-0.00488*T)}}{(API + \left(\frac{T}{30}\right) - 14.29)^{2.709}}$
Hossain M.S, 2005	$\mu_{od} = 10^{(-0.71523API+22.13766)} * T^{(0.269024API-8.268047)}$

Chapter 3

Methodology

Thirty three oil viscosity data samples, and Sixty one data samples, were selected from Fula North East (FNE) and Fula North (FN) Fields respectively.

3.1 Fula field:



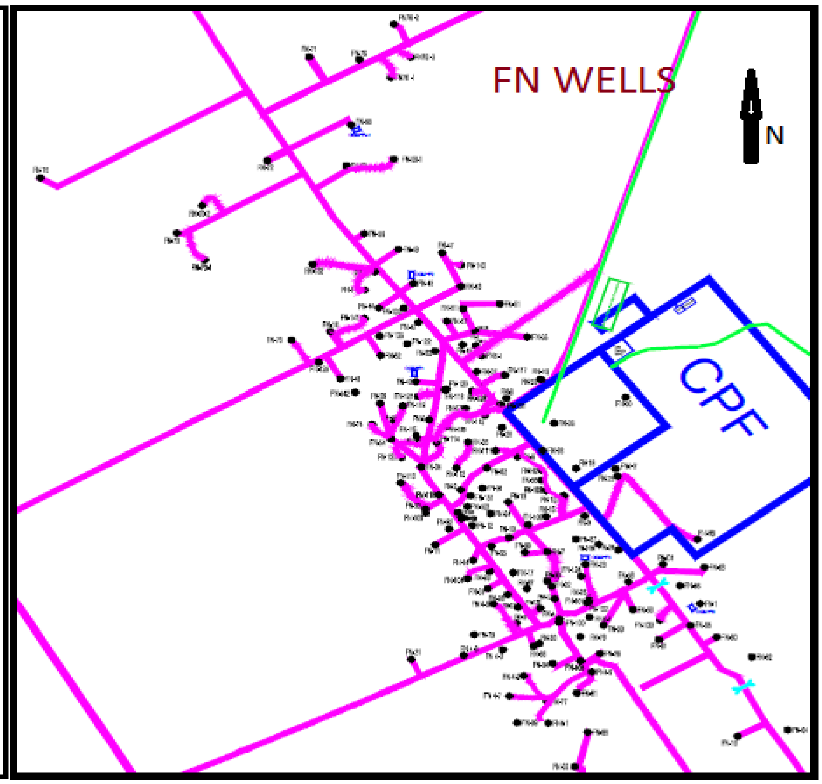


Fig.(3-1): FNE wells map.

Fig.(3-2): FN wells map.

Fula field is located in the north of the northwest of Mogled basin, and it's divided into four fields:-

1- Fula Primary field (F)
2- Fula North (FN)
3- Fula Central (FC)
4- Fula northeast (FNE)

The first three fields (F ,FN ,&FC) are considered the largest Fula field , while (FNE) is a moderate field in size located in the north east side of Fula greater field in Block6, it was discovered in 2005, it contains oil in various sandstone formations in Aradeiba , Bentiu , and Abu-Jabra of Mogled basin and Bentiu formation is the richest one of them all with oil about more than 90% of STOIIP, contains it's depth reaches about **550-600** m , 9 Km from Fula CPF 3D Area: 72 km^2.production started on Oct 1, 2009.

FN field is a horst structure confined by two major normal faults with uniform oil-water contacts. Bentiu-B reservoir is the major producing series in FN field, taking 85% of total reserves. Burial depth of Bentiu-B reservoir is 1250 m on average. Pressure gradient of B pool is rather low.

The methodology will be in two parts as:

3.2 Correlation Model's Prediction:

As it is known, viscosity is highly dependent on temperature. Koopmans et al.(KOOPMANS, M.P., LARTER, S.R., ZHANG, C., MEI, B., WU, T. and CHEN, Y) reported that viscosity data show a strong function of temperature in a form of exponent or logarithm with high correlation coefficient. So applying a multiple regression analysis on this data Using Excel, appears that the best viscosity-temperature correlation for oil samples in this work to be the power model as the following form:

$$\mu_T = mT^n \qquad (3.1)$$

Where:

μ_T = viscosity (mPa.s) at temperature T (°C)

T = temperature (°C)

m, n = constant

Equation (3.1), represent a direct relationship between temperature and viscosity

The parameters (m, n) are determined by analyzing of the viscosity temperature data least square approximation.(Richard L.Burden and J. Douglas Faires) as follows:

1- By taking the logarithm for both sides in Equation (3.1) so it becomes :

$$\log \mu_T = \log mT^n$$

$$\log \mu_T = \log m + n \log T \quad (3.2)$$

2-Using least square approximation to solve eq. (3.2) as:

$$a_0 \sum w_i + a_1 \sum w_i x = \sum w_i y \quad (3.3)$$

$$a_0 \sum w_i x + a_1 \sum w_i x^2 = \sum w_i xy \quad (3.4)$$

Where:

x = log (T).

y = log (μ_T).

.w_i= weight of point

, a_0. a_1 = constant should be found by solving the eq. (3.3) and (3.4) instantly.

m = 10^{a_0} n = a_1

These steps have been followed to introduce a viscosity-temperature model as Eq. (3.1):

1- The viscosity has been calculated for every well at different temperatures using equations (3.2) and this measured viscosity is called "the revised viscosity".

2- Then the revised viscosity has been compared with the original data and the error has been calculated to find an optimum matching.

3- Error Percentage % has been calculated from the equation below :

$$\boldsymbol{E\%} = \frac{\textit{Original viscosity value} - \textit{Revised viscosity value}}{\textit{Original viscosity value}} \quad (3.5)$$

4- The most value of revised viscosity which has shown an optimum matching has been used as a main parameter to develop the correlation.

Beside the optimum matching revised viscosity, the most existing viscosity value has been considered, which is μ_{29} (viscosity of oil at temperature 29°C), also it's an easy obtainable parameter from laboratory

Then a scatter of μ_{29} VS the revised viscosity values at other temperatures has been plotted and from the plot, the final equation will be in the form of :

$$\mu_T = a\mu_{29}{}^b \qquad (3.6)$$

Where:

μ_T = viscosity at temperature T(°C)

μ_{29} = viscosity at temperature 29°C

a,b = viscosity parameters

Equation (3.4) above is introduced by adding a trend line for the scatter and choose the form of equation of this trend as wanted (power model as it appears).

The values of a and b will be plotted with the specific temperature, as follow:

1- Values of a from all data points are gathered

2- Values of b from all data points are gathered

3- These values are put in order with every temperature they were calculated at.

4- A scatter between these values has been plotted.

After that a trend line has been added from the plot and the form of equation of the trend as wanted (logarithmic form) which is going to be a temperature based correlation as:

$$a = x_1 ln(T) + y_1 \qquad (3.7)$$

$$b = x_2 \ln(T) + y_2 \qquad (3.8)$$

Where:

x_1, x_2 , y_1, y_2 are constants calculated automatically from trend's line equation form.

3.3 Error Calculation for developed correlation:

After all calculations of viscosity have been done the “R” and “R squared” factors are calculated.

R is called “the linear correlation coefficient”, it measures the strength and direction of a relationship between two variables and can be calculated from the following equation:

$$R = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n\sum x^2 - (\sum x)^2} * \sqrt{n\sum y^2 - (\sum y)^2}} \qquad (3.9)$$

Where n is the number of pairs of data.[13]

The value of R can take two signs (+ve and –ve).

The R correlation value greater than 0.8 is generally described as strong, whereas a correlation less than 0.5 is generally described as weak.

On the other hand R^2 is called Coefficient of Determination, it gives the proportion of the variance (fluctuation) of one variable that is predictable from the other variable.

It is a measure that allows us to determine how certain one can be in making predictions from a certain model/graph. The coefficient of determination is the ratio of the explained variation to the total variation.

Also the coefficient of determination is a measure of how well the regression line represents the data. If the regression line passes exactly through every point on the scatter plot, it would be able to explain all of the variation. For example, if R = 0.922, then R^2 = 0.850, which means that 85% of the total variation in y can be explained by the linear relationship between x and y (as described by the regression equation).

