# Development of Fluid Properties Correlation For Malaysian Crude

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**PETROLEUM ENGINEERING**

**UNIVERSITI TEKNOLOGI PETRONAS**

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Dissertation submitted in partial fulfillment of
the requirement for the
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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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Approved by,

…………………….…………
(Dr. Aliyu Adebayo Sulaimon)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2013

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(NAZRIN BIN RAMLI)

# ABSTRACT

Crude oil is a complex mixture consist of up to 200 or more different organics compounds and mostly there are hydrocarbon. Each type of crude oils from different field might have different combination and concentration of these compounds. The American Petroleum Institute (API) value of a particular crude is the measure of its properties in terms of specific gravity or density. Higher API value implies less denser crude and vice versa. Each field has its own formation and the composition within a field can be similar or be significantly different. Other than API, crude can be characterized based on other non-wanted elements like sulphur which is regulated and must be removed.

The purpose of this project is to develop fluid properties correlation for Malaysian crude. This project will be using a dataset of 93 of PVT data gather from experimental work from previous researchers. There are three characteristic that will be developed in this project, those are bubble point pressure, solution gas oil ratio and oil formation volume factor. The model will be tested using experimental data to show the efficiency of the developed model and comparison will be done to compare new model more suitable for Malaysian crude rather than peviou researcher had done .

This project will be used MATLAB software and Microsoft Excel through the method of Group Method of Data Handling (GMDH) . GMDH is a family of inductive algorithms for computer-based mathematical modeling of multi-parametric datasets that features fully automatic structural and parametric optimization of models. The dataset were established and analyzed using summed contributions from each variable.

Based on the result, this model give better estimation by having lower average relative error compare to the previous one. The model describes and predicts and considered better than other published models for Malaysian crude with minimum error. The model can be used to predict the crude properties as the way out instead of using experimental work. The data are useful as an alternative for experimental works in order to predict the characteristics and can provide guidelines for future modification.

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## NOMENCLATURE

| Symbol | Definition |
|---|---|
| $B_o$ | Oil formation volume factor |
| $P_b$ | Bubble Point Pressure |
| $R_s$ | Solution Gas Oil Ratio |
| $\gamma_{gas}$ | Gas Gravity |
| $\gamma_{oil}$ | Oil Gravity |
| $M_o$ | Effective oil Molecular Weight |
| $\gamma_g$ | Separator Gas Mole Fraction |
| T | Reservoir Temperature |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Studies

Engineers typically require accurate estimation of crude oil properties in order to predict oil reserves, recovery efficiency, and production capacity of a reservoir. These properties will be used in analysis of well test and production data, as well as for production engineering activities such as hydrocarbon system optimization and flow measurement.

The best source of oil property data is laboratory PVT (pressure-volume-temperature) analysis of a reservoir fluid sample. However, in the absence of measured properties of reservoir fluids, these properties should be predicted by using suitable correlation.

Many correlations had been developed for estimating crude oil PVT properties in the past 50 years. Most of these correlations had been developed based on particular field and it might be applicable for certain field or might not applicable when we use it for another field. This work will be focusing on develop black oil correlation for Malaysian Crude. Previously, we use Standing's Correlation (M.1. Omar, A.C. Todd, Heriot-Watt U, 1993)

Another important result of this work is a new bubble point pressure, ($P_b$) solution gas oil ratio, ($R_s$) and formation volume factor, ($B_o$) and these correlation will be developed by using reservoir temperature, gas gravity, oil gravity, bubble point pressure, viscosity and formation volume factor. All parameters mentions might be used all or only certain of it.I am developing correlations by using Group Method of Data Handling Method (GMDH).This method will be described in detail in the next section.

Most of the correlations have been developed in the petroleum literature to estimate those characteristics of crude. However, some correlation were derived based on particular field depend on the researcher who developed it.Practicing engineer have used this empirical correlation of laboratory data. The efficiency of this correlation lies in the understanding of their development and the knowledge of their limitation. The most widely used black oil correlations are discussed in literature review.

## 1.2 Problem Statement

In reservoir engineering calculations, fluid property data are one of the important input data sets. These data can be obtained either by conducting a laboratory study on reservoir fluids or estimated from empirical correlations. Eventhough laboratory results will be giving better accuracy but the results are totally depend on the accuracy of the fluid samples, especially when the reservoir has depleted below the bubble point pressure. When the objective of experimental data cannot be achieved or there is a need to cross check the laboratory results, derivation from PVT correlations empirically can be used to estimate the reservoir fluid properties.

However, for Malaysian crude the crude correlations are yet to be developed and none of the existing correlations give good estimation of fluid properties for Malaysian crudes (Omar, and Todd, 1993). The PVT data are used in the calculation of reserves, material balance calculations and design of the surface operation facilities. The most commonly used correlation for Malaysian crude to determine the bubble point pressure, solution gas oil ratio and oil formation volume factor are those from Standing’s correlation (Omar,1993). Since the correlating factors for these correlations are obtained empirically based on the field that had been used to develop the correlation, it is difficult to achieve higher accuracy as expected when these correlations are applied to crude oil systems in Malaysia which have different physical and chemical properties than those of the developed correlation.

## 1.3 Objective

The objective of this project is to study the fluid properties correlation for Malaysian crude. There are also several objectives to be achieved in this study:

i. To study the current correlation being used for Malaysian crude
ii. To study the advantages and disadvantages or the current correlation that being used in the oil and gas industry.
iii. To develop new and suitable correlation for Malaysian crude.
iv. To ensure the new correlation gives good estimation of fluid properties by applying with the experimental data and compare both of the result.

## 1.4 Scope of the study

The scope of the study is to conduct research on the theory and the definition pf terms related to the study. In order to to know the current situation in this area, research will be done to see which correlation being used in industry. Lastly, a research to choose the right way to develop the method to finish this project also will be done.

# CHAPTER 2

# LITERATURE REVIEW AND THEORY

In this chapter, will present the popular black oil correlation developed during the period from 1947 to 1994. This section provides the necessity background perspective of the necessity for the development of the new correlation that will be present in Result and Discussion section later. This literature review considers work done by the following researchers: Standing, Vasquez & Beggs, Glaso, Al-Marhoun, Petrosky and Kartoatmodjo & Schmidt.

Although they presented correlating equation to estimates a variety of PVT properties, my work will be focusing on develop for estimating the bubble-point pressure,($P_b$), as well as estimating the oil formation volume factor, ($B_o$) and the solution gas-oil ratio, ($R_s$) correlations.

## 2.1 Standing Correlation

In 1947, Standing published correlation for estimating bubble-point pressure, ($P_b$) and oil formation volume factors ($B_o$) of gas saturated oils using field values of resevoir temperature, solution gas oil-oil-ratio at the bubble point, and the oil and gas gravities. Basically, Standing used 105 experimentally data points obained from 22 different crude oil/naturals gas mixtures from California Fields. The Standing's correlation are:

Bubble-Point Pressure

$$p_{bp} = 18.2 \cdot \left( \left( \frac{R_s}{\gamma_g} \right)^{0.83} \cdot \frac{10^{0.0009T}}{10^{0.0125\gamma_o}} - 1.4 \right) \quad (2.1)$$

Solution Gas-Oil Ratio

$$R_s = \left( \left( \frac{p}{18.2} + 1.4 \right) \cdot \frac{10^{0.0125\gamma_o}}{10^{0.0009T}} \right)^{\frac{1}{0.83}} \cdot \gamma_g \quad (2.2)$$

Oil Formation Volume Factor

$$B_o = 0.972 + 1.47 \cdot 10^{-4} \left( R_s \left( \frac{\gamma_g}{\gamma_o} \right)^{0.5} + 1.25 \cdot T \right)^{1.175} \quad (2.3)$$

Standing used two-stage flash liberation tests to collect the experimental data and the values that obtained by him were solution gas-oil ratios, gas gravity, oil gravity and formation volume factor and then were used to develop his correlation. During the experiments,the gas released must be free of Nitrogen ($N_2$) and Hydrogen Sulfide ($H_2S$). However, a few samples did contain carbon dioxide ($CO_2$) in quantities less than 1 mole percent. In short, Standing's correlation should be considered valid only for black oil systems with minimum composition of any non-hydrocarbon components.

Standing just developed bubble point pressure and oil formation volume factor correlations. Solution gas oil ratio, ($R_s$) been developed through the rearrangement of bubble point pressure to get the correlation for solution gas oil ratio (Standing, 1947). Based on the Standing's report, average relative error (ARE) obtained by him was 4.8% and 1.17% for $P_b$ and $R_s$ (Standing, 1947). The range of data used by Standing to come out with his correlation are:

$$\begin{aligned} 130 &< P_b < 7000 \text{ psia} \\ 100 &< T < 258\ ^\circ\text{F} \\ 20 &< Rs < 1425 \text{ scf/STB} \\ 16.5 &< \gamma_{API} < 63.8\ ^\circ\text{API} \\ 0.59 &< \gamma_g < 0.95 \text{ (air=1)} \end{aligned} \quad (2.4)$$

## 2.2 Lasater Correlation

In 1958, Lasater came up a correlation for bubble-point pressure, ($P_b$) based on 158 experimentally data using 137 diferent crude oil system from reservoirs in Canada, U.S, and South America. The natural gas associated with these crudes essentially free of non-hydrocarbon.

To be used for developing his correlation, he assumed that a unique molecular weight could be assigned to a given black oil sample, where it was called the '*effective oil molecular weight'*,(Lasater, 1958).The effective oil molecular weight was correlated as a function of the API gravity of the oil. He introduced a bubble-point pressure factor and correlated this parameter with the separator gas mole fraction.Eventhough the original correlation was presented graphically in the form of two charts, he had developed the correlation to give the best fit of Lasater's graphical results.

Bubble Point Pressure

$$P_b = \frac{0.2268 \, x \, 10^{4.258\gamma_g} \, (T+459.67)}{\gamma_g} \qquad (\gamma_g \leq 0.7) \qquad (2.5)$$

$$P_b = \frac{8.26\gamma_g^{3.56} \, (T+459.67)}{\gamma_g} \qquad (\gamma_g > 0.7) \qquad (2.6)$$

Separator Gas Mole Fraction

$$\gamma_g = \frac{R_S/379.3}{\frac{R_S}{379.3}+\frac{350\gamma_O}{Mo}} \qquad (2.7)$$

Effective Oil Molecular Weight

$$M_o = 630 - 10\gamma_{API} \qquad (API \leq 40)$$

$$M_o = 73{,}110\gamma_{API}^{-1.562} \qquad (API < 40) \qquad (2.8)$$

Bubble-Point Pressure Factor

$$y_g = \frac{\ln(\frac{P_f}{0.2268})}{4.258} \qquad (P_f \leq 5) \qquad (2.9)$$

$$y_g = (\frac{Pf - 1.95}{8.26})^{0.2809} \qquad (P_f > 5)$$

Solution Gas Oil Ratio

$$R_s = \frac{132{,}755\gamma_o\gamma_g}{M_o(1-y_g)} \qquad (2.10)$$

The correlation for solution gas oil ration, ($R_s$) as a result from the rearrangement of bubble point pressure. Lasater did not develop correlation for oil formation volume factor, $B_o$. The ranges of data used to develop his correlation as below:

$$\begin{aligned} 48 &< P_b < 5780 \text{ psia} \\ 100 &< T < 258\ °F \\ 3 &< Rs < 2905 \text{ scf/STB} \\ 17.9 &< \gamma_{API} < 51.1\ °API \\ 0.574 &< \gamma_g < 1.223 \text{ (air=1)} \end{aligned} \qquad (2.11)$$

**2.3 Vasquez And Beggs Correlations**

In 1976, Vasquez and Beggs used experimental data more than 600 crude oil system to develop empirical correlation to predict several crude oil properties such as solution gas-oil ratio, ($R_s$) and the oil formation volume factor, ($B_o$). Their data included approximately 6000 data points, measured over wide ranges of pressure, temperature, oil gravity, and gas gravity.

