Sudan University of Science and Technology

College of graduate studies

Deduction of New Correlation and Computational Programme to Estimate Bubble and Dew Points Pressures using the Equation of State

استنتاج علاقة جديدة وبرنامج حسابي لتقدير ضغط الفقاعة ودرجة الندى باستخدام معادلة الحالة

A Dissertation Submitted to Sudan University of Science and Technology In partial fulfillment of the requirements for the degree of MASTER OF SCIENCE

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الاستهلال

قال تعالى :

((هُوَ الَّذِي خَلَقَ لَكُم مَّا فِي الْأَرْضِ جَمِيعًا ثُمَّ اسْتَوَىٰ إِلَى

السَّمَاءِ فَسَوَّاهُنَّ سَبْعَ سَمَاوَاتٍ ۚ وَهُوَ بِكُلِّ شَيْءٍ عَلِيمٌ))

البقرة الآية (29)

ABSTRACT

In this thesis new correlation of bubble point pressure (P_b) has been created using software called VariReg depending on the theory of Artificial Neural Networks (ANN). A computer program has been designed using MATLAB® software to simplify the calculation of the bubble and dew points pressures depending on the theory of the equation of state (EOS), the program includes some of others known empirical correlations of bubble point and dew point pressures, and a comparison study between results of these programs (VariReg and developed program) and laboratory. The program verified Sudanese oil fields PVT data. The program contains the others known empirical correlations of bubble and dew points pressures for the purpose of comparison. From the statistical results; the new developed model found to be more precise due to the large correlation factor (R^2) obtained and lowest degree of errors compared to the known models.

التجريد

في هذا البحث تم إنشاء معادلات لضغط الفقاعة بإستخدام برنامج يسمى (VariReg) يعتمد على نظرية الشبكة العصبية الإصطناعية (ANN). أيضا تم تصميم برنامج بإستخدام (MATLAB®) لتسهيل حساب كل من ضغط الفقاعة وضغط التكثيف إعتمادا على نظرية معادلة الحالة. وتمت دراسة مقارنة بين نتائج برنامجي (VariReg) والبرنامج المطور باستخدام (MATLAB®) وبين نتائج المعمل. هذه البرامج تم التطبيق فيها بإستخدام بيانات حقول نفط سودانية. البرنامج يتضمن المعادلات الاخرى المعروفة لحساب ضغط الفقاعة وضغط الندى وتم استخدامها في المقارنة.من النتائج الحسابية يملك النموذج الجديد أعلى معامل ارتباط (R^2) وأقل درجة أخطاء مقارنة بالنماذج الأخرى.

DEDICATION

To my beloved father's spirit may Allah join us in his high paradise, in dedication of his profound love that gave me the strength to continue, and his patience that made possible to reach this stage.

To my beloved mother, in dedication of your encouragement, help, patience, and love which made this work so simple and so easy. No words can express all my gratitude to you.

To my brothers and sisters who were an inspiration to me when times were tough, and their help to overcome the obstacles.

To all my family members who have encouraged me a lot and provide me a suitable environment.

To my all Colleagues of (PETRO19).

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I would like to express my deep respect and appreciation to Dr. **Satti Merghani**, for his help and guidance; without his determination this work would not be done, and thank you for the hours of patience.

Special thanks to my colleague and dear friend Eng. **Hamza Ahmed**, for encouraging me to overcome this stage and for his help in programming; thank you very much.

I would like also to thank Mr. **Mohanned Mahjoub,** Eng. **Osman Ahmed Hamad,** Eng. **Mohammed Abdelrahman Manofali,** and Eng. **Mohamed Abdulkhalig** for providing me information and guides which needed to complete this work.

Special thanks to my **Family,** for emotional support and patience that strongly help me to finish this research.

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NOMENCLATURE

P_b = bubble point pressure, psia.

P_d = dew-point pressure, psia.

P = system pressure, psia.

R = gas constant.

V = gas volume, ft^3/mol.

T = Temperature, $\mathring{R}$

γ_g = gas specific gravity.

γ_o = oil specific gravity, API.