Chapter 4

Results and Discussion

4.1 Introduction:

In this chapter analyzing has been done depending on the methodology which presented in chapter 3 according to the data points taken from FNE & FN fields.

As a first step the data of both fields has been filtered, as there are some wells have been transformed into a CSS wells, and only heavy oil has been considered in this data. Also available data of viscosity with different temperatures has been filtered (table 4-1, table 4-2).

As mentioned before viscosity data show a strong function of temperature in a form of exponent or logarithm with high correlation coefficient using Eq. (3-1) for every data point and has been analyzed.

4.2 FNE Field:

If FNE-9 is taken as example to perform the calculations and applying the following form:

$$\log(\mu) = \log(m) + n\log(T)$$

For this well two viscosity values at temperature 29°C and 50°C and they are 4488 & 757 respectively has been taken ,by using least approximation the values will be calculated as shown in the following table :

Table (4-3): least approximation method used in Well-FNE-9

	X = log(T)	Y = log(μ)	W	W*X	W*Y	W*(X)^2	W*X*Y
	Log(29) = 1.462398	log(4488) = 3.652053	1	1.462398	3.652053	2.138608	5.340755
	Log (50) = 1.69897	Log(757) = 2.879096	1	1.69897	2.879096	2.886499	4.891498
∑	-	-	2	3.16137	6.53115	5.025107	10.2323

Then from the solution for Eq. (3-2) by taking the values from table (4-1):

$$2a_0 + 3.16137a_1 = 6.53115$$

$$3.16137a_0 + 5.025107a_1 = 10.2323$$

Now solving Eq. (4-1) and Eq. (4-2) instantly:

$a_0 = 8.42858$ ⟶ m= $10^{8.42858}$ =268274874.267

$a_1 = -3.26631 = n$

Equation.(3-1) for FNE-9 will be : 268274874.3$T^{-3.26631}$

Another example has been taken for a well with three points.

FNE-8 :-

Table (4-4): least approximation method used in Well FNE-8

	X = log(T)	Y = log(μ)	W	W*X	W*Y	W*(X)2	W*X*Y
	Log(29) = 1.462398	log(3906) = 3.591732	1	1.462398	3.591732	2.138608	5.340755
	Log(40) = 1.60206	Log(1567) = 3.195069	1	1.60206	3.195069	2.566596	5.118692
	Log (50) = 1.69897	Log(761) = 2.881385	1	1.69897	2.881385	2.886499	4.891498
∑	-	-	2	4.763428	9.668186	7.591703	15.2666

So the equations will be:

$$3a_0 + 4.76343a_1 = 6.53115$$

$$4.76343a_0 + 7.5917a_1 = 15.2666$$

Solving Eq. (4-4) and Eq. (4-5) instantly:-

$a_0 = 7.92310993$ ⟶ m= $10^{7.92310993}$=83774130.7

$a_1 = -2.984979937 = n$

Eq. (3-1) for FNE-8 will be: 83774130.7*$T^{-2.984979937}$

The rest of the data is shown in the table below:

Table (4-5): least approximation method parameters

Well	a0	m	a1=n
FNE-9	8.42858	268274874.3	-3.26631
FNE-15	8.292705	196202709.2	-3.2022002
FNE-25	2.93172873	854.532	0.54468085
FNE-22	7.957275337	90630700.55	-2.981365887
FNE-21	8.077644843	119576226.2	-3.036316434
FNE-19	8.998398736	996319742	-3.422167437
FNE-24	9.206391109	1608389055	-3.478353441
FNE-29	8.505200632	320037325.2	-3.230394185
FNE-18	8.018462439	104342788.5	-3.054386193
FNE-16	8.084430309	121459170	-3.076644182
FNE-26	8.617386077	414367873.9	-3.128517748
FNE-2	7.9509698	89324336.72	-2.987786814
FNE-17	8.169967725	147899847.1	-3.096845813
FNE-4	9.385894942	2431920760	-3.582525894
FNE2	5.777789976	599501.0885	-1.650021969
FNE3	4.811696872	64818.18589	-1.338427246
FNE-2	7.456748024	28625166.67	-2.797963115
FNE-3	6.173909229	1492482.436	-2.269792544
FNE-4	9.385894942	2431615718	-3.582525894
FNE-5	-0.60457447	0.2485567319	2.90638298
FNE-6	2.95409574	899.6958972	0.54893617
FNE-7	1.08034575	12.03221961	1.7483617
FNE-11	8.036030688	108650239.5	-3.048662882
FNE-13	8.088002158	122462228.4	-3.087707012
FNE-15	8.292704806	196202621.6	-3.202200189
FNE-20	-0.2456117	0.5680522704	2.65957447
FNE-24	9.206391109	1608389055	-3.478353441
FNE-27	3.05117021	1125.045819	0.44255319
FNE-28	2.74052511	550.2817503	0.62127659
FNE-30	-2.27960106	0.00525897664	3.98723404
FNE-31	1.60412233	40.19040013	1.46808511
FNE-8	7.923110993	83774130.7	-2.984979937
FNE-86	0.29093085	1.954028303	2.57021277

Direct relationship between viscosity and temperature Eq. (3-1) and check the accuracy of data collected, by calculating the revised viscosity) as follows:-

Table (4-6): viscosity-temperature model

Well name	Viscosity-Temperature Model
FNE-9	$268274874.3*T^{-3.26631}$
FNE-15	$196202709.2*T^{-3.2022002}$
FNE-25	$854.532*T^{0.54468085}$
FNE-22	$90630700.55*T^{-2.981365887}$
FNE-21	$119576226.2*T^{-3.036316434}$
FNE-19	$996319742*T^{-3.422167437}$
FNE-24	$1608389055*T^{-3.478353441}$
FNE-29	$320037325.2*T^{-3.230394185}$
FNE-18	$104342788.5*T^{-3.054386193}$
FNE-16	$121459170*T^{-3.076644182}$
FNE-26	$414367873.9*T^{-3.128517748}$
FNE-2	$89324336.72*T^{-2.987786814}$
FNE-17	$147899847.1*T^{-3.096845813}$
FNE-4	$2431920760*T^{-3.582525894}$
FNE2	$599501.0885*T^{-1.650021969}$
FNE3	$64818.18589*T^{-1.338427246}$
FNE-H1	$34.51690999*T^{1.38297872}$
FNE-2	$28625166.67*T^{-2.797963115}$
FNE-3	$1492482.436*T^{-2.269792544}$
FNE-4	$2431615718*T^{-3.582525894}$
FNE-5	$0.248556732*T^{2.90638298}$
FNE-6	$899.6958972*T^{0.54893617}$
FNE-7	$12.03221961*T^{1.7483617}$
FNE-11	$108650239.5*T^{-3.048662882}$
FNE-13	$122462228.4*T^{-3.087707012}$
FNE-15	$196202621.6*T^{-3.202200189}$
FNE-20	$0.568052270*T^{2.65957447}$
FNE-24	$1608389055*T^{-3.478353441}$
FNE-27	$1125.045819*T^{0.44255319}$
FNE-28	$550.2817503*T^{0.62127659}$
FNE-30	$0.005258977*T^{3.98723404}$
FNE-31	$40.19040013*T^{1.46808511}$
FNE-8	$83774130.7*T^{-2.984979937}$
FNE-86	$1.954028303*T^{2.57021277}$

Revised viscosity values have been given in the table:

Table (4-7): Revised viscosity

Well	µ29	E%	µ40	E%	µ50	E%
FNE-9	4486.78	0.027184	_	_	757.21	-0.02774
FNE-15	4072.05	-0.05037	_	_	711.64	0.050562
FNE-25	5348.94	0.001122	_	_	_	_
FNE-22	3956.688	-0.01739	_	_	779.87	0.016667
FNE-21	4338.52	-0.01199	_	_	829.916	0.01012
FNE-19	9858.88	-0.03937	_	_	1528.407	0.03881
FNE-24	13172.06	0.022315	_	_	1980.49	-0.02475
FNE-29	6040.58	-0.04273	_	_	1039.57	0.041346
FNE-18	3562.33	-0.03735	_	_	674.76	0.035556
FNE-16	3847.26	-0.00676	_	_	719.95	0.006944
FNE-26	11021.08	0.008347	_	_	2005.06	-0.00299
FNE-2	3816.24	-0.05873	_	_	749.56	0.058667
FNE-17	4376.69	0.007082	_	_	810.06	-0.00741
FNE-4	14023.96	-0.06393	_	_	1992.25	0.037632
FNE2	2316.333	-0.01438	_	_	942.87	0.013786
FNE3	715.127	-0.01776	_	_	344.944	0.016232
FNE-H1	3634.939	0.001678	_	_	_	_
FNE-2	2317.46	-0.06304	942.4	0.063627	_	_
FNE-3	715.433	-0.06056	344.79	0.06087	_	_
FNE-4	14022.2	-0.05137	_	_	1992.007	0.049824
FNE-5	4382.9	0.906624	_	_	_	_
FNE-6	5712.9	0.00175	_	_	_	_
FNE-7	4336.57	0.194016	_	_	_	_
FNE-11	3781.57	-0.06801	_	_	718	0.139082
FNE-13	3737.19	0.021669	_	_	695.11	-0.01583
FNE-15	4072.05	-0.05037	_	_	711.64	0.050562
FNE-20	4402.95	0.001136	_	_	_	_
FNE-24	13172.06	0.022315	_	_	1980.4	-0.0202
FNE-27	4992.9	0.002003	_	_	_	_
FNE-28	4457.98	0.000449	_	_	_	_
FNE-30	3563.06	-0.11408	_	_	_	_
FNE-31	5636.98	0.000355	_	_	_	_
FNE-8	3613.11	7.498464	1383.54	11.70772	710.7	6.609724
FNE-86	11209.9	0.000892	_	_	_	_

Note that the error has been calculated from Eq. (3-3)

From the revised viscosity calculation a scatter has been plotted between µ29 VS µ40 and another one between µ29 VS µ50 as follows:

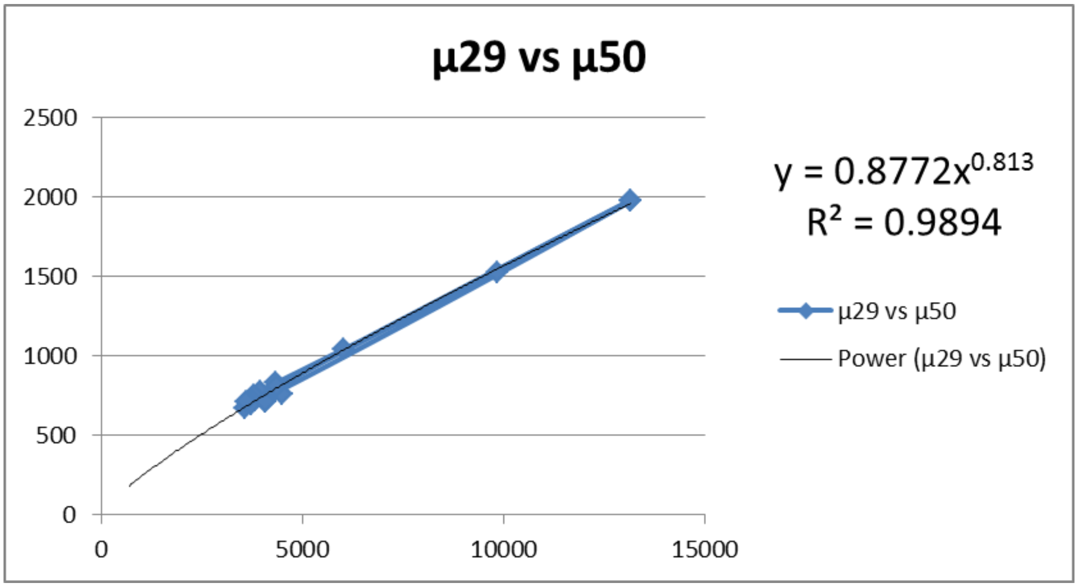


Fig. (4-1): µ29 VS µ50

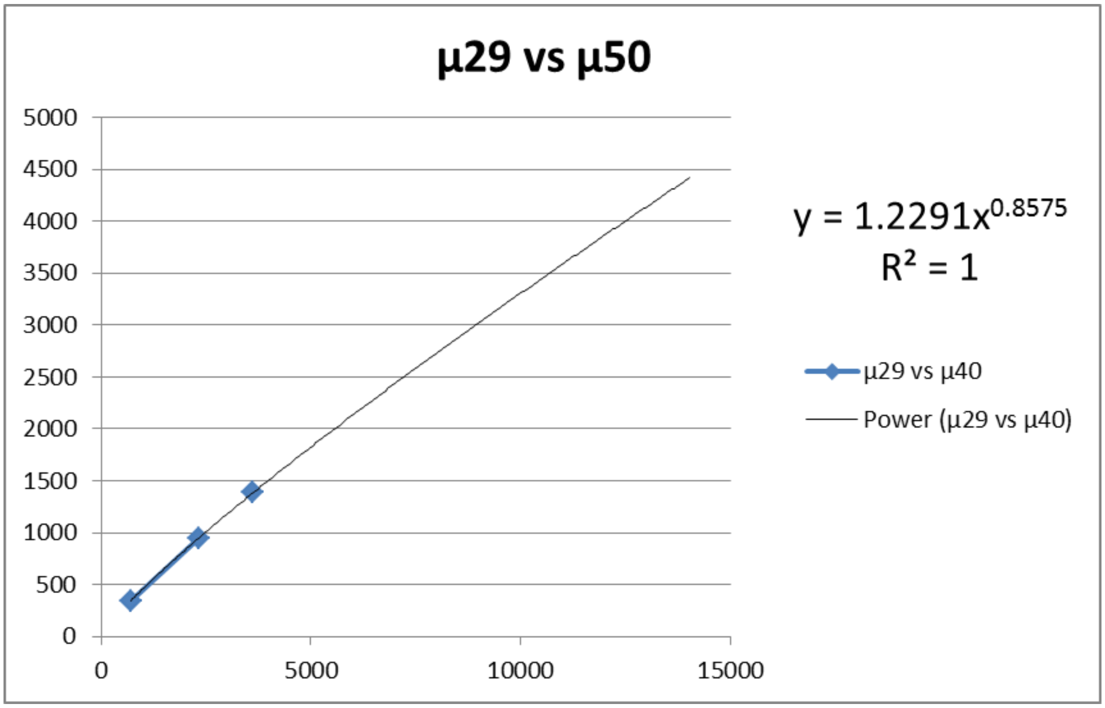


Fig.(4-2): µ29 VS µ40

In both scatters, a trend line has been added and it's format in a power model.

So the equations are:

For µ29 VS µ50

$$\mu_{50} = 0.8772\mu_{29}^{0.813}$$
$$R^2 = 0.9515$$

And for µ29 VS µ40

$$\mu_{40} = 1.2291\ \mu_{29}^{0.8575}$$
$$R^2 = 1$$

a and b values has been taken from Eq. (4-7) , Eq. (4-8) and shown in the following table:

Table (4-8): a , b and temperature

T	A	b
40	1.2291	0.8575
50	0.8772	0.813

.

Then the data in the above table was plotted to give the scatter as below:

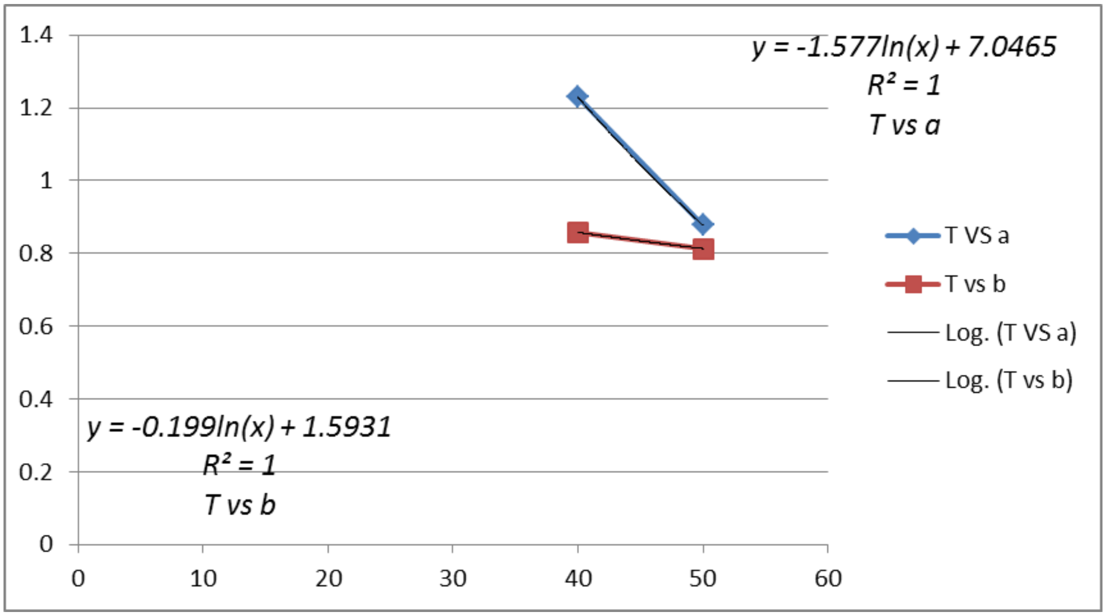


Fig. (4-3): T VS a and T VS b

In the above scatter, a trend line has been added and it format in a logarithmic model.