Vasquez and Beggs found that the gas gravity was a main correlating parameter (Vasquez and Beggs, 1980) and unfortunately, this is often one of the variable measured with the least degree of consistency. The gravity of the evolved gas depends on the pressure and temperature of the separators, which might not be available. The gas gravity used to develop all of the correlations presented by Vasquez and Beggs was the gas gravity which would have resulted from a two stage separation. The first separation stage was chosen as 100 psig and the second stage was the stock tank which is 0 psig.(Vasquez and Beggs, 1980).

Correlation for solution gas oil ratio was originally planned to estimate solution gas oil ratio values at and below bubble-point pressure, this equation can be arranged and used to solve for the bubble-point pressure.

Solution Gas-Oil Ratio

$$R_s = C_1 \gamma_g p^{C_2} \exp\left(C_3\left(\frac{\gamma_o}{(T+460)}\right)\right) \tag{2.12}$$

Bubble-Point Pressure

$$p_{bp} = \left(\frac{R_s}{C_1 \gamma_g \exp\left(C_3\left(\frac{\gamma_o}{(T+460)}\right)\right)}\right)^{\frac{1}{C_2}} \tag{2.13}$$

where

| **Coefficient** | **$\gamma_o$ <= 30°API** | **$\gamma_o$ > 30°API** |
|---|---|---|
| $C_1$ | 0.0362 | 0.0178 |
| $C_2$ | 1.0937 | 1.1870 |
| $C_3$ | 25.7240 | 23.9310 |

(2.14)

Oil Formation Volume Factor

$$B_o = 1 + C_1 R_s + C_2 (T-60)\left(\frac{\gamma_o}{\gamma_g}\right) + C_3 R_s (T-60)\left(\frac{\gamma_o}{\gamma_g}\right) \tag{2.15}$$

where

| Coefficient | $\gamma_o$ <= 30°API | $\gamma_o$ > 30°API |
|---|---|---|
| $C_1$ | $4.677\text{x}10^{-4}$ | $4.670\text{x}10^{-4}$ |
| $C_2$ | $1.751\text{x}10^{-5}$ | $1.100\text{x}10^{-5}$ |
| $C_3$ | $-1.811\text{x}10^{-8}$ | $1.377\text{x}10^{-9}$ |

The range of data used to develop his correlation as below:

$$\begin{array}{rcl} 15 < & P_b & < 6055 \text{ psia} \\ 70 < & T & < 295\ °F \\ 0 < & Rs & < 2199 \text{ scf/STB} \\ 15.3 < & \gamma_{API} & < 59.5\ °API \\ 0.511 < & \gamma_g & < 1.351 \text{ (air=1)} \end{array}$$

(2.16

**2.4 Glaso Correlation**

Glaso presented his correlation in 1980. It was used to estimate bubble-point pressure, ($P_b$) as well as the solution gas-oil ratio, ($R_s$) and the oil formation volume factor, ($B_o$) at the gas saturated of black oils. Glaso took data from 26 different crude oil system, primarily from North Sea Region.(Glaso, 1980). Glaso approached was based on the theory of the paraffinicity of the oil influences the gas equilibrium of black oil mixtures containing methane. Using graphical method and regression analysis, Glaso come out with his correlation as below:

Bubble-Point Pressure

$$\log(p_{bp}) = 1.7669 + 1.7447 \cdot \log(x) - 0.30218 \cdot (\log(x)^2) \tag{2.17}$$

$$p_{bp} = 10^{\log(p_{bp})} \quad (2.18)$$

where $x = \left(\frac{R_s}{\gamma_g}\right)^{0.816} \frac{T^{0.172}}{\gamma_o^{0.989}}$

Solution Gas-Oil Ratio

$$R_s = \left(\frac{x \cdot \gamma_o^{0.989}}{T^{0.172}}\right)^{\frac{1}{0.816}} \gamma_g \quad (2.19)$$

where

$$\log(x) = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

$$x = 10^{\log(x)}$$

$$a = -0.30218$$
$$b = 1.7447$$
$$c = 1.7669 - \log(p)$$

Oil Formation Volume Factor

$$\log(B_o - 1) = \log\left(-6.58511 + 2.91329 \cdot \log(y) - 0.27683 \cdot (\log(y))^2\right) \quad (2.20)$$

$$B_o = 1 + 10^{\log(B_o - 1)}$$

where

$$y = R_s \left(\frac{\gamma_g}{\gamma_o}\right)^{0.526} + 0.968 \cdot T$$

Glaso also provided a bubble point correlation for volatile oils as well as method for correcting the predicted bubble-point pressure for the presence of $CO_2$, $N_2$, and $H_2S$ in the surface gases. The range of data used as below:

$$165 < P_b < 7142 \text{ psia}$$
$$80 < T < 280\ °F$$
$$90 < Rs < 2637 \text{ scf/STB} \qquad (2.21)$$
$$22.3 < \gamma_{API} < 48.1\ °API$$
$$0.650 < \gamma_g < 1.273 \text{ (air=1)}$$

**2.5 Al-Marhoun Correlations**

In 1985, Al- Marhoun developed his correlations for estimating the bubble-point pressure,($P_b$) as well as the solution gas-oil ratio, ($R_s$) and the oil formation volume factor,($B_o$) for Middle East crude oils at the bubble point pressure. These correlations were developed froam a database 69 bottomhole fluid samples and expressed as functions of reservoir temperature, gas gravity, solution gas-oil ratio and stock tank oil gravity. Al-Marhoun used nonlinear regression methods to develop the following correlation:

Bubble-Point Pressure,

$$P_b = 5.38088 \times 10^{-3} R_s^{0.715082} \gamma_g^{-1.87784} \gamma_o^{3.1437} (T + 460)^{1.32657} \qquad (2.22)$$

Oil Formation Volume Factor$_o$

$$R_s = 0.497069 + 8.26963 \times 10^{-4}(T + 460) + 1.82594 \times 10^{-3}F + 3.18099 \times 10^{-6}F^2$$

where (2.23)

$$F = R_s^{0.74239} \gamma_g^{0.323294} \gamma_o^{-1.202040}$$

Solution Gas-Oil Ratio

$$R_s = \left( \frac{x}{\gamma_g^{-1.879109} \cdot \gamma_o^{3.04659} \cdot T^{1.302347}} \right)^{\frac{1}{0.722569}} \qquad (2.24)$$

where

$$x = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \qquad a = -2.278475 \cdot 10^{-9}$$
$$b = 7.02362 \cdot 10^{-3}$$
$$c = -64.13891 - p$$

Al-Marhoun reported an avergae error 0.03% for bubble point pressure and average relative error of -0.01% for oil formation volume factor. (Al- Marhoun,1988) The ranges of data used to develop his correlation are:

$$\begin{aligned} 130 &< P_b < 3573 \text{ psia} \\ 74 &< T < 240\ °F \\ 26 &< Rs < 1602 \text{ scf/STB} \\ 19.4 &< \gamma_{API} < 44.6\ °API \\ 0.752 &< \gamma_g < 1.367 \ (\text{air}=1) \end{aligned} \tag{2.25}$$

**2.6 Petrosky Correlations**

In 1990, Petrosky developed empirical PVT correlation for Gulf of Mexico crude oils. His correlation included the bubble-point pressure, solution gas-oil ratio and oil formation volume factor at the bubble point. Petrosky used a total of 128 data and he developed his correlation by using non-linear regression analysis.

Bubble –Point Pressure

$$p_{bp} = 112.727 \cdot \left( \frac{R_s^{\,0.5774}}{\gamma_g^{\,0.8439}} \cdot 10^x - 12.34 \right) \tag{2.26}$$

where

$$x = 4.561 \cdot 10^{-5} \cdot T^{1.3911} - 7.916 \cdot 10^{-4} \cdot \gamma_o^{\,1.541}$$

Solution Gas-Oil Ratio

$$R_s = \left( \left( \frac{p}{112.727} + 12.34 \right) \cdot \gamma_g^{\,0.8439} \cdot 10^x \right)^{1.73184} \tag{2.27}$$

Oil Formation Volume Factor

$$B_o = 1.0113 + 7.2046 \cdot 10^{-5} \cdot \left( R_s^{\,0.3738} \left( \frac{\gamma_g^{\,0.2914}}{\gamma_o^{\,0.6265}} \right) + 0.24626 \cdot T^{0.5371} \right)^{3.0936} \tag{2.28}$$

Petrosky's correlation get average relative error of -0.17% for $P_b$ and -0.01% for $B_o$.(Petrosky, 1990) The ranges of data used to develop his correlation are:

$$\begin{aligned} 1574 &< P_b < 6523 \text{ psia} \\ 114 &< T < 288\ °F \\ 217 &< Rs < 1406 \text{ scf/STB} \\ 16.3 &< \gamma_{API} < 45.0\ °API \\ 0.578 &< \gamma_g < 0.851 \text{ (air=1)} \end{aligned} \quad (2.29)$$

**2.7 Kartoatmodjo And Schmidt Correlations**

In 1994, Kartoatmodjo and Schmidt presented what should be considered the most comprehensive study of balck oil PVT properties. Kartoatmodjo and Schmidt developed a new set of empirical correlations based on a large data collection developed from reservoirs all over the world. The authors used to independent databases; the first database was used to develop the correlations while the second was used to verify the developed correlation. The first database contained 740 different crude oil samples and the second database contained 998 data points. The following were presented by them:

Bubble-Point Pressure

$$P_b = \left[\frac{R_S}{0.05958\gamma_g^{0.7972}10^{13.1405\gamma_{API}(T+460)}}\right]^{0.9986} \quad (API \leq 30)$$

(2.30)

$$P_b = \left[\frac{R_S}{0.03150\gamma_g^{0.7587}10^{11.28955\gamma_{API}(T+460)}}\right]^{0.9143} \quad (API > 30)$$

Solution Gas-Oil Ratio

$$R_s = 0.05958\gamma_g^{0.7972}p^{1.0014}10^{13.1405\gamma_{API}(T+460)} \quad (API \leq 30)$$

(2.31)

$$R_s = 0.05958\gamma_g^{0.7972}p^{1.0014}10^{13.1405\gamma_{API}(T+460)} \quad (API > 30)$$

Oil Formation Volume Factor

$$B_o = 0.98496 + 0.0001 \times F^{1.50} \qquad (2.32)$$

where

$$F = R_s^{0.755}\gamma_g^{0.25}\gamma_o^{-1.5} + 0.45T$$

Kartoatmodjo and Schmidt reported average relative errors of 3.34% for $P_b$ and 4.68% for $R_s$ and 0.104 for $B_o$.( Kartoatmodjo and Schmidt, 1994). The ranges of data used to develop are:

$$\begin{aligned} 15 &< P_b < 6054 \text{ psia} \\ 75 &< T < 320\ °F \\ 14 &< Rs < 2473 \text{ scf/STB} \\ 14.4 &< \gamma_{API} < 58.9\ °API \\ 0.37 &< \gamma_g < 1.71 \text{ (air=1)} \end{aligned} \qquad (2.33)$$

From the solution gas-oil ratio equations presented in this chapter, it is clear that although each of the authors (excepts Vasquez ang Beggs) developed their correlations for bubble point pressure, and then arranged these correlation to solve for solution gas-oil ratio. In practice, for pressure below bubble point, the bubble point pressure term is replaced by other values of pressure, with all other variable remaining the same. This concept is assumed to be valid because all conditions below the original bubble-point pressure also represent saturated conditions.