M_o = oil molecular weight, lb_m/lb_m – mol.

R_s = solution gas, SCF/STB.

$SG_{C_{7+}}$ = Specific gravity of Heptane plus.

$MW_{C_{7+}}$= Molecular weight of Heptane plus.

H_2S = Sulfur hydrogen.

N = Nitrogen.

C_1, C_2, C_3, C_4, C_5, C_6, C_7 = number of carbons in the component.

C_{7+} = Heptane plus more than 7 carbons.

$RSP1_d$ = first separator gas/liquid ratio calculated using dew-point gas, (SCF/STB).

API_d = stock-tank condensate gravity calculated using dew-point gas, API.

γ_{gd} = Reservoir gas specific gravity of dew-point gas.

T_c = critical temperature, $\mathring{R}$.

P_c = critical pressure, psia.

ω = Accentric factor.

P_k = convergence pressure, psia.

P_b = bubble point pressure, psia.

P_d = Dew point pressure, psia.

a = “attraction” parameter.

b = “repulsion” parameter.

K_i = equilibrium ratio of component i.

SSE = Sum of Squared Error.

MSE = Mean of Squared Error.

RMSE = Relative Mean of Squared Error.

RRMSE = Relative Root of Mean Squared Error.

STD = Standard Deviation.

VAR = Variance.

R^2 = Correlation factor.

Chapter 1

Introduction

CHAPTER1

Research Fundamentals

2.1 General Introduction:

Engineers typically require accurate estimates of crude oil properties in order to compute oil reserves, production capacity, and recovery efficiency of a reservoir. These properties are also used in the analysis of well test and production data, as well as for production engineering activities such as hydrocarbon system optimization and flow measurements.

The best source of oil property data is a laboratory PVT (pressure-volume-temperature) analysis of a reservoir fluid sample. These physical properties also can be estimated from correlations.

Many correlations for estimating crude oil PVT properties have been published in the past 50 years. Most of these correlations yield reasonably accurate results when applied at the bubble-point pressure. However, for pressures below the bubble point, the computed PVT properties may yield considerable error.

Because the cost of using laboratories is very high also takes a lot of time; so the using of correlations for the same purpose is very suitable and useful.

1.2 Bubble point pressure:

The bubble-point pressure (P_b) of a hydrocarbon system is defined as the highest pressure at which a bubble of gas is first liberated from the oil. (Tarig Ahmed, 2001). This important property can be measured experimentally for a crude oil system by conducting a constant-composition expansion test (CCE). In the absence of the experimentally measured bubble-point pressure, it is necessary for the engineer to make an estimate of this crude oil property from the readily available measured producing parameters. Several graphical and mathematical correlations for determining (P_b) have been proposed during the past four decades.

These correlations are essentially based on the assumption that the bubble-point pressure is a strong function of gas solubility R_s, gas gravity γ_g, oil gravity API, and temperature T, or:

$P_b = f(R_s, \gamma_g, API, T)$

1.3 Dew point pressure:

Dew point pressure is defined as the pressure at which the first drop of condensate liquid comes out of the solution of the gas condensate; many gas condensate reservoirs are saturated at initial conditions, meaning that the dew point is equal to the initial reservoir pressure. Condensate dissolution is called retrograde condensation because this is counter to the behavior of pure substances, which vaporize when the pressure drops below the saturation pressure under isothermal (constant temperature) conditions, (Schlumberger Oilfield Glossary).

The figures below show the bubble and dew-points pressures curves:

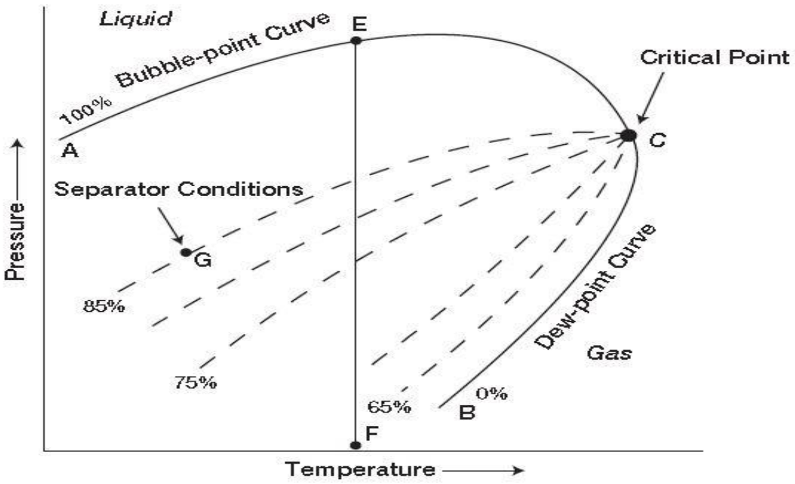


Figure (1.1): shows the bubble and dew-points pressures curves at Separator Conditions (Tarig Ahmed, 2001).

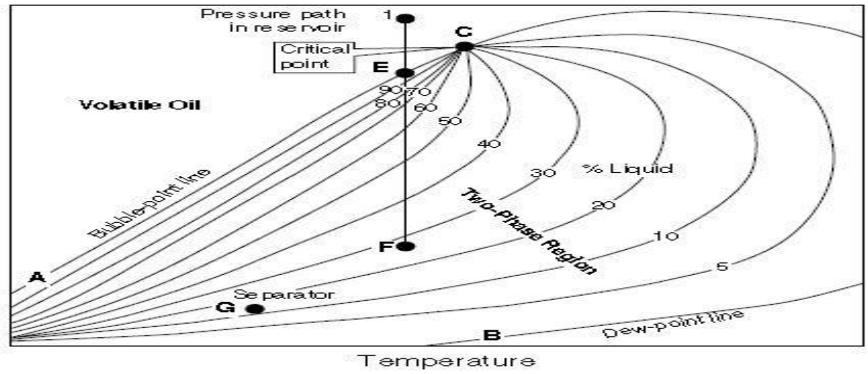


Figure (1.2): shows the bubble and dew-points pressures curves for Volatile oil (Tarig Ahmed, 2001).

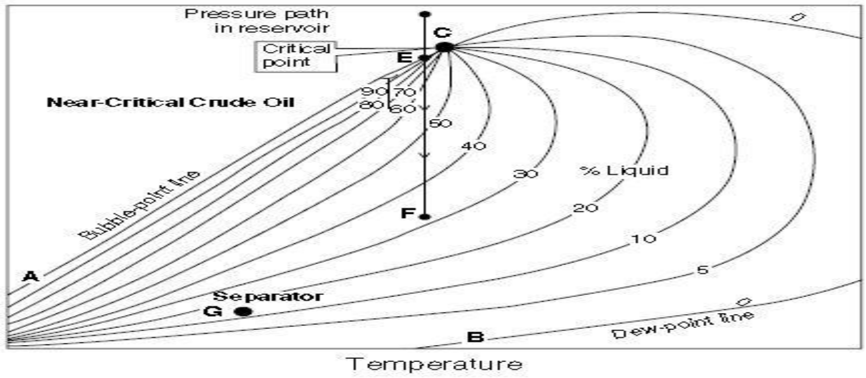


Figure (1.3): shows the bubble and dew-points pressures curves for Near-Critical crude oil (Tarig Ahmed, 2001).