So the equations are:

a =-1.577 ln (T) + 7.0465

$R^2 = 1$

b =-0.199 ln (T) + 1.5931

$R^2 = 1$

Then the developed correlation will be:

$$\mu_T = a\mu_{29}{}^{b}$$

a =-1.577 ln (T) + 7.0465

b =-0.199 ln (T) + 1.5931

The correlation coefficient R is calculated from the equation:

$$R = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n\sum x^2 - (\sum x)^2} * \sqrt{n\sum y^2 - (\sum y)^2}}$$

n=number of pairs of data X=original viscosity values

Y=the calculated viscosity values from the introduced correlation

Table (4-9): R calculation

	X=	Y=	X*Y	X^2	Y^2
	757	828.1474	626907.6	573049	685828.1
	712	764.75211	544503.5	506944	584845.8
	780	747.25694	582860.4	608400	558392.9
	830	805.52931	668589.3	688900	648877.5
	1529	1571.7397	2403190	2337841	2470366
	1980	1991.1213	3942420	3920400	3964564
	1040	1054.5371	1096719	1081600	1112049
	675	685.89111	462976.5	455625	470446.6
	720	730.44148	525917.9	518400	533544.8
	750	725.33324	543999.9	562500	526108.3
	810	811.42377	657253.3	656100	658408.5
	719	719.90643	517612.7	516961	518265.3
	695	713.53746	495908.5	483025	509135.7
	712	764.75211	544503.5	506944	584845.8
	1980	1991.1213	3942420	3920400	3964564
	761	739.55423	562800.8	579121	546940.5
∑	15450	15645.045	18118583	17916210	18337182

Note that μ_{50} new has been calculated from the developed correlation (3-6):

$$R = \frac{16 * 18118583 - 15450 * 15645.045}{\sqrt{16 * 17916210 - 15450^2} * \sqrt{16 * 18337182 - 15645.045^2}}$$

$$R = 0.99773$$

$$R^2 = 0.995465 = 99.54\%$$

Based on the linear coefficient value calculated above, this developed correlation is strong.

Then comparison has been done between the original data and the calculating values to check for the accuracy of the correlation.

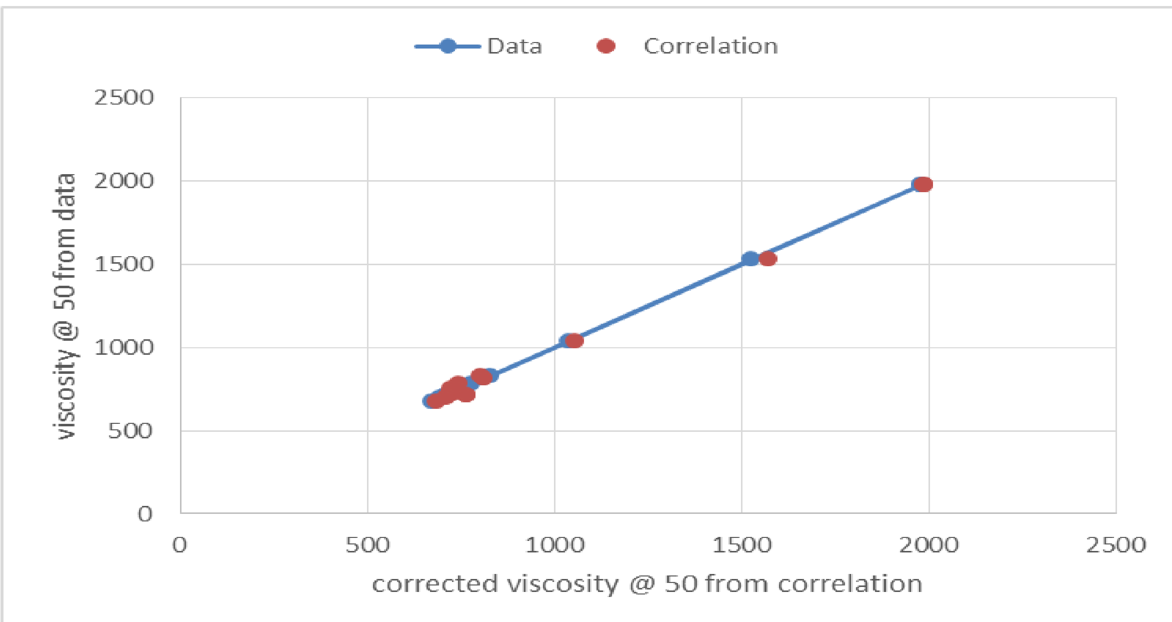


Fig. (4-4): original data VS calculated values

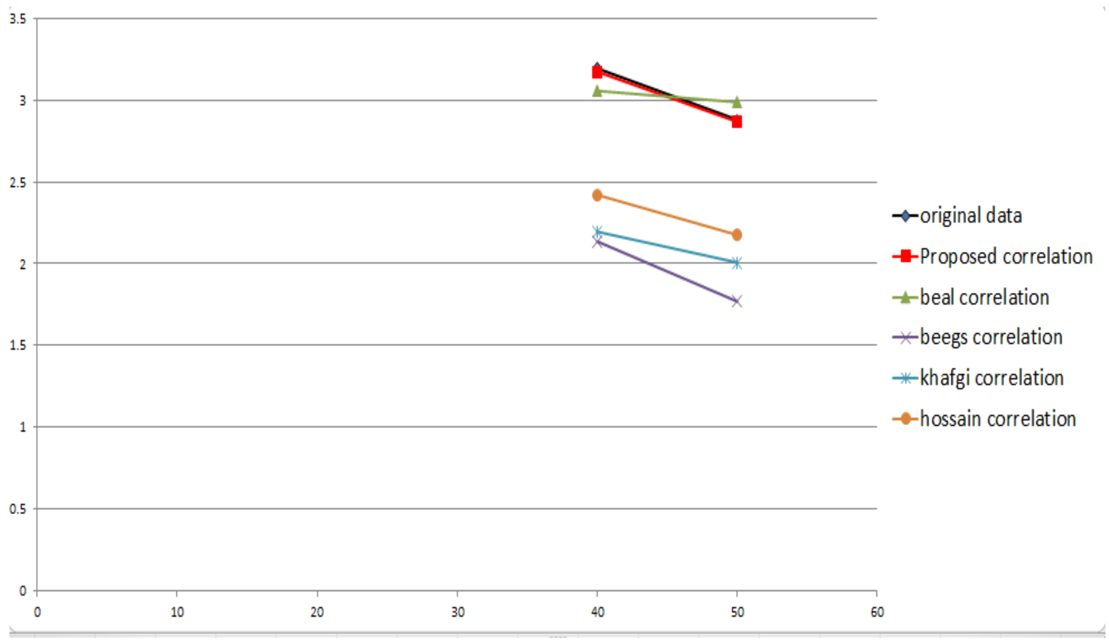


Fig (4-5): comparison of original data with the proposed correlation and calculated values from published correlations for FNE field

4.3 FN Field:

The same procedures that have been followed in developing FNE's correlation have been also done here.