# CHAPTER 3

# METHODOLOGY / PROJECT WORK

## 3.1 Data Collection

For the data collections, the PVT data can be collected from published literature. These data can be found in ‘Development of New Modified Black Oil Correlation’, (Omar,1993).During dataset preparation, the first step is to write all the data into Microsoft Excel. This file will be used by MATLAB Software to perform the prediction. The data in Table 1 will be used as a dataset for MATLAB code to process the data comprised in this dataset and predict the best fit model (the model which can give the most accurate results between the experimental and predicted values). The accuracy of the obtained results will be depending on how accurate the data set table build.The PVT data of Malaysian crude will be shown below:

Table 1:PVT Data of Malaysian Crude

| $P_b$, (psia) | $B_o$, (bbl/STB) | μ, (cp) | $R_s$ (scf/STB) | $\gamma_{gas}$ | $\gamma_{oil}$, (API) | T, ( °F) |
|---|---|---|---|---|---|---|
| 2193 | 1.425 | 0.459 | 634 | 0.717 | 45.3 | 214 |
| 2402 | 1.619 | 0.627 | 844 | 0.919 | 40.7 | 242 |
| 2194 | 1.438 | 0.376 | 664 | 0.750 | 42.9 | 214 |
| 1562 | 1.261 | 0.693 | 463 | 1.281 | 38.9 | 196 |
| 1225 | 1.176 | 0.806 | 267 | 1.263 | 38.0 | 211 |
| 1660 | 1.221 | 1.605 | 421 | 1.298 | 37.1 | 203 |
| 1530 | 1.241 | 1.211 | 355 | 1.228 | 35.0 | 209 |
| 1760 | 1.222 | 1.625 | 372 | 1.195 | 31.0 | 211 |
| 1225 | 1.171 | 0.806 | 260 | 1.168 | 38.0 | 211 |
| 1700 | 1.232 | 0.826 | 364 | 1.028 | 36.6 | 206 |
| 1370 | 1.192 | 0.785 | 313 | 1.174 | 38.2 | 205 |
| 1593 | 1.268 | 0.625 | 421 | 1.181 | 39.8 | 203 |
| 1982 | 1.246 | 0.802 | 415 | 1.140 | 36.1 | 224 |
| 1450 | 1.214 | 1.534 | 359 | 1.250 | 35.4 | 208 |
| 1570 | 1.241 | 0.938 | 366 | 1.315 | 39.0 | 207 |
| 1750 | 1.521 | 0.336 | 714 | 0.820 | 48.7 | 189 |
| 1810 | 1.423 | 0.316 | 606 | 0.707 | 50.5 | 189 |
| 1658 | 1.212 | 0.538 | 368 | 0.865 | 41.4 | 186 |
| 2632 | 1.578 | 0.255 | 888 | 0.730 | 49.3 | 228 |
| 1755 | 1.481 | 0.339 | 694 | 0.790 | 49.5 | 190 |
| 1728 | 1.259 | 0.481 | 397 | 0.941 | 41.8 | 215 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2058 | 1.52 | 0.159 | 765 | 0.939 | 48.8 | 205 |
| 2221 | 1.362 | 0.310 | 547 | 0.693 | 45.3 | 238 |
| 2274 | 1.451 | 0.327 | 546 | 0.689 | 45.2 | 245 |
| 2081 | 1.315 | 0.356 | 494 | 0.677 | 44.5 | 230 |
| 1220 | 1.173 | 0.930 | 267 | 0.884 | 31.4 | 174 |
| 2390 | 1.538 | 0.736 | 956 | 0.811 | 43.2 | 226 |
| 1302 | 1.170 | 1.243 | 242 | 0.824 | 31.4 | 180 |
| 1085 | 1.128 | 1.931 | 169 | 0.638 | 29.1 | 187 |
| 1271 | 1.139 | 1.814 | 198 | 0.775 | 29.2 | 187 |
| 1195 | 1.152 | 1.257 | 214 | 0.664 | 31.9 | 180 |
| 2562 | 1.491 | 0.383 | 741 | 0.795 | 42.0 | 234 |
| 0790 | 1.168 | 0.940 | 274 | 1.005 | 39.8 | 150 |
| 1530 | 1.334 | 0.493 | 566 | 0.817 | 45.2 | 185 |
| 1510 | 1.365 | 0.438 | 522 | 0.730 | 47.8 | 189 |
| 1741 | 1.409 | 0.357 | 563 | 0.759 | 48.4 | 217 |
| 2111 | 1.471 | 0.146 | 692 | 0.740 | 53.2 | 220 |
| 1758 | 1.442 | 0.212 | 628 | 0.762 | 48.4 | 199 |
| 1769 | 1.401 | 0.365 | 585 | 0.765 | 49.1 | 204 |
| 1805 | 1.424 | 0.351 | 599 | 0.767 | 48.1 | 204 |
| 1414 | 1.249 | 0.590 | 425 | 1.155 | 41.0 | 185 |
| 2540 | 1.712 | 0.236 | 1020 | 0.730 | 50.4 | 239 |
| 1790 | 1.496 | 0.212 | 686 | 0.800 | 47.1 | 224 |
| 1620 | 1.265 | 0.416 | 404 | 0.847 | 42.9 | 188 |
| 2165 | 1.517 | 0.244 | 856 | 0.916 | 46.6 | 211 |
| 2550 | 1.884 | 0.225 | 1170 | 0.858 | 48.9 | 231 |
| 2360 | 1.716 | 0.172 | 993 | 1.014 | 48.4 | 267 |
| 2020 | 1.321 | 0.606 | 491 | 1.051 | 39.2 | 211 |
| 2145 | 1.697 | 0.246 | 1022 | 1.045 | 47.9 | 216 |
| 2090 | 1.680 | 0.250 | 1011 | 1.050 | 48.2 | 210 |
| 2822 | 1.695 | 0.238 | 1006 | 0.876 | 46.8 | 280 |
| 2290 | 1.653 | 0.724 | 990 | 0.801 | 43.1 | 208 |
| 2500 | 1.843 | 0.197 | 1355 | 0.877 | 48.8 | 228 |
| 3148 | 1.954 | 0.212 | 1440 | 0.788 | 50.3 | 250 |
| 0952 | 1.092 | 2.232 | 142 | 0.667 | 26.9 | 146 |
| 2368 | 1.282 | 0.481 | 440 | 0.756 | 32.5 | 235 |
| 2310 | 1.345 | 0.380 | 636 | 0.801 | 38.3 | 161 |
| 2408 | 1.384 | 0.380 | 683 | 0.821 | 38.6 | 166 |
| 3449 | 1.503 | 0.407 | 899 | 0.769 | 39.3 | 195 |
| 3440 | 1.455 | 0.345 | 863 | 0.764 | 37.4 | 192 |
| 1910 | 1.238 | 0.990 | 384 | 0.733 | 32.6 | 152 |
| 2168 | 1.297 | 0.417 | 544 | 0.789 | 37.1 | 164 |
| 2480 | 1.357 | 0.360 | 686 | 0.737 | 38.2 | 171 |
| 2350 | 1.352 | 0.380 | 680 | 0.818 | 37.0 | 169 |
| 1744 | 1.325 | 0.351 | 524 | 0.727 | 40.5 | 190 |
| 3142 | 1.484 | 0.372 | 761 | 0.723 | 33.3 | 247 |
| 2970 | 1.445 | 0.227 | 737 | 0.707 | 34.6 | 239 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1951 | 1.23 | 0.527 | 367 | 0.627 | 37.5 | 173 |
| 2616 | 1.371 | 0.386 | 667 | 0.842 | 37.7 | 177 |
| 1818 | 1.153 | 1.105 | 285 | 0.704 | 26.6 | 152 |
| 2611 | 1.525 | 0.340 | 810 | 0.789 | 39.6 | 225 |
| 1058 | 1.130 | 0.890 | 220 | 0.790 | 32.3 | 127 |
| 3387 | 1.505 | 0.338 | 919 | 0.673 | 41.4 | 194 |
| 1492 | 1.201 | 0.710 | 341 | 0.716 | 37.4 | 159 |
| 935 | 1.085 | 1.460 | 150 | 0.612 | 31.9 | 125 |
| 3780 | 1.581 | 0.380 | 1023 | 0.658 | 40.2 | 209 |
| 3063 | 1.301 | 0.483 | 577 | 0.737 | 31.2 | 180 |
| 2423 | 1.399 | 0.294 | 713 | 0.765 | 40.1 | 169 |
| 2360 | 1.399 | 0.325 | 694 | 0.765 | 40.0 | 167 |
| 1838 | 1.208 | 0.810 | 366 | 0.664 | 34.8 | 153 |
| 2106 | 1.194 | 1.250 | 344 | 0.648 | 28.9 | 161 |
| 1390 | 1.154 | 0.880 | 287 | 0.718 | 33.4 | 141 |
| 2470 | 1.429 | 0.430 | 760 | 0.758 | 40.0 | 166 |
| 2692 | 1.230 | 0.503 | 393 | 0.631 | 38.6 | 179 |
| 3420 | 1.683 | 0.330 | 1212 | 0.685 | 42.3 | 194 |
| 3160 | 1.707 | 0.305 | 1213 | 0.705 | 45.4 | 186 |
| 1765 | 1.184 | 0.600 | 345 | 0.695 | 34.0 | 151 |
| 1780 | 1.362 | 0.470 | 509 | 0.853 | 37.8 | 205 |
| 3063 | 1.287 | 0.448 | 586 | 0.628 | 32.2 | 180 |
| 2609 | 1.622 | 0.350 | 1019 | 1.038 | 40.4 | 198 |
| 2344 | 1.429 | 0.460 | 791 | 0.743 | 40.4 | 184 |
| 1698 | 1.408 | 0.460 | 646 | 0.964 | 40.0 | 193 |
| 3851 | 1.466 | 0.371 | 819 | 0.663 | 34.1 | 243 |

### 3.2 Data Preparation

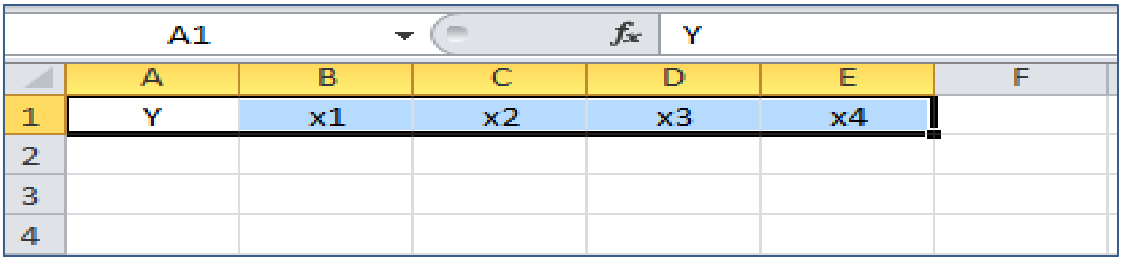


Figure 1: Microsoft Excel

Before the data being imported into MATLAB, it must be arranged first according to what we are looking for.As example, if we would like to predict bubble point pressure, the experimental datamust be write at column A and other parameter can be put any column as long as not column A. When the file being imported into MATLAB, column A will be automatically read by MATLAB as Y and other column as $X_1$, $X_2$ and etc. So, the output later will come out in form of Y, $X_1$, $X_2$,$X_3$ and etc. In this project, there are three correlation will be developed. Thus three files of Microsoft Excel need to be prepared namely with Bubble Point Pressure, Solution Gas Oil Ratio and Oil Formation Volume Factor.