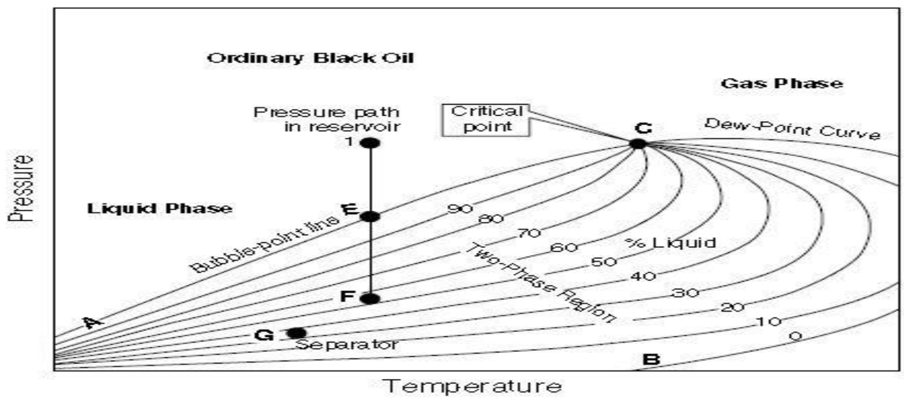


Figure (1.4): shows the bubble and dew-points pressures curves for Ordinary Black oil (Tarig Ahmed, 2001).

1.4 Equation of State (EOS):

An equation of state (EOS) is an analytical expression relating the pressure, *p*, to the temperature, *T*, and the volume, *V*. A proper description of this PVT relationship for real hydrocarbon fluids is essential in determining the volumetric and phase behavior of petroleum reservoir fluids and predicting the performance of surface separation facilities; these can be described accurately by equations of state. In general, most equations of state require only the critical properties and accentric factor of individual components. The main advantage of using an EOS is that the same equation can be used to model the behavior of all phases, thereby assuring of consistency when performing phase equilibrium calculations.

Equation of state (EOS) is an analytical expression relating the pressure P to the temperature T and the volume V.

$$P = \frac{RT}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.1)$$

Where:

P = pressure in psi.

R = gas constant.

T = temperature in F.

V = gas volume in cubic feet per 1 mol of gas.

MATLAB Introduction:

The name of MATLAB stands for **MAT**rix-**LAB**oratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects (Houcque, D., 2005).

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research (Houcque, D., 2005).

MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems.

1.4 Introduction to VariReg:

VariReg is a software tool for general purpose multidimensional regression modeling with the main emphasis on methods used in metamodelling / surrogate modeling. VariReg is primarily intended for use on small and moderately-sized numerical data sets; it was developed by GINTS JEKABSONS at the Riga Technical University.

The tool provides means for creating "full" polynomial regression models (also called Response Surface models), sparse polynomial models (also called partial polynomial models) employing subset selection algorithms, such as Sequential Forward Selection (SFS; also known as Forward Selection or Forward Stepwise Selection), Steepest Descent Hill Climbing (SDHC), Random Restart Hill Climbing (RRHC), and Sequential Floating Forward Selection (SFFS), as well as different other regression modeling techniques – Adaptive Basis Function Construction (ABFC), Locally Weighted Polynomials (LWP), k-Nearest Neighbours (k-NN), Radial Basis Function (RBF) interpolation, Kriging interpolation, Multivariate Adaptive Regression Splines (MARS), and Polynomial Neural Networks (PNN) induced by Group Method of Data Handling (GMDH).

In the methods, the model evaluation and hyperparameter selection is done using one of the following criteria:

- F-test.
- Corrected Akaike's Information Criterion (AICC).
- Schwarz's Bayesian Information Criterion (BIC).
- Generalized Cross-Validation (GCV).

- *v*-fold Cross-Validation (CV).
- Leave-One-Out Cross-Validation (LOOCV).
- A simple Hold-Out.

1.5 Problem Statement:

Is the difficulty of getting the PVT properties from oil field data because it requires high developed laboratories; using these labs are costly and takes long time comparing with the using of a computer program.

1.6 Objectives:

- To calculate bubble point pressure (P_b) and dew point pressure (P_d) using the applications of the equation of state (EOS).
- To generate correlations for bubble point pressure (P_b) and dew point pressure (P_d) using VariReg program with the concept of polynomial Neural Network (PNN) for Sudanese blocks (2 and 4).
- To compare the results from equation of state with the results of laboratory.
- A comparison study between equation of state and VariReg & laboratory results.

1.7 Scope of work:

This work applies artificial intelligent tool to predict bubble point pressure using oil gravity, reservoir temperature, gas specific gravity and oil gravity. The tool that used called polynomial neural network (PNN). Also this work applies equation of state to estimate both bubble and dew points pressures. The results of applying these tools will be compared with some of others known correlations and with laboratory results. The data used in this work were taken from ALMOGLAD basin in western Sudan including blocks (2, 4 and 6).