FN-90 for example:-

Also Eq. (3-1) has been given in the following the shape to introduce to develop correlation:

$$\log(\mu) = \log(m) + n\log(T)$$

For this well there are two viscosity values at temperature 29°C and 50°C as shown in table (4-2) and they are 6158 & 1111 respectively, using least approximation to calculate the values as in the following table:

Table (4-10): least approximation method used in Well FN-90

	X = log(T)	Y = log(μ)	W	W*X	W*Y	W*	W*X*Y
	Log(29) = 1.462398	log(6158) = 3.78944	1	1.462398	3.78944	2.138608	5.541669
	Log (50) = 1.69897	Log(1111) = 3.045714	1	1.69897	3.045714	2.886499	5.174577
∑	-	-	2	3.16137	6.835154	5.025107	10.71625

The equation will be

$$2a_0 + 3.16137a_1 = 6.835154$$

$$3.16137a_0 + 5.025107a_1 = 10.71625$$

Solving these two equations instantly:

$a_0 = 8.386650 \longrightarrow$ m= $10^{8.386650}$ =243584697

$a_1 = -3.1436 = n$

And the equation of this well will be : $243584697T^{-3.1436}$

And the rest of the data has been shown in the table below:-

Table(4-11): least approximation method parameters

well name	a0	M	a1 = n
FN-90	8.38665	2.44E+08	-3.1436
FN-76-3	8.84201	6.95E+08	-3.24516
FN-110	8.39088	2.46E+08	-3.06601
FN-47	7.77394	59420869	-2.58475
FN119	8.74708	5.59E+08	-3.23527
FN-67	7.88363	76493815	-2.71999
F-17	7.71849	52298472	-2.81671
FN-76-4	9.77082	5.9E+09	-3.6434
FN-76-3	8.72213	5.27E+08	-3.15976
FN-76-4	8.9107	8.14E+08	-3.23299
FN-139	8.37009	2.34E+08	-3.00787
FN-140	8.55204	3.56E+08	-3.06584
Fula-15	8.80663	6.41E+08	-3.29644
FN-31	-6.07467	8.42E-07	7.127729
FN-67	7.88363	76493758	-2.71999
FN 112	8.37565	2.37E+08	-2.94582
FN 113	8.2319	1.71E+08	-2.95192
FN 114	7.78702	61237596	-2.66843
FN 115	8.6263	4.23E+08	-3.2122
FN 111	8.21168	1.63E+08	-2.96779
FN 119	8.09575	1.25E+08	-2.89203
FN 123	8.24189	1.75E+08	-2.99129
FN 128	8.4346	2.72E+08	-3.09653
FN-39	4.06045	11493.42	-0.26499
FN-113	8.30551	2.02E+08	-3.04778
FN-114	8.61421	4.11E+08	-3.21612
FN-119	8.27387	1.88E+08	3.021635
FN-74	8.62874	4.25E+08	-3.19258
FN-112	8.75363	5.67E+08	3.19255
FN-156	2.65217	448.9231	0.757779
FN-43	10.0712	1.18E+10	-4.10047
FN-45	-4.78553	1.64E-05	5.942386
FN-47	2.82997	676.0363	0.81238
FN-140	11.3558	2.27E+11	-5.03543
FN-76.3	1.70642	50.86453	1.61342
FN-48	5.26771	185230.6	-0.80115
FN-122	-5.00464	9.89E-06	-6.10824

Well name	a0	M	a1=n
FN-156	2.65217	448.9231	0.757779
FN-60	9.21479	1.64E+09	-3.56009
FN-61	-6.14423	7.17E-07	6.8935
FN-62	9.47643	3E+09	-3.5739
FN-65	6.01076	1025084	-1.37102
FN-86	-11.2104	6.16E-12	10.56094
FN 22	5.57065	372092.1	-1.02444
FN 23	14.5884	3.88E+14	-7.20121
FN 24	-8.21135	6.15E-09	8.532836
FN 26	-1.38343	0.041359	3.68983
FN 58	-1.54366	0.028598	3.989039
FN D1	1.91149	81.56278	1.594602
FN 4	9.45893	2.88E+09	-4.38863
FN-18	6.11213	1294570	-1.49614
FN-51	15.674	4.72E+15	-7.91567
FN-3R	2.36182	230.0465	1.111464
FN-149	3.94153	8740.298	-0.00103
FN-113	3.84939	7069.534	-0.00065
FN-114	3.9118	8162.064	-0.00059
FN-119	3.855	7161.484	2.14E-05
FN-74	3.95762	9070.349	0.001556
FN-112	4.08652	12204.61	-0.00116
F-10	9.30535	2.02E+09	-3.30311
F-2	10.2152	1.64E+10	-3.84272

Note : E=10^{no} (e.g E+09 = 10^9).

Again the model as a direct relationship between viscosity and temperature to introduce the model as equation (3-1-1) and check the accuracy of data collected, by calculating the new viscosity (revised viscosity) as follows:-

Table (4-12): Viscosity-temperature model

Well name	Viscosity-temperature model
FN-90	$243584696.6\ T^{-3.1436}$
FN-76-3	$695046722.9\ T^{-3.245164}$
FN-110	$245968787.3\ T^{-3.06601}$
FN-47	$59420869.16\ T^{-2.58475}$
FN119	$558571719\ T^{-3.23527024}$
FN-67	$76493815\ T^{-2.71999262}$
F-17	$52298471.96\ T^{-2.816711}$
FN-76-4	$5899510793\ T^{-3.643398}$
FN-76-3	$527383722.1\ T^{-3.15975694}$
FN-76-4	$814148472\ T^{-3.23298777}$
FN-139	$234473655\ T^{-3.00786994}$
FN-140	$356487291\ T^{-3.06584365}$
Fula-15	$640658620\ T^{-3.29644114}$
FN-31	$0.8420347213*10^{-6}\ T^{7.1277287}$
FN-67	$76493758.43\ T^{-2.71999}$
FN 112	$237493938\ T^{-2.94582241}$
FN 113	$170568466\ T^{-2.95192444}$
FN 114	$61237596\ T^{-2.66842628}$
FN 115	$422963875\ T^{-3.21219953}$
FN 111	$162810049\ T^{-2.96778889}$
FN 119	$1424667343\ T^{-2.89202639}$
FN 123	$174539247\ T^{-2.99129118}$
FN 128	$272021654\ T^{-3.09653484}$
FN-39	$11493.418\ T^{-0.2649898}$
FN-113	$202073935.7\ T^{-3.047781}$
FN-114	$411349524.9\ T^{-3.216118}$
FN-119	$187873272.4\ T^{3.021635}$
FN-74	$425342716.1\ T^{-3.192579}$
FN-112	$567056065.2\ T^{3.192550}$
FN-156	$448.9231483\ T^{0.757779}$
FN-43	$1178232505\ T^{-4.100474}$
FN-45	$16386*10^{-5}\ T^{5.942386}$
FN-47	$676.0362748\ T^{0.81238}$
FN-140	$2.2689211*10^{11}T^{-5.0354259}$
FN-76.3	$50.8645258\ T^{1.61342}$

Well name	Viscosity-temperature model
FN-48	$185230.6284\ T^{-0.8011521}$
FN-122	$9.89366*10^{-6}\ T^{-6.1082412}$
FN-156	$448.9231483\ T^{0.757779}$
FN-60	$1639783077\ T^{-3.5600923}$
FN-61	$7.174225115*10^{-7}\ T^{6.8934995}$
FN-62	$2995214986\ T^{-3.5273899}$
FN-65	$1025084.106\ T^{-1.3710213}$
FN-86	$6.160429615*10^{-12}\ T^{10.56094}$
FN 22	$372092.1433\ T^{-1.0244433}$
FN 23	$3.876514386*10^{14}\ T^{-7.2012146}$
FN 24	$6.146841292*10^{-9}\ T^{8.532836}$
FN 26	$0.04135918765\ T^{3.6898297}$
FN 58	$0.02859815397\ T^{3.9890394}$
FN D1	$81.56277626\ T^{1.5946022}$
FN 4	$2876913472\ T^{-4.3886336}$
FN-18	$1294570.183\ T^{-1.4961385}$
FN-51	$4.721151698*10^{15}\ T^{-7.9156662}$
FN-3R	$230.046537\ T^{1.1114643}$
FN-149	$8740.297997\ T^{-0.0010313}$
FN-113	$7069.534203\ T^{-0.0006535}$
FN-114	$8162.064079\ T^{-0.0005858}$
FN-119	$7161.483572\ T^{-0.000021359}$
FN-74	$9070.349047\ T^{0.00155618}$
FN-112	$12204.61264\ T^{-0.00116177}$
F-10	$2019979677\ T^{-3.30310968}$
F-2	$16413832610\ T^{-3.84271878}$