### 3.3 Group Method of Data Handling Method

This project will be using Group Method of Data Handling (GMDH) method to perfom the prediction.GMDH is a family of inductive algorithms for computer-based mathematical modeling of multi-parametric datasets that features fully automatic structural and parametric optimization of models. GMDH is used in such fields as data mining, knowledge discovery, prediction, complex systems modeling, optimization and pattern recognition.GMDH algorithms are characterized by inductive procedure that performs sorting-out of gradually complicated polynomial models and selecting the best solution by means of the so-called external criterion.A GMDH model with multiple inputs and one output is a subset of components of the base function :

$$Y(x_1, \ldots, x_n) = a_0 + \sum_{i=1}^{m} a_i f_i \qquad (3.1)$$

where f are elementary functions dependent on different sets of inputs, a are coefficients and m is the number of the base function components.In order to find the best solution GMDH algorithm consider various component subsets of the base function called partial models. Coefficients of these models estimated by the least squares method. GMDH algorithm gradually increase the number of partial model components and find a model structure with optimal complexity indicated by the minimum value of an external criterion. This process is called self-organization of models.The most popular base function used in GMDH is the gradually complicated Kolmogorov-Gabor polynomial :

$$Y(x_1, \ldots, x_n) = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n}\sum_{j=i}^{n} a_{ij} x_i x_j + \sum_{i=1}^{n}\sum_{j=i}^{n}\sum_{k=j}^{n} a_{ijk} x_i x_j x_k + \cdots \qquad (3.2)$$

GMDH approach will be very useful because:

i. The optimal complexity of model structure is found, adequate to level of noise in data sample. For real problems solution with noised or short data, simplified forecasting models are more accurate.
ii. The number of layers and neurons in hidden layers, model structure and other optimal Neural Network parameters are determined automatically.
iii. It guarantees that the most efficient will be found and the method does not miss the best solution during sorting of all variants.
iv. Input variables are used any non-linear functions, which can influence the output variable.
v. It automatically finds interpretable relationships in data and selects effective input variables.
vi. GMDH sorting algorithms are rather simple for programming..
vii. Method uses information clearly from data sample and minimizes influence of assumptions about results of modeling.
viii. Approach gives possibility to find unbiased physical model of object and the same for future samples.

MATLAB has been used to write the code and predict the fluid properties correlation.The author will be supervised by an experienced person in MATLAB. The computing facility is provided by UTP. In order to develop the model, in this project, there will be three models od correlation will be develope. All of them will be using the same coding but the different is how the data will be arranged in the Microsoft Excel file as explained earlier. As mentioned earlier, GMDH method will eliminate the least contribution factor to the result and the will use the remaining variable to develop the correlation.Figure below show how the model will be showed by MATLAB at the end of the process.

```
Layer #1
Number of neurons: 1
y = 4677.68367375698 -114.913506589439*x5 -5622.90910059234*x4 +9.5514441670233*x3 +14.2557079884696*x4*x5
```

Figure 2:Output displayed by MATLAB

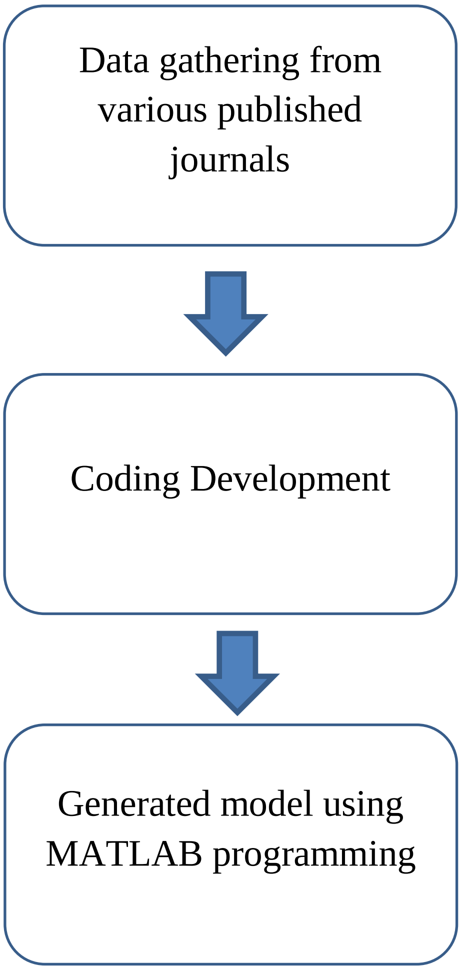


Figure 3:Basic Step in GMDH Model Generation

### 3.4 Statistical Error Analysis

There are four main statistical and error analysis parameters that will be considered in this study. These parameters help to evaluate the accuracy of the predicted value of fluid properties obtained from the estimations.

#### 3.4.1 Average Relative Error

This parameter is to measure the average value of the absolute relative deviation of the measured value from the experimental data. The value of ARE is expressed in percent. The parameter can be defined as:

$$ARE = \frac{1}{N}\sum_{i=1}^{n}\left|\frac{X_{Exp}-X_{Est}}{X_{Exp}}\right| \tag{3.2}$$

### 3.4.2 Average Absolute Deviation

The absolute difference between that element and a given point. . The parameter can be defined as:

$$\frac{1}{n}\sum_{i=1}^{n}|x_i - m(X)|. \tag{3.3}$$

Where,

$m(X)$ = Mean of the dataset

$X_{i=}$ Data Element

### 3.4.3 Correlation Coefficient and Correlation of Determination

The purpose of performing correlation coefficient is to describe the strength of the association between two variables namely experimental and calculated values that obtained from the developed correlation. The value of correlation coefficients varies from -1.0 to +1.0 where zero indictae no relationship between experimental and calculated while +1.0 shows good estimation through the developed correlation.The correlation coefficient can be calculated using the following equation.

$$R= \sqrt{1-\left[\sum_1^n\left(X_{exp}-X_{Est}\right)^2 / \sum_1^n\left(X_{exp}-\bar{X}\right)^2\right]} \tag{3.4}$$

where

$$\bar{X} = \frac{1}{n}\sum_1^n(X_{exp})$$

The square value of correlation coefficient is known as coefficient of detennination,$R^2$. The coefficient of detennination is defined as the proportion of the validity in the predicted value that is encountered for experimental value.

### 3.5 GANTT CHART AND KEY MILESTONE

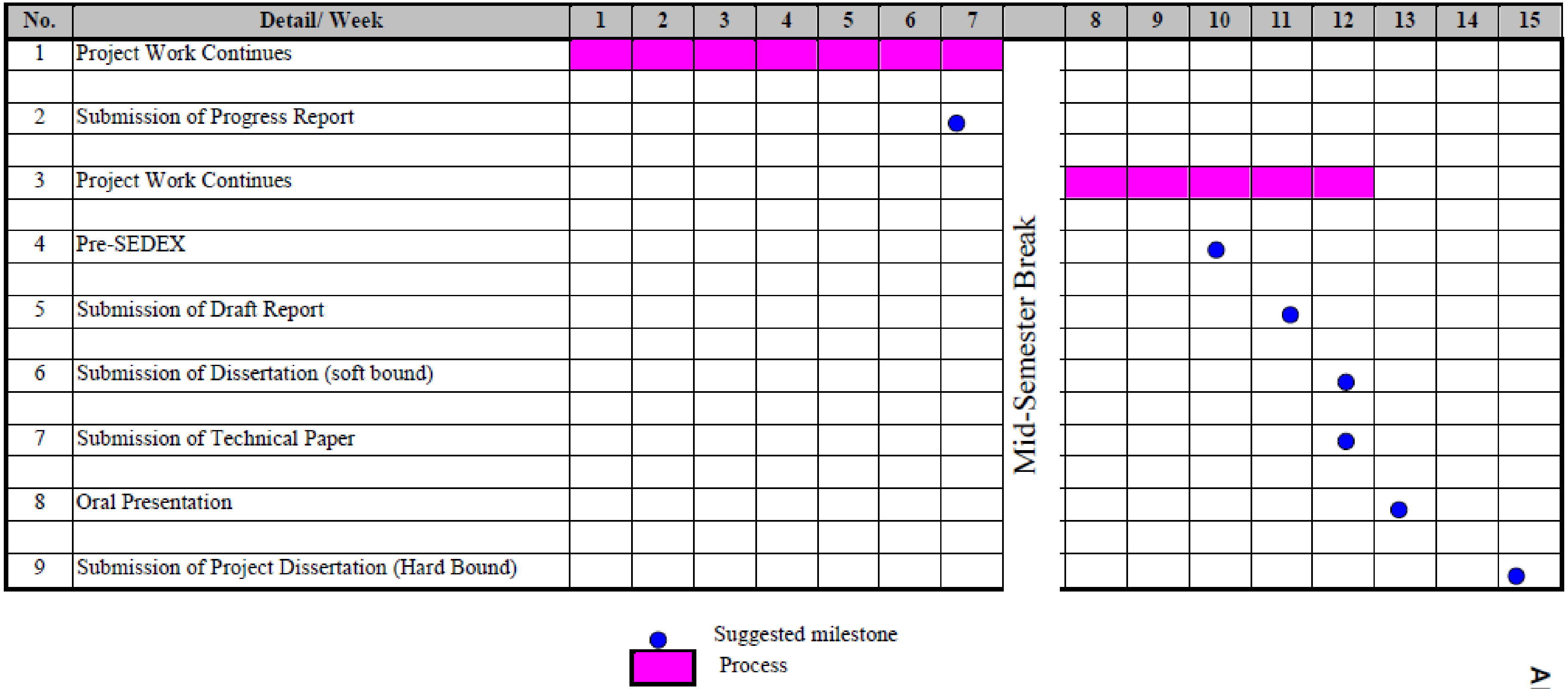


Figure 4:Gantt Chart and Key Milestone for FYP 2

# CHAPTER 4:

# RESULT AND DISCUSSION

In this chapter, I will present the result and discussion that has been obtained of our new set of correlation for Malaysian crude.A total of 93 PVT data taken from various Malaysian offshore oil-fields was used in the study. The PVT data consist of oil gravity range from 26.6 - 53.2 API and bubble point pressures of 790 psig to 3851 psig. The crudes are essentially free of hydrogen sulphide with low nitrogen content . Developed correlation for the following properties:

i. Solution Gas Oil Ratio, $R_s$
ii. Oil Formation Volume Factor, $B_o$
iii. Bubble Point Pressure, $P_b$

Three correlations presented in this report are the result of Group Method of Data Handling (GMDH) applied over experimental data. All these correlations were developed using MATLAB and Microsoft Excel interactively. Excel was used to tune to the initial guesses on small portions of a particular database, and MATLAB was used to develop coding for GMDH to generate the correlation.

**4.1 Correlation For Solution Gas Oil Ratio**

As mentioned earlier, this correlation has been developed strictly to estimate values of solution gas oil ratio. In contrast to the approaches presented in the past, our calculation of solution gas oil ratio is not derived from rearranging the bubble point pressure correlation. The solution used GMDH approach to develop new correlation for Malaysian Crude. The performance of the power series model was superior to any model tested. The power series model was tested on a case by case basis and as a multi-case correlating equation and the result that by using this model have been excellent. From five parameters, only three used by this model to estimate the value of solution gas oil ratio. Those are formation volume factor, oil gravity and gas gravity. Table below will show the data of Malaysian Crude that has been used and the estimated value using new correlation.

Table 2 shows the experimental data and estimated value of solution gas oil ratio and those variable that been used to develop this correlation.based on the result obtained, the new model give good estimation of the value of solution gas oil ratio by having lower relative error.