1.8 Methodology:

- Using VariReg software that depends mainly on the concept of artificial neural network to Generate new correlation of bubble point pressure (P_b).
- Using equation of state to calculate bubble point pressure (P_b) and dew point pressure (P_d).
- Using MATLAB® to develop a computational program containing new generated correlation and equation of state steps of calculations.

1.9 Thesis Outlines:

This thesis contains five chapters illustrated as follow:

- **Chapter1** contains general introduction of bubble point pressure, dew point pressure, equation of state, Matlab program and VariReg program.
- **Chapter2** contains intensive literature review of the general empirical correlations that has been used to calculate the bubble point pressure and dew point pressure.
- **Chapter3** contains the methodologies that have been used to generate new bubble point pressure using the VariReg software depending on the theory of neural network, and to develop a computer program to simplify the steps of calculating bubble and dew points pressures using the application of the equation of state (EOS).
- **Chapter4** contains the results from the new correlation that has been developed by VariReg to calculate just bubble point pressure and the results from the computer program that has been developed by MATLAB to calculate both bubble and dew points pressures, also contains the comparison between the results from VariReg, general empirical correlations and the results from the equation of state with the laboratory measurements.
- **Chapter5** contains recommendations, references and appendices.

Chapter 2

Literature Review and Theoretical Background

CHAPTER2

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Introduction:

The phase behavior of subsurface fluids (oil, gas and water) is an important issue in the petroleum industry, because pressure, temperature and other parameters can affect the physical phases, compositions and chemical properties of fluids.

A good understanding of the phase behavior of reservoir fluids is the basic foundation to predict oil and gas production and manage the reservoirs. Phase behavior research includes phase equilibrium study, phase envelope (bubble point and dew point lines) calculation, compositions determination and so on. Calculating the phase behavior correctly is challenging, especially for multicomponent system because the interaction between the components will play important roles in final results. Conventionally, the constant pressure and constant temperature flash (PT-flash) calculation based on cubic equation of state (EOS) is one option to study phase behavior for certain system.

There exist seven well-known petroleum fluids in nature. In the order of their fluidity, they are natural gas, gas-condensate (also known as NGL standing for natural-gas liquid), light crude, intermediate crude, heavy oil, tar sand and oil shale. These are all naturally occurring complex mixtures made up of hydrocarbons and other organic and inorganic compounds with variety of molecular structures and sizes.

PVT calculations are used to describe the phase behaviour and to determine the thermodynamic properties of hydrocarbon systems at the given pressure and temperature. PVT properties of reservoir fluids are required by the most of petroleum engineering calculations including : reservoir simulation, well testing, pipeline flow calculations and separator design and the accurate prediction of phase behaviour is essential in case of planning some tertiary recovery methods like gas injection or in situ combustion. As this is an input data for the mentioned calculations its accuracy is crucial, wrong PVT properties lead to erroneous calculation results, so the applied calculation method must be chosen carefully.

Since the 1940's engineers have realized the importance of developing empirical correlations for bubble and dew points pressure. Studies carried out in this field resulted in the development of new correlations. Several studies of this kind were published by Katz, Standing, Lasater and Cronquist …etc. For several years, these correlations were the only source available for estimating bubble and dew points pressure when experimental data were unavailable. In the last thirty years there has been an increasing interest in developing new correlations for crude oils obtained from the various regions in the world.

2.2 LITERATURE SURVEY:

The literature contains many thesis and articles on the subject of phase behavior. Most of them deal with "specific binary systems, while others are available on ternary systems. Since the main interest of the present work concerns the phase behavior of reservoir fluids, We first review the conventional PVT experiments commonly conducted in laboratories, we then review the common trends in hydrocarbon phase behavior, we discuss the equations of state commonly used to represent this behavior, and at the end we present the detailed review of the various simulation studies that attempt to represent the effect of confinement on phase behavior.