And the revised viscosity value is calculated in the table:

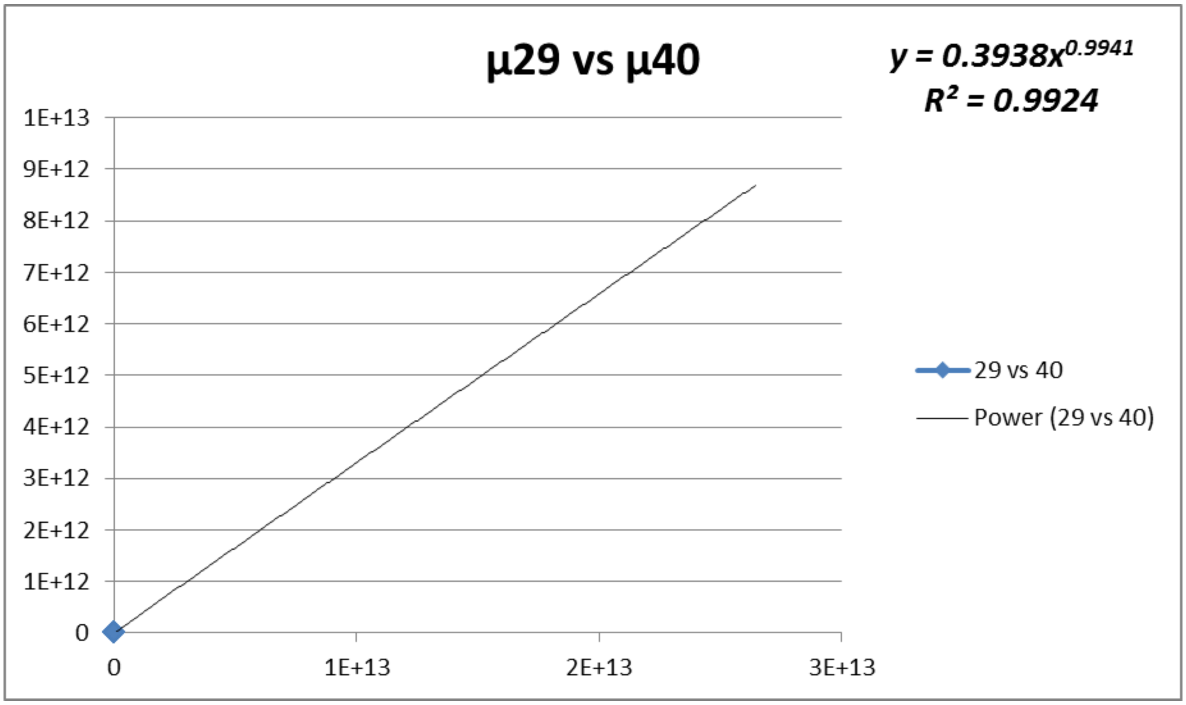
Table (4-13): Revised viscosity

Well name	μ29	E%	μ40	E%	μ50	E%
FN-90	6158.226436	-0.0036771		0	1111.137729	-0.0124
FN-76-3	12482.24388	-0.00195383		0	2130.971811	0.001323
FN-110	8075.196783	-0.00243695		0	1519.920865	0.005206
FN-47	9862.926006	17.68547817		0	2412.82754	-21.4918
FN119	10371.13343	-1.69771942	3664.223288	4.052807	1780.130534	-2.48305
FN-67	8052.200112	-0.00248525		0	1829.955158	0.00245
F-17	3974.993958	0.000151988		0	857.0013382	-0.00016
FN-76-4	27715.2027	-0.00433969		0	3808.834341	0.004349
FN-76-3	12627.12553	-0.00099418	4570.950783	0.001077		0
FN-76-4	15233.11673	-0.00076629	5385.961608	0.000713		0
FN-139	9362.483711	-0.00516675	3558.819515	0.005071		0
FN-140	11710.09547	-0.00081532	4368.965349	0.000793		0
Fula-15	9680.944951	-2.2275074	3353.746325	5.234633	1607.207891	-3.22466
FN-31	22330.89762	0.00045847		0		0
FN-67	8052.265197	-0.00329355		0	1829.972561	0.001499
FN 112	11686.58802	-0.0050318	4531.774634	0.004973		0
FN 113	8222.622507	-4.22895813	3182.282283	-4.2346		0
FN 114	7668.614102	0.005031917	3251.166043	-0.00511		0
FN 115	8487.682289	0.003743057	3021.112689	-0.00373		0
FN 111	7440.338187	-0.00454553	2864.872929	0.004435		0
FN 119	84027.1951	-1042.76071	33152.30246	-1042.79		0
FN 123	7369.446413	0.007511356	2816.210907	-0.00749		0
FN 128	8058.183011	-0.00227118	2976.931887	0.002288		0
FN-39	4708.999547	9.61008E-06		0		0
FN-113	7054.097656	-0.0013844		0	1340.978458	0.001606
FN-114	8146.413976	-0.00508195		0	1412.937617	0.004415
FN-119	4.92831E+12	-6.8812E+10		0	2.55583E+13	-1.9E+12
FN-74	9118.383679	-0.00420793		0	1601.928185	0.004483
FN-112	2.64487E+13	-2.1756E+11		0	1.50547E+14	-7E+12
FN-156	5758.992228	0.000134958		0		0
FN-43	11876.98018	0.000166858		0		0
FN-45	8027.981068	0.000235819		0		0
FN-47	10423.00355	-3.4018E-05		0		0
FN-140	9817.991215	8.94794E-05		0		0
FN-76.3	11637.96851	0.000270571		0		0
FN-48	12476.9827	0.000138627		0		0

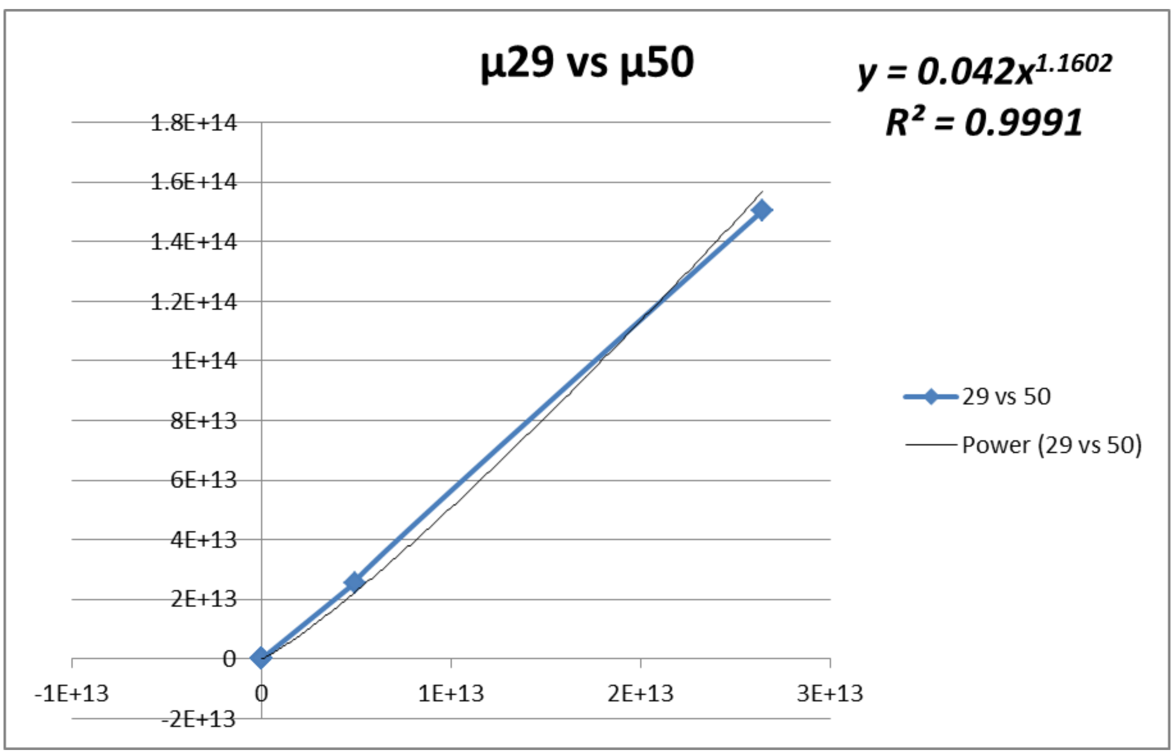
Well name	µ29	E%	µ40	E%	µ50	E%
FN-122	1.15525E-14	100		0		0
FN-156	5758.992228	0.000134958		0		0
FN-60	10197.98921	0.000105786		0		0
FN-61	8645.992755	8.37918E-05		0		0
FN-62	20796.01262	-6.0706E-05		0		0
FN-65	10133.99523	4.70526E-05		0		0
FN-86	17135.96285	0.000216807		0		0
FN 22	11816.98459	0.000130416		0		0
FN 23	11412.99394	5.31305E-05		0		0
FN 24	18494.99775	1.21636E-05		0		0
FN 26	10293.7014	-0.20151267		0		0
FN 58	19494.01214	-6.2263E-05		0		0
FN D1	17516.00517	-2.9523E-05		0		0
FN 4	1099.000297	-2.7027E-05		0		0
FN-18	8397.995798	-45.8238548		0		0
FN-51	12536.99788	1.69383E-05		0		0
FN-3R	9709.991888	8.35477E-05		0		0
FN-149	8709.998274	1.98201E-05		0		0
FN-113	7053.9946	7.65493E-05		0		0
FN-114	8145.979771	0.000248327		0		0
FN-119	7160.968522	0.014402097		0		0
FN-74	9118.003499	-3.837E-05		0		0
FN-112	12156.96118	0.000319332		0		0
F-10	29845.99193	-0.00667446	10317.32556	0.006537		0
F-2	39411.75277	0.000627303		0	4858.990588	0.000194