**Table 2:Solution Gas Oil Ratio Result**

| $R_s$ (Experimental) | Bo bbl/STB | $\gamma_g$ scf/STB | $\gamma_o$ API | $R_s$ (Estimated) | E, % |
|---|---|---|---|---|---|
| 590 | 2500 | 0.617 | 40.0 | 571.0460 | 3.2124 |
| 844 | 2290 | 0.919 | 40.7 | 846.7402 | 0.3246 |
| 664 | 2350 | 0.850 | 42.9 | 651.2493 | 1.9202 |
| 463 | 1650 | 1.181 | 38.9 | 459.3618 | 0.7857 |
| 267 | 1300 | 1.263 | 38.0 | 266.1156 | 0.3312 |
| 421 | 1800 | 1.198 | 37.1 | 421.9819 | 0.2332 |
| 330 | 1700 | 1.038 | 35.0 | 318.1651 | 3.5863 |
| 376 | 1650 | 1.295 | 31.0 | 383.9987 | 2.1273 |
| 260 | 1225 | 1.168 | 38.0 | 272.4316 | 4.7813 |
| 420 | 1700 | 0.735 | 36.6 | 425.6548 | 1.3464 |
| 305 | 1250 | 1.274 | 38.2 | 301.6168 | 1.1092 |
| 405 | 1580 | 1.061 | 40.0 | 397.4852 | 1.8555 |
| 515 | 1982 | 1.140 | 36.1 | 514.6718 | 0.0637 |
| 359 | 1450 | 1.250 | 35.4 | 370.2750 | 3.1406 |
| 640 | 1570 | 1.315 | 39.0 | 649.1518 | 1.4299 |
| 714 | 1760 | 0.820 | 48.7 | 701.0374 | 1.8154 |
| 400 | 1810 | 0.770 | 50.5 | 382.1355 | 4.4661 |
| 720 | 1658 | 0.865 | 41.4 | 725.7537 | 0.7991 |
| 888 | 2640 | 0.630 | 49.3 | 873.4083 | 1.6431 |
| 400 | 1755 | 0.790 | 49.5 | 406.6548 | 1.6637 |
| 750 | 1728 | 0.941 | 41.8 | 777.1521 | 3.6200 |
| 765 | 2058 | 0.939 | 48.8 | 777.5163 | 1.6361 |
| 650 | 2221 | 0.693 | 45.3 | 661.4551 | 1.7623 |
| 546 | 2220 | 0.599 | 45.2 | 520.5384 | 4.6632 |
| 120 | 2081 | 0.677 | 44.5 | 120.1456 | 0.1213 |
| 490 | 1220 | 0.884 | 31.4 | 498.6104 | 1.7570 |
| 330 | 2390 | 0.811 | 43.2 | 332.4300 | 0.7360 |
| 242 | 1302 | 0.824 | 31.4 | 221.0483 | 8.6576 |
| 175 | 1085 | 0.638 | 29.1 | 179.5283 | 2.5876 |
| 290 | 1271 | 0.775 | 29.2 | 301.7253 | 4.0432 |
| 400 | 1195 | 0.664 | 31.9 | 401.3880 | 0.3470 |
| 741 | 2562 | 0.795 | 42.0 | 730.2743 | 1.4474 |

| | | | | | |
|---|---|---|---|---|---|
| 274 | 790 | 1.005 | 39.8 | 267.7729 | 2.2726 |
| 566 | 1530 | 0.817 | 45.2 | 549.7636 | 2.8686 |
| 450 | 1510 | 0.730 | 47.8 | 445.7276 | 0.9494 |
| 710 | 1741 | 0.759 | 48.4 | 715.0554 | 0.7120 |
| 692 | 2111 | 0.740 | 53.2 | 667.5466 | 3.5337 |
| 628 | 1758 | 0.762 | 48.4 | 607.5352 | 3.2587 |
| 585 | 1769 | 0.765 | 49.1 | 577.2983 | 1.3165 |
| 390 | 1805 | 0.767 | 48.1 | 396.1280 | 1.5712 |
| 600 | 1300 | 1.155 | 41.0 | 600.5407 | 0.0901 |
| 850 | 2540 | 0.730 | 50.4 | 845.4164 | 0.5392 |
| 490 | 1790 | 0.800 | 47.1 | 491.0508 | 0.2144 |
| 606 | 1620 | 0.847 | 42.9 | 606.9867 | 0.1628 |
| 950 | 2165 | 0.916 | 46.6 | 957.5899 | 0.7989 |
| 1070 | 2550 | 0.858 | 48.9 | 1069.481 | 0.0484 |
| 730 | 2360 | 1.014 | 48.4 | 732.2966 | 0.3146 |
| 944 | 2020 | 1.051 | 39.2 | 944.3734 | 0.0395 |
| 1022 | 2145 | 1.045 | 47.9 | 987.8630 | 3.3402 |
| 900 | 2090 | 1.050 | 48.2 | 910.8004 | 1.2000 |
| 1006 | 2822 | 0.876 | 46.8 | 998.1958 | 0.7757 |
| 990 | 2290 | 0.801 | 43.1 | 967.4259 | 2.2802 |
| 1100 | 2500 | 0.877 | 48.8 | 1141.808 | 3.8007 |
| 153 | 3148 | 0.788 | 50.3 | 153.4108 | 0.2685 |
| 270 | 952 | 0.667 | 26.9 | 272.6460 | 0.9800 |
| 710 | 2368 | 0.756 | 32.5 | 718.2476 | 1.1616 |
| 636 | 2310 | 0.801 | 38.3 | 649.4950 | 2.1210 |
| 683 | 2408 | 0.821 | 38.6 | 719.6231 | 5.3621 |
| 899 | 3449 | 0.769 | 39.3 | 928.5524 | 3.2870 |
| 674 | 3440 | 0.764 | 37.4 | 674.5773 | 0.0856 |
| 600 | 1910 | 0.733 | 32.6 | 521.9501 | 13.008 |
| 580 | 2168 | 0.789 | 37.1 | 597.4224 | 3.0038 |
| 590 | 2480 | 0.737 | 38.2 | 593.1390 | 0.5320 |
| 760 | 2350 | 0.818 | 37.0 | 765.7145 | 0.7519 |
| 220 | 1744 | 0.727 | 40.5 | 226.8801 | 3.1273 |
| 761 | 3142 | 0.723 | 33.3 | 739.7461 | 2.7928 |
| 800 | 2970 | 0.707 | 34.6 | 801.0336 | 0.1290 |
| 367 | 1951 | 0.627 | 37.5 | 382.3046 | 4.1702 |
| 260 | 2616 | 0.842 | 37.7 | 264.9814 | 1.9159 |
| 670 | 1818 | 0.704 | 26.6 | 671.1945 | 0.1782 |
| 450 | 2611 | 0.789 | 39.6 | 449.6280 | 0.0826 |
| 380 | 1058 | 0.790 | 32.3 | 380.0564 | 0.0148 |
| 770 | 3387 | 0.673 | 41.4 | 765.3924 | 0.5983 |
| 200 | 1492 | 0.716 | 37.4 | 181.3117 | 9.3441 |
| 258 | 935 | 0.612 | 31.9 | 258.7093 | 0.2740 |
| 500 | 3780 | 0.658 | 40.2 | 499.6278 | 0.0744 |
| 1000 | 3063 | 0.737 | 31.2 | 1041.8340 | 4.1834 |
| 713 | 2423 | 0.765 | 40.0 | 692.2320 | 2.9127 |

| | | | | | |
|---|---|---|---|---|---|
| 460 | 2360 | 0.765 | 4001 | 465.6871 | 1.2363 |
| 166 | 1838 | 0.664 | 34.8 | 166.4964 | 0.2990 |
| 470 | 2106 | 0.648 | 28.9 | 471.5817 | 0.3365 |
| 420 | 1390 | 0.718 | 33.4 | 420.9896 | 0.2356 |
| 650 | 2470 | 0.758 | 40.0 | 645.3195 | 0.7200 |
| 790 | 2692 | 0.631 | 38.6 | 781.3130 | 1.0996 |
| 1212 | 3420 | 0.685 | 42.3 | 1230.7170 | 1.5443 |
| 490 | 3160 | 0.705 | 45.4 | 489.3275 | 0.1372 |
| 450 | 1765 | 0.695 | 34.2 | 454.4384 | 0.9863 |
| 310 | 1780 | 0.853 | 37.8 | 317.2167 | 2.3279 |
| 950 | 3063 | 0.628 | 32.2 | 952.4424 | 0.2570 |
| 930 | 2609 | 1.038 | 40.4 | 927.3812 | 0.2815 |
| 642 | 2344 | 0.743 | 40.4 | 639.8678 | 0.3321 |
| 360 | 1698 | 0.964 | 40.2 | 366.7657 | 1.8793 |
| 1360 | 3851 | 0.663 | 34.1 | 1362.5301 | 0.1861 |

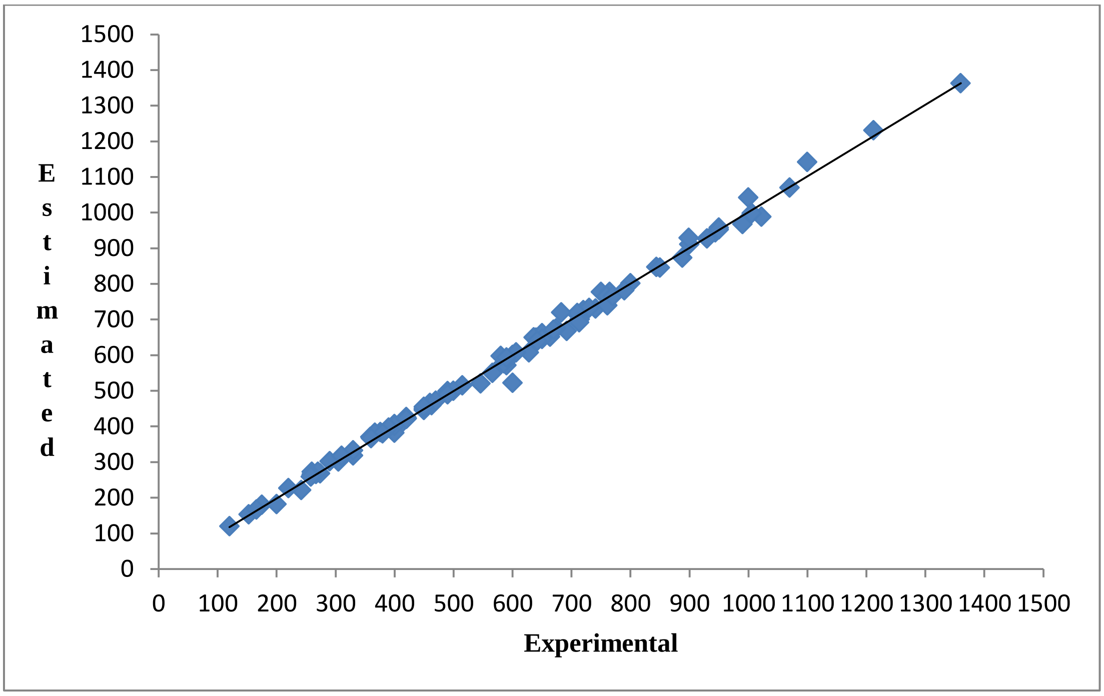


Figure 5: Crossplot of Solution Gas Oil Ratio

Based on the Figure 5, the crossplot of solution gas oil ratio show best fit line that passed through all the points that has been plotted. Based on the crossplot, that prove that new correlation been developed through GMDH method for solution gas oil ratio for Malaysian crude give better estimation.

### 4.1.1 Statistical Error Analysis

In order to prove the perfomance of new correlation, this model has been compared with previous correlation by conducting statistical error analysis.. The result will be shown in the table below.

Table 3: Statistical Accuracy of Solution Gas Oil Ratio

| | This Study | Standing | Vasquez | Glaso | Petrosky |
|---|---|---|---|---|---|
| ARE, % | 3.21 | 55.66 | 20.73 | 12.29 | 25.09 |
| Average Absolute Deviation | 2.79 | 10.05 | 36.34 | 26.06 | 30.10 |
| Correlation Coefficient | 0.99 | 0.91 | 0.71 | 0.92 | 0.82 |
| Coefficent of Determination | 0.99 | 0.82 | 0.50 | 0.85 | 0.67 |
| Max. ARE, % | 10.04 | 39.96 | 72.65 | 38.19 | 60.25 |
| Min ARE, % | 0.02 | 0.08 | 0.18 | 0.25 | 0.10 |

### 4.1.2 Final Form of Correlation

The final form of the solution gas oil ratio correlation shown below:

$$R_s = A_1 - (A_2.\gamma_o) + (A_3.\gamma_g) - (A_4.B_o) + (A_5.\gamma_g.\gamma_o) + (A_6.B_o.\gamma_o) + (A_7.B_o.\gamma_g) + (A_8.\gamma_o^2) - (A_9.\gamma_g^2) + (A_{10}.B_o^2)$$

$A_1$=880.530400778922

$A_2$=51.175351343501

$A_3$=535.47940627238

$A_4$=0.512728646063882

$A_5$=36.9437213528499

$A_6$=0.01665509716446

$A_7$=0.200784044152712

$A_8$=0.100272767669885

$A_9$=1094.60230889884

$A_{10}$=9.31803133793895E-06

Using this correlation, it can estimate values for solution gas oil ratio for Malaysian crude. It is estimated the statistical accuracy of this correlation using least-square regression analysis and calculated average absolute error of 3.21% as shown in the Table 3. The crossplot of Figure 6 illustrates the excellent agreement between the plotted value of measured Rs versus estimated Rs.

### 4.2 Correlation For Oil Formation Volume Factor

Table 4 below show the result of estimated oil formation volume factor obtained by using new model generated through GMDH method. From five variables, only three parameters was chosen to be used for this model and those are solution gas oil ratio, gas gravity and oil gravity. Two parameter has been eliminated because gave least contribution to the model,they are bubble point pressure and temperature. Based on the result shown, there is no big gap between experimental data and the estimated data. This can be prove by performing relative error for each set of data. Thus, this model gives better estimation compare to the previous one and this statement will be proved by looking at statistical error analysis on Table 5.

Table 4: Oil Formation Volume Factor Result

| Bo, (Experimental) | $R_s$ scf/STB | $\gamma_g$ | $\gamma_o$ API | Bo, (Estimated) | Error, % |
|---|---|---|---|---|---|
| 1.425 | 634 | 0.717 | 45.3 | 1.4118 | 0.9245 |
| 1.619 | 844 | 0.919 | 40.7 | 1.5212 | 6.0394 |
| 1.438 | 664 | 0.750 | 42.9 | 1.4162 | 1.5148 |
| 1.261 | 463 | 1.281 | 38.9 | 1.2854 | 1.9366 |
| 1.176 | 267 | 1.263 | 38.0 | 1.1538 | 1.8804 |
| 1.221 | 421 | 1.298 | 37.1 | 1.2547 | 2.7675 |
| 1.240 | 355 | 1.228 | 35.0 | 1.2155 | 1.9694 |
| 1.222 | 372 | 1.195 | 31.0 | 1.2303 | 0.6840 |
| 1.170 | 260 | 1.168 | 38.0 | 1.1564 | 1.1620 |
| 1.232 | 364 | 1.028 | 36.6 | 1.2270 | 0.3994 |
| 1.192 | 313 | 1.174 | 38.2 | 1.1904 | 0.0840 |
| 1.268 | 421 | 1.181 | 39.8 | 1.2635 | 0.3507 |
| 1.246 | 415 | 1.140 | 36.1 | 1.2564 | 0.8404 |
| 1.214 | 359 | 1.250 | 35.4 | 1.2168 | 0.2366 |
| 1.241 | 366 | 1.315 | 39.0 | 1.2172 | 1.9136 |
| 1.500 | 714 | 0.820 | 48.7 | 1.4943 | 0.3786 |
| 1.423 | 606 | 0.770 | 50.5 | 1.4361 | 0.9246 |

| | | | | | |
|---|---|---|---|---|---|
| 1.212 | 368 | 0.865 | 41.4 | 1.2383 | 2.1748 |
| 1.578 | 888 | 0.730 | 49.3 | 1.6001 | 1.4030 |
| 1.480 | 694 | 0.790 | 49.5 | 1.4862 | 0.4211 |
| 1.259 | 397 | 0.941 | 41.8 | 1.2579 | 0.0809 |
| 1.520 | 765 | 0.939 | 48.8 | 1.5347 | 0.9682 |
| 1.362 | 547 | 0.693 | 45.3 | 1.3580 | 0.2880 |
| 1.451 | 546 | 0.689 | 45.2 | 1.3565 | 6.5077 |
| 1.315 | 494 | 0.677 | 44.5 | 1.3206 | 0.4294 |
| 1.173 | 267 | 0.884 | 31.4 | 1.1697 | 0.2747 |
| 1.538 | 956 | 0.811 | 43.2 | 1.5915 | 3.4843 |
| 1.170 | 242 | 0.824 | 31.4 | 1.1545 | 1.3162 |
| 1.128 | 169 | 0.638 | 29.1 | 1.1100 | 1.5480 |
| 1.139 | 198 | 0.775 | 29.2 | 1.1324 | 0.5739 |
| 1.152 | 214 | 0.664 | 31.9 | 1.1322 | 1.7182 |
| 1.491 | 741 | 0.795 | 42.0 | 1.4587 | 2.1633 |
| 1.168 | 274 | 1.005 | 39.8 | 1.1740 | 0.5464 |
| 1.334 | 566 | 0.817 | 45.2 | 1.3763 | 3.1720 |
| 1.365 | 522 | 0.730 | 47.8 | 1.3608 | 0.3058 |
| 1.409 | 563 | 0.759 | 48.4 | 1.3922 | 1.1873 |
| 1.471 | 692 | 0.740 | 53.2 | 1.5148 | 2.9809 |
| 1.442 | 628 | 0.762 | 48.4 | 1.4337 | 0.5712 |
| 1.401 | 585 | 0.765 | 49.1 | 1.4116 | 0.7607 |
| 1.424 | 599 | 0.767 | 48.1 | 1.4134 | 0.7396 |
| 1.249 | 425 | 1.155 | 41.0 | 1.2695 | 1.6468 |
| 1.712 | 1020 | 0.730 | 50.4 | 1.6920 | 1.1588 |
| 1.496 | 686 | 0.800 | 47.1 | 1.4627 | 2.2200 |
| 1.265 | 404 | 0.847 | 42.9 | 1.2653 | 0.0303 |
| 1.517 | 856 | 0.916 | 46.6 | 1.5733 | 3.7122 |
| 1.884 | 1170 | 0.858 | 48.9 | 1.7828 | 5.3680 |
| 1.716 | 993 | 1.014 | 48.4 | 1.6846 | 1.8272 |
| 1.321 | 491 | 1.051 | 39.2 | 1.3098 | 0.8438 |
| 1.697 | 1022 | 1.045 | 47.9 | 1.7009 | 0.2307 |
| 1.680 | 1011 | 1.050 | 48.2 | 1.6971 | 1.0191 |
| 1.695 | 1006 | 0.876 | 46.8 | 1.6632 | 1.8747 |
| 1.653 | 990 | 0.801 | 43.1 | 1.6082 | 2.7084 |
| 1.843 | 1355 | 0.877 | 48.8 | 1.8942 | 2.7823 |
| 1.954 | 1440 | 0.788 | 50.3 | 1.9475 | 0.3307 |
| 1.092 | 142 | 0.667 | 26.9 | 1.1036 | 1.0659 |
| 1.282 | 440 | 0.756 | 32.5 | 1.2537 | 2.2060 |
| 1.345 | 636 | 0.801 | 38.3 | 1.3794 | 2.5611 |
| 1.384 | 683 | 0.821 | 38.6 | 1.4086 | 1.7799 |
| 1.503 | 899 | 0.769 | 39.3 | 1.5225 | 1.2994 |
| 1.455 | 863 | 0.764 | 37.4 | 1.4896 | 2.3822 |
| 1.238 | 384 | 0.733 | 32.6 | 1.2235 | 1.1666 |
| 1.297 | 544 | 0.789 | 37.1 | 1.3231 | 2.0145 |
| 1.357 | 686 | 0.737 | 38.2 | 1.3991 | 3.1035 |

| | | | | | |
|---|---|---|---|---|---|
| 1.352 | 680 | 0.818 | 37.0 | 1.3987 | 3.4601 |
| 1.325 | 524 | 0.727 | 40.5 | 1.3211 | 0.2901 |
| 1.484 | 761 | 0.723 | 33.3 | 1.4095 | 5.0180 |
| 1.445 | 737 | 0.707 | 34.6 | 1.4020 | 2.9725 |
| 1.23 | 367 | 0.627 | 37.5 | 1.2161 | 1.1290 |
| 1.371 | 667 | 0.842 | 37.7 | 1.3973 | 1.9251 |
| 1.153 | 285 | 0.704 | 26.6 | 1.1732 | 1.7559 |
| 1.525 | 810 | 0.789 | 39.6 | 1.4801 | 2.9392 |
| 1.130 | 220 | 0.790 | 32.3 | 1.1411 | 0.9838 |
| 1.505 | 919 | 0.673 | 41.4 | 1.5347 | 1.9745 |
| 1.201 | 341 | 0.716 | 37.4 | 1.2076 | 0.5557 |
| 1.085 | 150 | 0.612 | 31.9 | 1.0968 | 1.0896 |
| 1.581 | 1023 | 0.658 | 40.2 | 1.5739 | 0.4458 |
| 1.301 | 577 | 0.737 | 31.2 | 1.3163 | 1.1780 |
| 1.399 | 713 | 0.765 | 40.0 | 1.4271 | 2.0136 |
| 1.399 | 694 | 0.765 | 40.0 | 1.4167 | 1.2681 |
| 1.208 | 366 | 0.664 | 34.8 | 1.2122 | 0.3502 |
| 1.194 | 344 | 0.648 | 28.9 | 1.1938 | 0.0152 |
| 1.154 | 287 | 0.718 | 33.4 | 1.1732 | 1.6667 |
| 1.429 | 760 | 0.758 | 40.0 | 1.4519 | 1.6072 |
| 1.230 | 393 | 0.631 | 38.6 | 1.2332 | 0.3035 |
| 1.683 | 1212 | 0.685 | 42.3 | 1.6950 | 0.7470 |
| 1.707 | 1213 | 0.705 | 45.4 | 1.7371 | 1.7750 |
| 1.184 | 345 | 0.695 | 34.0 | 1.2024 | 1.5598 |
| 1.362 | 509 | 0.853 | 37.8 | 1.3104 | 3.7815 |
| 1.287 | 586 | 0.628 | 32.2 | 1.3088 | 1.6987 |
| 1.622 | 1019 | 1.038 | 40.4 | 1.6320 | 0.6213 |
| 1.429 | 791 | 0.743 | 40.4 | 1.4695 | 2.8360 |
| 1.408 | 646 | 0.964 | 40.0 | 1.4049 | 0.2197 |
| 1.466 | 819 | 0.663 | 34.1 | 1.4308 | 2.3946 |

A crossplot in Figure 6 has been plotted between experimental value and estimated value. Based on the crossplot, we can see the line pass through majority all of the points and give best fit lines. This can show that this model give better estimation of the formation volume factor for Malaysian crude.