Note that the error has been calculated from Eq. (3-3)

From the revised viscosity calculation, a scatter has been plotted as mentioned before between µ29 VS µ40 and another one between µ29 VS µ50 as follows:



Fig(4-5): **µ29 vs µ40**



Fig(4-6): **µ29 vs µ50**

In both scatters, a trend line has been added and it's format in a power model as shown in the above figures. So the equations are:

For µ29 VS µ50

$$\mu_{50} = 0.042\ \mu_{29}^{1.1602}$$
$$R^2 = 0.9991$$

And for µ29 VS µ40

$$\mu_{40} = 0.3938\ \mu_{29}^{0.9941}$$
$$R^2 = 0.9924$$

a and b values has been taken from the above equation and shown in the following table:

Table (4-14): a , b and temperature

T	A	B
40	0.3938	0.9941
50	0.042	1.1602

Then the data in the above table has been plotted to give the scatter below:

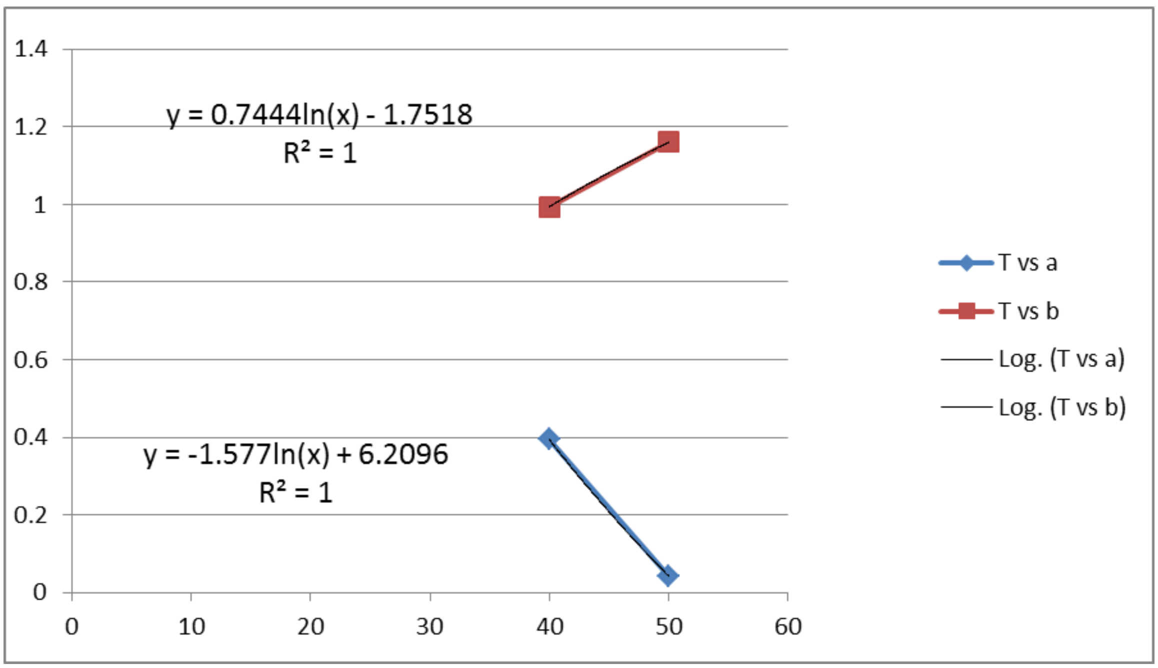


Fig (4-7): T VS a and T VS b

In the above scatter, a trend line has been added and it's format in a logarithmic model. So the equations are:

$$a = -1.577\ \ln(T) + 6.2096$$
$$R^2 = 1$$

b =0.7444 ln(T) - 1.7518

$R^2 = 1$

Then the developed correlation as in eq. (3-6):

$$\mu_T = a\mu_{29}{}^{b}$$

a=-1.577 ln(T) + 6.2096

b =0.7444 ln(T) - 1.7518

The correlation accuracy R is calculated from the equation (3-9):

$$R = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n\sum x^2 - (\sum x)^2} * \sqrt{n\sum y^2 - (\sum y)^2}}$$

n=number of pairs of data.

X=original viscosity values

Y=the calculated viscosity values from the introduced correlation

Table (4-15): R calculation

	X=	Y=	X*Y	X^2	Y^2
	1111	1006.138	1117818.8	1234321	1012312.8
	2131	2283.979	4867158.9	4541161	5216559.3
	1520	1377.936	2094463.2	2310400	1898708.5
	1986	2178.166	4325837.2	3944196	4744406.1
	1737	1806.561	3137996.5	3017169	3263662.7
	1830	1373.383	2513291.6	3348900	1886181.9
	857	605.4517	518872.08	734449	366571.73
	3809	5762.897	21950876	14508481	33210985
	1557	1657.797	2581189.2	2424249	2748289.4
	1341	1177.906	1579572.3	1798281	1387463.2
	1413	1392.004	1966901.7	1996569	1937675.2
	1381	1198.857	1655621.8	1907161	1437258.6
	1602	1586.513	2541594.1	2566404	2517024
	2136	2215.121	4731499.2	4562496	4906762.5
	4859	8671.34	42134041	23609881	75192138
∑	29270	34294.05	97716733	72504118	141725998

$$R = \frac{15 * 97716733 - 29270 * 34294.05}{\sqrt{15 * 72504118 - 29270^2} * \sqrt{15 * 141725998 - 34294.05^2}}$$

R=.986609

R^2=0.973398 = 97.34%

Comparison has been done between the original data and the calculating values to check for the accuracy of the correlation.