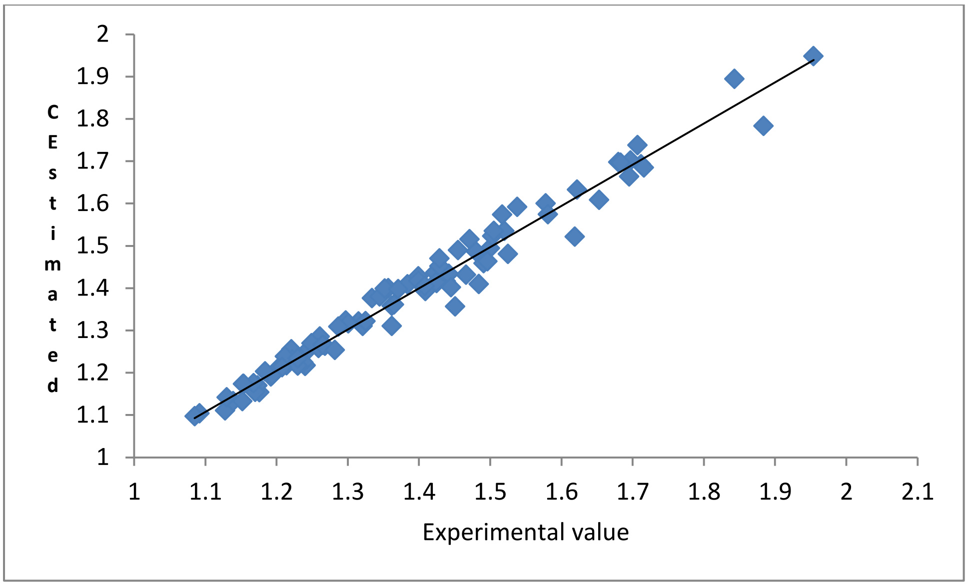


Figure 6: Crossplot of Oil Formation Volume factor

### 4.2.1 Statistical Error Analysis

Table 5:Statistical accuracy of Oil Formation Volume Factor

| | This Study | Standing | Glaso | Vasquez | Al-Marhoun | Petrosky |
|---|---|---|---|---|---|---|
| ARE, % | 1.60 | 2.35 | 2.99 | 2.38 | 2.43 | 2.00 |
| Average Absolute Deviation | 2.07 | 3.11 | 3.65 | 3.34 | 3.23 | 2.54 |
| Correlation Coefficient | 1 | 0.97 | 0.95 | 0.94 | 0.96 | 0.98 |
| Coefficent of Determination | 1 | 0.94 | 0.91 | 0.88 | 0.92 | 0.96 |
| Max. ARE, % | 4.04 | 9.60 | 9.48 | 12.26 | 9.08 | 8.40 |
| Min ARE, % | 0.01 | 0.01 | 0.02 | 0.11 | 0.11 | 0.03 |

Based on the statistical error analysis by comparing new model with previous, it gives better estimation compare to the previous researcher had done. This prove that the model gives better estimation value of oil formation volume factor.

### 4.2.2 Final Form of Correlation

$$B_o = A_1 - (A_2.\gamma_o) + (A_3.\gamma_g) + (A_4.R_s) - (A_5.\gamma_g.\gamma_o) + (A_6.R_s.\gamma_o) + (A_7.R_s.\gamma_g) + (A_8.\gamma_o^2) - (A_9.\gamma_g^2) - (A_{10}.R_s)$$

| | |
|---|---|
| $A_1$=1.08199630980282 | $A_6$=9.11296341546098E-06 |
| $A_2$=0.00805577535122104 | $A_7$=0.000207478721653173 |
| $A_3$=0.294012771678018 | $A_8$=0.000133609923028163 |
| $A_4$=0.0000994971241197314 | $A_9$=0.111668392867066 |
| $A_5$=0.00402938539792537 | $A_{10}$=5.24239118889319E-08 |

### 4.3 Correlation For Bubble Point Pressure

Correlation for bubble point pressure has been developed through GMDH method. The correlation has been tested with 93 PVT data of Malaysian crude.After undergone elimination of few parameters through the GMDH method, there are four variables that will be used to develop this correlation and those are oil formation volume factor, solution gas oil ratio, gas gravity and oil gravity. Viscosity and reservoir temperature have been eliminated and will not be used to develop this model The outcome of the result will be shown in Table 6:

Table 6: Bubble Point Pressure Result

| Pb (Exp.) | Bo Bbl/STB | Rs Scf/STB | $\gamma_g$ | $\gamma_o$ API | Pb, (Predicted) | Error,% |
|---|---|---|---|---|---|---|
| 2193 | 1.425 | 634 | 0.717 | 45.3 | 2153.3017 | 1.8102 |
| 2402 | 1.619 | 844 | 0.919 | 40.7 | 2512.1320 | 4.5850 |
| 2194 | 1.438 | 664 | 0.705 | 42.9 | 2261.9210 | 3.0957 |
| 1700 | 1.261 | 463 | 1.281 | 38.9 | 1757.0990 | 3.3587 |
| 1300 | 1.176 | 267 | 1.263 | 38.0 | 1304.7021 | 0.3617 |
| 1728 | 1.259 | 540 | 0.941 | 41.8 | 1736.6007 | 0.4977 |
| 2058 | 1.520 | 900 | 0.939 | 48.8 | 2056.3900 | 0.0782 |
| 2221 | 1.362 | 647 | 0.693 | 45.3 | 2238.0115 | 0.7650 |
| 2274 | 1.451 | 650 | 0.689 | 45.2 | 2258.6998 | 0.6721 |
| 2081 | 1.315 | 560 | 0.677 | 44.5 | 2089.4312 | 0.4051 |
| 1220 | 1.173 | 247 | 0.884 | 31.4 | 1219.2689 | 0.0599 |
| 2390 | 1.538 | 776 | 0.811 | 43.2 | 2384.7905 | 0.2179 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2300 | 1.683 | 620 | 0.685 | 42.3 | 2320.5620 | 0.8940 |
| 3160 | 1.707 | 1100 | 0.705 | 45.4 | 3136.3063 | 0.7497 |
| 1765 | 1.184 | 345 | 0.695 | 34.0 | 1744.8979 | 1.1389 |
| 1780 | 1.362 | 470 | 0.853 | 37.8 | 1786.6610 | 0.3742 |
| 3063 | 1.287 | 586 | 0.628 | 32.2 | 2966.9660 | 3.1352 |
| 2609 | 1.622 | 970 | 1.038 | 40.4 | 2630.8102 | 0.8350 |
| 2344 | 1.429 | 640 | 0.743 | 40.4 | 2342.5907 | 0.0601 |
| 1698 | 1.408 | 500 | 0.964 | 40.0 | 1688.4453 | 0.5627 |
| 3851 | 1.466 | 900 | 0.663 | 34.1 | 3850.0690 | 0.0241 |
| 1302 | 1.170 | 255 | 0.824 | 31.4 | 1300.1310 | 0.1431 |
| 1085 | 1.128 | 129 | 0.638 | 29.1 | 1076.8106 | 0.7547 |
| 1271 | 1.139 | 215 | 0.775 | 29.2 | 1268.1439 | 0.2247 |
| 1195 | 1.152 | 185 | 0.664 | 31.9 | 1202.5054 | 0.6280 |
| 2562 | 1.491 | 800 | 0.795 | 42.0 | 2547.5469 | 0.5640 |
| 730 | 1.168 | 150 | 1.005 | 39.8 | 724.04183 | 0.8161 |
| 1530 | 1.334 | 440 | 0.817 | 45.2 | 1530.4270 | 0.0279 |
| 1510 | 1.365 | 390 | 0.730 | 47.8 | 1505.2320 | 0.3157 |
| 1741 | 1.409 | 515 | 0.759 | 48.4 | 1725.7113 | 0.8781 |
| 2111 | 1.471 | 792 | 0.740 | 53.2 | 2097.4924 | 0.6398 |
| 2350 | 1.352 | 630 | 0.818 | 37.0 | 2368.2966 | 0.7785 |
| 1744 | 1.325 | 430 | 0.727 | 40.5 | 1750.1732 | 0.3539 |
| 3200 | 1.484 | 761 | 0.723 | 33.3 | 3279.0782 | 2.4711 |
| 3100 | 1.445 | 737 | 0.707 | 34.6 | 3126.0990 | 0.8419 |
| 1951 | 1.230 | 367 | 0.627 | 37.5 | 1836.2703 | 5.8805 |
| 2616 | 1.371 | 740 | 0.842 | 37.7 | 2599.7537 | 0.6210 |
| 1818 | 1.153 | 285 | 0.704 | 26.6 | 1828.6992 | 0.5885 |
| 2611 | 1.525 | 760 | 0.789 | 39.6 | 2623.1383 | 0.4648 |
| 1058 | 1.130 | 200 | 0.790 | 32.3 | 1078.0434 | 1.8944 |
| 3387 | 1.505 | 1000 | 0.673 | 41.4 | 3394.9374 | 0.2343 |
| 1492 | 1.201 | 320 | 0.716 | 37.4 | 1494.3677 | 0.1581 |
| 935 | 1.085 | 100 | 0.612 | 31.9 | 908.7660 | 2.8057 |
| 3780 | 1.581 | 1110 | 0.658 | 40.2 | 3831.7351 | 1.3686 |
| 3063 | 1.301 | 660 | 0.737 | 31.2 | 3058.2494 | 0.1550 |
| 2165 | 1.517 | 856 | 0.916 | 46.6 | 2153.8957 | 0.5129 |
| 2550 | 1.884 | 1170 | 0.858 | 48.9 | 2495.8501 | 2.1232 |
| 2360 | 1.716 | 1350 | 1.014 | 48.4 | 2342.4818 | 0.7422 |
| 2020 | 1.321 | 640 | 1.051 | 39.2 | 2025.9650 | 0.2951 |
| 2145 | 1.697 | 1022 | 1.045 | 47.9 | 2108.4974 | 1.7017 |
| 2090 | 1.680 | 1011 | 1.050 | 48.2 | 2073.0184 | 0.8125 |
| 2822 | 1.695 | 1320 | 0.876 | 46.8 | 2803.6860 | 0.6480 |
| 2290 | 1.653 | 720 | 0.801 | 43.1 | 2283.9811 | 0.2628 |
| 2500 | 1.843 | 1230 | 0.877 | 48.8 | 2515.3462 | 0.6138 |
| 3148 | 1.954 | 1700 | 0.788 | 50.3 | 2910.6102 | 7.5409 |
| 1165 | 1.092 | 142 | 0.667 | 26.9 | 1171.6091 | 0.5673 |
| 1740 | 1.221 | 421 | 1.298 | 37.1 | 1745.7242 | 0.3289 |
| 1530 | 1.24 | 355 | 1.228 | 35.0 | 1554.0268 | 1.5703 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1760 | 1.222 | 372 | 1.195 | 31.0 | 1728.2201 | 1.8054 |
| 1100 | 1.170 | 260 | 1.168 | 38.0 | 1160.7507 | 5.5227 |
| 1400 | 1.232 | 364 | 1.028 | 36.6 | 1409.4786 | 0.6770 |
| 1300 | 1.192 | 313 | 1.174 | 38.2 | 1302.4428 | 0.1879 |
| 1500 | 1.268 | 400 | 1.181 | 39.8 | 1485.8223 | 0.9451 |
| 1982 | 1.246 | 440 | 1.140 | 30.0 | 1969.7613 | 0.6174 |
| 1450 | 1.214 | 315 | 1.250 | 35.4 | 1460.8250 | 0.7465 |
| 1570 | 1.241 | 345 | 1.315 | 39.0 | 1556.0375 | 0.8893 |
| 1750 | 1.500 | 570 | 0.820 | 48.7 | 1733.4441 | 0.9460 |
| 1810 | 1.423 | 600 | 0.770 | 50.5 | 1828.4780 | 1.0208 |
| 1658 | 1.212 | 470 | 0.865 | 41.4 | 1642.5358 | 0.9327 |
| 2632 | 1.578 | 888 | 0.730 | 46.3 | 2605.9362 | 0.9902 |
| 1755 | 1.480 | 570 | 0.790 | 49.5 | 1762.2553 | 0.4134 |
| 1758 | 1.442 | 628 | 0.762 | 48.4 | 1943.9109 | 10.5750 |
| 1769 | 1.401 | 585 | 0.765 | 49.1 | 1839.4079 | 3.9800 |
| 1805 | 1.424 | 599 | 0.767 | 48.1 | 1887.0057 | 4.5432 |
| 1414 | 1.249 | 425 | 1.155 | 41.0 | 1493.0150 | 5.5880 |
| 2540 | 1.712 | 1020 | 0.730 | 50.4 | 2546.6026 | 0.2599 |
| 1790 | 1.496 | 570 | 0.800 | 47.1 | 1800.2430 | 0.5722 |
| 1620 | 1.265 | 470 | 0.847 | 42.9 | 1619.0136 | 0.0608 |
| 2368 | 1.282 | 510 | 0.756 | 32.5 | 2351.1013 | 0.7136 |
| 2310 | 1.345 | 636 | 0.801 | 38.3 | 2337.0185 | 1.1696 |
| 2408 | 1.384 | 683 | 0.821 | 38.6 | 2417.3481 | 0.3882 |
| 3449 | 1.503 | 1050 | 0.769 | 39.3 | 3428.2057 | 0.6029 |
| 3440 | 1.455 | 963 | 0.764 | 37.4 | 3411.6584 | 0.8238 |
| 1910 | 1.238 | 384 | 0.733 | 32.6 | 1895.2345 | 0.7730 |
| 2168 | 1.297 | 544 | 0.789 | 37.1 | 2143.6922 | 1.1212 |
| 2480 | 1.357 | 646 | 0.737 | 38.2 | 2500.5703 | 0.8294 |
| 2423 | 1.399 | 713 | 0.765 | 40.0 | 2521.1900 | 4.0524 |
| 2360 | 1.399 | 694 | 0.765 | 40.0 | 2469.2937 | 4.6310 |
| 1838 | 1.208 | 366 | 0.664 | 34.8 | 1855.5887 | 0.9560 |
| 2106 | 1.194 | 344 | 0.648 | 28.9 | 2088.9708 | 0.8086 |
| 1390 | 1.154 | 287 | 0.718 | 33.4 | 1495.1928 | 7.5678 |
| 2470 | 1.429 | 760 | 0.758 | 40.0 | 2663.4591 | 7.8323 |
| 2692 | 1.230 | 600 | 0.631 | 38.6 | 2589.6920 | 3.8000 |