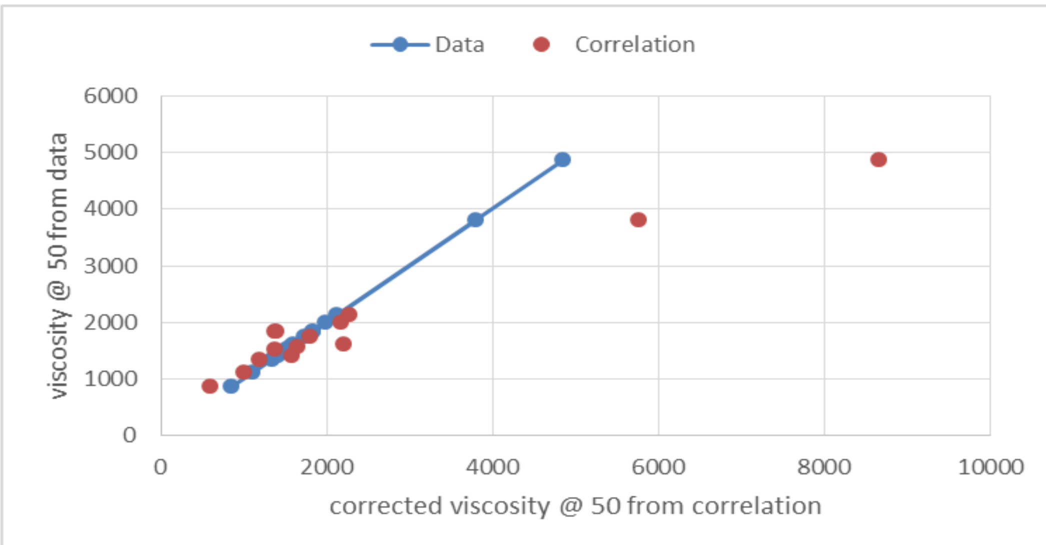


Fig (4-8): original data VS calculated values

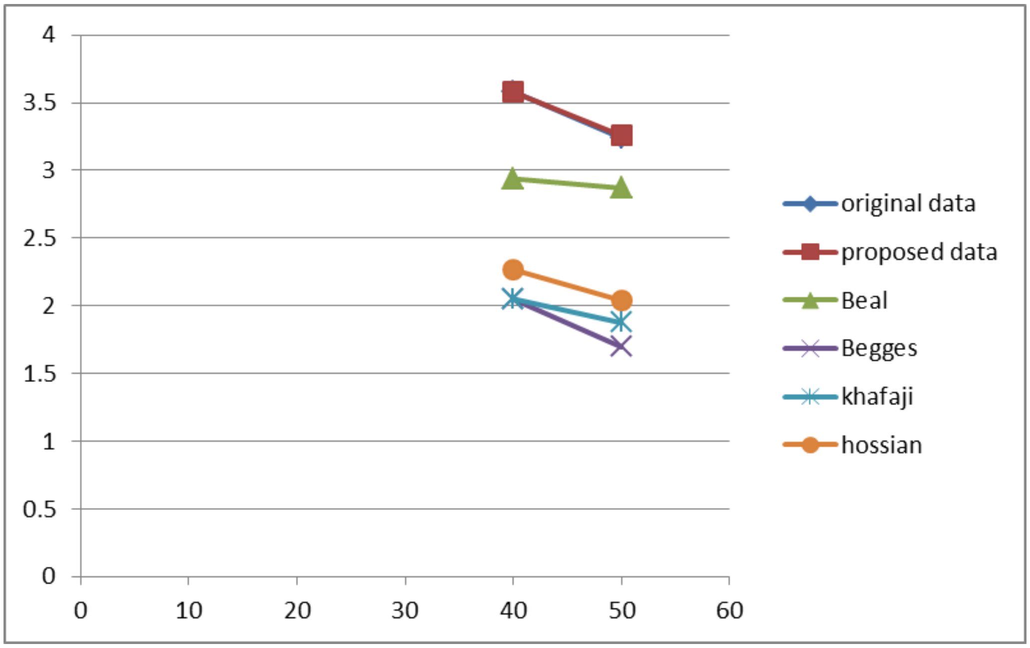


Fig (4-9): comparison of original data with the proposed correlation and calculated values from published correlations for FN field

Chapter 5
Conclusion and Recommendations

5.1 Conclusion:

In this research a new correlation has been developed depending on the fields (FNE and FN) data. The correlation coefficients a and b are calculated as a function of T and the general correlation coefficient R for correlation accuracy and coefficient of determination as the following:

Table (5-1): final results

Field	**Coefficient (a)**	**Coefficient (b)**	**R**	**R^2**
FNE	-1.577 ln (T) + 7.0465	=-0.199 ln (T) + 1.5931	0.99773	*99.54%*
FN	-1.577ln(T) + 6.2096	0.7444ln(T) – 1.7518	0.983444	96.71%

5.2 Recommendations:

- Using more data points to increase validity.
- Lack of viscosity values at different temperatures (only few values were available at 40°C and 50°C) and these values can be estimated by laboratory experiments for more accuracy.
- More studies must be done to develop a correlation for light crude oil.
- Cost estimation must be considered.

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Appendix

Table(4-1): FNE filtered data.

Well name	API 15℃	Viscosity(mPa.s)		
		µ29	µ40	µ50
FNE-9	17.66	4488		757
FNE-15	17.6	4070		712
FNE-25	17.33	5349		
FNE-22	17.67	3956		780
FNE-21	17.56	4338		830
FNE-19	16.42	9855		1529
FNE-24	16.23	13175		1980
FNE-29	16.81	6038		1040
FNE-18	17.78	3561		675
FNE-16	17.62	3847		720
FNE-26	17.01	11022		2005
FNE-2	17.65	3814		750
FNE-17	17.47	4377		810
FNE-4	15.8	14015		1993
FNE2	19.9	2316		943
FNE3	20.41	715		345
FNE-H1	17.49	3635		
FNE-2	19.9	2316	943	
FNE-3	20.41	715	345	
FNE-4	15.8	14015		1993
FNE-5	-	4423		
FNE-6	-	5713		
FNE-7	17.21	4345		
FNE-11	17.73	3779		719
FNE-13	17.79	3738		695
FNE-15	17.6	4070		712
FNE-20	-	4403		
FNE-24	16.23	13175		1980
FNE-27	-	4993		
FNE-28	-	4458		
FNE-30	-	3559		
FNE-31	-	5637		
FNE-8	17.61	3906	1567	761
FNE-86	17.82	11210	-	-

Table(4-2): FN filtered data.

Well Name	API 15℃	Viscosity(mPa.s)		
		29℃	40℃	50℃
FN-90	17.85	6158		1111
FN-76-3	17.67	12482		2131
FN-110	18.09	8075		1520
FN-47	17.83	11982		1986
FN119	18.5	10198	3819	1737
FN-67	17.88	8052		1830
F-17	19.59	3975		857
FN-76-4	15.99	27714		3809
FN-76-3	17.82	12627	4571	
FN-76-4	17.65	15233	5386	
FN-139	17.79	9362	3559	
FN-140	17.34	11710	4369	
Fula-15	17.64	9470	3539	1557
FN-31		22331		
FN-67	17.88	8052		1830
FN 112	16.8	11686	4532	
FN 113	17.9	7889	3053	
FN 114	18.1	7669	3251	
FN 115	17.96	8488	3021	
FN 111	18.09	7440	2865	
FN 119	18.33	7353	2901	
FN 123	18.07	7370	2816	
FN 128	18.1	8058	2977	
FN-39	18.77	4709		
FN-113	18.15	7054		1341
FN-114	17.99	8146		1413
FN-119	18.21	7162		1381
FN-74	17.72	9118		1602
FN-112	16.64	12157		2136
FN-156	16.6	5759		
FN-43	17.02	11877		
FN-45	17.36	8028		
FN-47	17.40	10423		
FN-140	17.65	9818		
FN-76.3	18.24	11638		
FN-48	17.23	12477		
FN-122	17.96	8473		
FN-156	16.6	5759		
FN-60	17.35	10198		

Well name	API	29°C	40°C	50°C
FN-61	16.48	8646		
FN-62	15.07	20796		
FN-65	18.61	10134		
FN-86	16.78	17136		
FN 22	16.91	11817		
FN 23	17.16	11413		
FN 24	16.50	18495		
FN 26	17.41	10273		
FN 58	15.3	19494		
FN D1	16.75	17516		
FN 4	17.58	1099		
FN-18	18.28	8398		
FN-51	17.3	12537		
FN-3R	17.67	9710		
FN-149	18.12	8710		
FN-113	18.15	7054		
FN-114	17.99	8146		
FN-119	18.21	7162		
FN-74	17.72	9118		
FN-112	16.64	12157		
F-10		29844	10318	4294@45
F-2		39412		4859