Figure 7 show the result of crossplot for bubble point pressure between experimental data and estimated data. Based on the result, the best fit line fit most of the points and this shows that new correlation give good estimation for bubble point pressure.

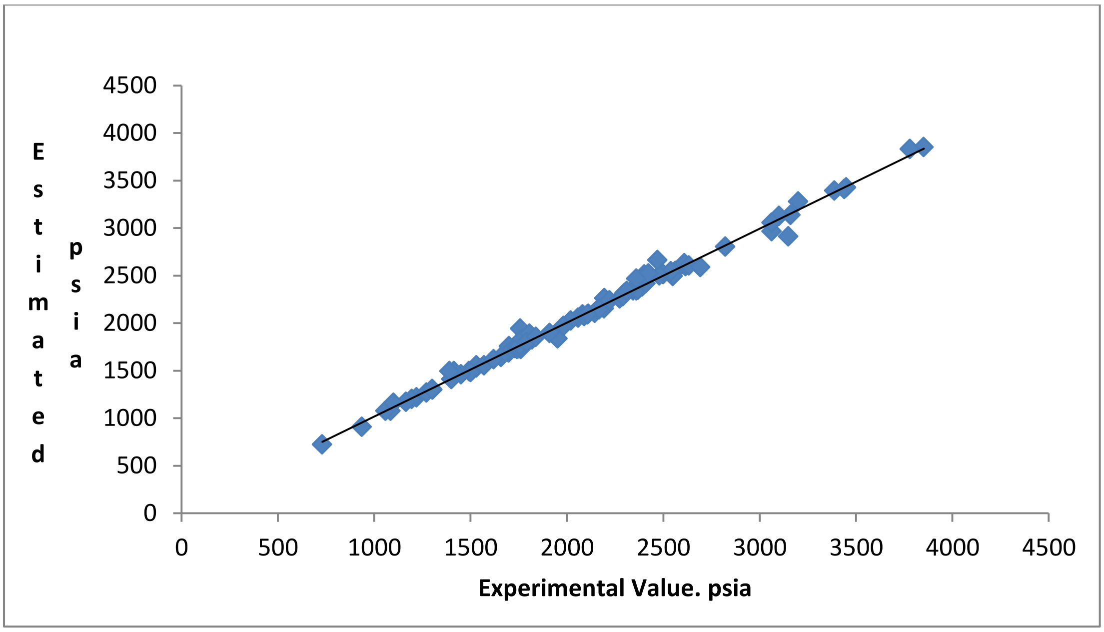


Figure 7: Crossplot of Bubble Point Pressure

### 4.3.1 Statistical Error Analysis

Table 7:Statistical Analysis of Bubble Point Pressure

| | This Study | Standing | Glaso | Vasquez | Al-Marhoun | Lasater |
|---|---|---|---|---|---|---|
| ARE, % | 1.53 | 12.04 | 20.73 | 12.29 | 25.09 | 15.57 |
| Average Absolute Deviation | 2.53 | 16.05 | 26.34 | 16.06 | 30.10 | 20.09 |
| Correlation Coefficient | 0.99 | 0.92 | 0.81 | 0.92 | 0.82 | 0.90 |
| Coefficent of Determination | 0.85 | 0.85 | 0.66 | 0.85 | 0.68 | 0.81 |
| Max. ARE, % | 15.01 | 39.96 | 72.65 | 38.19 | 60.25 | 47.23 |
| Min ARE, % | 0.01 | 0.08 | 0.18 | 0.25 | 0.10 | 0.06 |

Table 7 show the result of statistical error analysis for bubble point pressure. New model developed has been compared with the previous correlation to show new model give better estimation of bubble point pressure for Malaysian crude.

### 4.3.2 Final Form of Correlation

$P_{b}= A_1 - (A_2.\gamma_o) - (A_3.\gamma_g) + (A_4.R_s) + (A_5.\gamma_g.\gamma_o) - (A_6.R_s.\gamma_o) - (A_7.R_s.\gamma_g) + (A_8.\gamma_o^2) + (A_9.\gamma_g^2) - (A_{10}.Rs^2)$

| | |
|---|---|
| **$A_1$=**4677.68367375698 | **$A_6$=**0.109977471902134 |
| **$A_2$=**114.913506589439 | **$A_7$=**2.04440785144326 |
| **$A_3$=**5622.90910059234 | **$A_8$=**1.49020106743208 |
| **$A_4$=**9.5514441670233 | **$A_9$=**2857.29075281598 |
| **$A_5$=**14.2557079884696 | **$A_{10}$=**0.000609089867700527 |

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

The experimental investigations for fluid properties correlation are in need of sufficient time and significant in reservoir engineering. Therefore, a faster and more cost-effective approach should be introduced to estimate the properties of Malaysian crude  Prior to that, the datasets have been collected from the published literature. The developed models, bubble point pressure, solution gas oil ratio and oil formation volume facrtor, for prediction the fluid properties  is more accurately where the accuracy and standard error were estimated R2 higher than 0.97 and standard error less than 0.028, respectively. So, the model is giving more promising results as compare with other establish  model. These models could be the alternative to experimental data of fluid properties

The R2 value can reach higher if the dataset utilized in this project were fragment in more detail. There are some error correction needs to be done where some values that obtain are far from the experimental data . In order to enhance the accuracy, the datasheet of PVT data need to be check.

In conclusion, the proposed model by using GMDH method is capable of reliably predicting the fluid properties for Malaysian crude. This model  provides a practical, cost-effective, convenient and reliable alternative to experimental data of assessment.. This model show very accurate results when compared with those from published works such as Standing, Glaso, and Vasquez. Moreover, for the first trial, the accuracy of the developed models were compared with other established models and found to have a higher accuracy than others established models. It can be concluded that these models can save time and effort by providing the users with models that can be used to estimate fluid properties  for Malaysian crude.

This research was carefully conducted and my results represent our best effort to correlate the experimental dat to get good estimation of each properties. Based on my experience during completing this project, I have some recommendation as possible extension of our work. In order to validate our result, the correlations presented here should be tested using and independent database. For a database nof similar size and type, Ii would expect that the errors should not be signficantly diffeerent from the results reported in this work. Other than that, a recommendation for that future work, correlation developed will not be using parameter. If we see the researched that had been done in this are, most of the researcer used same parameter in order to come outwith new correlation. As example, if they would like to develeop solution gas oil ratio, they will take bubble point pressure as one of the parameter used since bubble boint pressure also been estimated by correlation. So, this might effect the result later. Maybe in the future, when further research has been done, we can come out with correlation and least usage of same parameter.

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21. *https://www.google.com.my/url?sa=f&rct=j&url=http://www.vinci-technologies.com/productsexplo.aspx%3FIDM%3D711153%26IDR%3D82291%26IDR2%3D82558&q=&esrc=s&ei=Hq0lUeOCI43RrQe4koDABg&usg=AFQjCNEoZit3UMAIOSUwJchzICgpyP1wBQ*

22. *http://www.pe.tamu.edu/blasingame/data/0_TAB_Grad/TAB_Grad_Thesis_Archive/MS_013_VELARDE_Javier_TAMU_Thesis_(Aug_1996).pdf*

# APPENDIX

Group Method of Data Handling coding for MATLAB

- Prediction Coding

```
function Yq = gmdhpredict(model, Xq)

if nargin < 2
    error('Too few input arguments.');
end
if model.d ~= size(Xq, 2)
    error('The matrix should have the same number of columns as the
matrix with which the network was built.');
end

[n, d] = size(Xq);
Yq = zeros(n, 1);

for q = 1 : n
    for i = 1 : model.numLayers
        if i ~= model.numLayers
            Xq_tmp = zeros(1, model.layer(i).numNeurons);
        end
        for j = 1 : model.layer(i).numNeurons

            numTerms =  size(model.layer(i).terms(j).r,1);
            Vals = ones(numTerms,1);
            for idx = 2 : numTerms
                bf = model.layer(i).terms(j).r(idx, :);
                t = bf > 0;
                tmp = Xq(q, model.layer(i).inputs(j,t)) .^ bf(1, t);
                if size(tmp, 2) == 1
                    Vals(idx,1) = tmp;
                else
                    Vals(idx,1) = prod(tmp, 2);
                end
            end

            predY = model.layer(i).coefs(j,1:numTerms) * Vals;
            if i ~= model.numLayers

                Xq_tmp(j) = predY;
            else
                Yq(q) = predY;
            end

        end
        if i ~= model.numLayers
            Xq(q, d+1:d+model.layer(i).numNeurons) = Xq_tmp;
        end
    end
end

return
```

- Correlation Development and Precision Coding

```
function gmdheq(model, precision)
if nargin < 1
    error('Too few input arguments.');
end
if (nargin < 2) || (isempty(precision))
    precision = 15;
end

if model.numLayers > 0
    p = ['%.' num2str(precision) 'g'];
    fprintf('Number of layers: %d\n', model.numLayers);
    for i = 1 : model.numLayers
        fprintf('Layer #%d\n', i);
        fprintf('Number of neurons: %d\n',
model.layer(i).numNeurons);
        for j = 1 : model.layer(i).numNeurons
            [terms inputs] = size(model.layer(i).terms(j).r);
            if (i == model.numLayers)
                str = ['y = ' num2str(model.layer(i).coefs(j,1),p)];
            else
                str = ['x' num2str(j + i*model.d) ' = '
num2str(model.layer(i).coefs(j,1),p)];
            end
            for k = 2 : terms
                if model.layer(i).coefs(j,k) >= 0
                    str = [str ' +'];
                else
                    str = [str ' '];
                end
                str = [str num2str(model.layer(i).coefs(j,k),p)];
                for kk = 1 : inputs
                    if (model.layer(i).terms(j).r(k,kk) > 0)
                        for kkk = 1 : model.layer(i).terms(j).r(k,kk)
                            if (model.layer(i).inputs(j,kk) <=
model.d)
                                str = [str '*x'
num2str(model.layer(i).inputs(j,kk))];
                            else
                                str = [str '*x'
num2str(model.layer(i).inputs(j,kk) + (i-2)*model.d)];
                            end
                        end
                    end
                end
            end
            disp(str);
        end
    end
else
    disp('The network has zero layers.');
end

return
```