2.2.1 Correlation of Black Oil Properties At Pressures Below The Bubble-Point: JORGE JAVIER VELARDE, (Texas A&M University), (1996):

In this study non-linear regression methods were used to adjust the coefficients of all the models, the new developed correlation is similar to the equation developed by petrosky, which in turn is similar to the equation developed by standing but in this study one additional coefficient was added to the model in order to increase the accuracy of the correlation.
The table (2.1) below illustrates the statistical results of the developed model

Table (2.1): shows the statistical results of the JORGE JAVIER VELARDE model.

Parameter	**Value**
Sum of squared residuals, $psia^2$	50,261,226
Standard deviation, psia	263
Variance, $psia^2$	69,517
Average Absolute Error, %	11.7

2.2.2 New Correlation for Dew-Point, Specific Gravity and Producing Yield for Gas Condensate: ADRIANA PATRICIA OVALLE CORTISSOZ, (Texas A&M University), (2002):

The developed correlation may be used to predict the dew-point pressure of the reservoir gas at reservoir temperature using readily available field data. There have been several attempts to correlate dew-point pressures to original reservoir gas composition. The results have been reasonably accurate, but there was no evidence in the literature that a correlation based on reservoir gas specific gravity has been attempted.

- Relative errors

AARE = 9.05%,   ARE = 0.0%

- The proposed correlation was developed using 615 sets of data.

2.2.3 Prediction of PVT properties in crude oil Using Machine Learning Techniques

MLT: A.M.Ramirez, (Universidad Nacional de Ingenieria); G.A.Valle, F Romero, and M.Jaimes, (Universidad Industrial de Santander) (2017) (SPE) :

A new mathematical model is proposed using machine learning techniques for estimating PVT fluids properties such as bubble point pressure.
The results obtained with new approach are compared with previous published correlations. The proposed method for PVT properties estimation consists of two stages: data decorrelation through principal component analysis (PCA) and PVT properties estimation through Artificial Neural Network (ANN).

The table (2.2) below shows the statistical results of the A.M.Ramirez model.

Table (2.2): shows the statistical results of the A.M.Ramirez model.

Average absolute percent error %	Min. absolute percent error %	Max. absolute percent error %	Correlation coefficient R^2	Pressure range [Psia]
14.732	0.001	142.850	0.967	107.33o 7127

2.2.4 Using Artificial Neural Network to Develop New PVT Correlations for Saudi Crude Oils: M.A.AL-Marhoun (SPE), and E. A. Osman (SPE), King Fahd University of petroleum and Minerals, Dhahran, Saudi Arabia (2002):

The present study presents new models developed to predict the bubble point pressure and formation volume factor at the bubble point pressure. The model was developed using 283 data sets collected from Saudi reservoirs.

The details of data used in new developed model are illustrated in the table (2.3) below:

Table (2.3): shows the details of data used in M.A.AL-Marhoun model.

Min P_b	Max P_b	Average P_b	St. Dev	Skewness	Kurtoisis
90	3331	1461.85	874.50	0.0896	-1.0253

2.2.5 Estimating Dew point pressure Using Artificial Intelligence: Malik K. Alarfaj (Saudi Aramco); Abdulazeez Abdulraheem (KFUPM); Yasser R. Busaleh (Saudi Aramco) ,(2012):

In this paper, data from 98 PVT reports was used to construct Artificial Intelligence models using Artificial Neural Networks methods such as MLP, GRNN, and RBF. Also AI methods were used such as decision tree, Support Vector Machines, Genetic Expression, and Adaptive Neuro-Fuzzy Inference Systems.
The results were compared with both Nemeth and Kennedy correlations.
The details of data used in new developed model are illustrated in the table (2.4) below:

Table (2.4): shows the details of data used in Abdulazeez Abdulraheem model.

Min P_d	Max P_d	Average P_d	St. Dev	Correlation coefficient R^2
2679	6400	5280.8	659.2427	1

2.2.6 Dew Point Pressure Estimation of Gas Condensate Reservoir, Using Artificial Neural Network (ANN): Meisam Karbalaee Akbari and Farhang Jalali Farhang (U. of Tehran) and Yaser Abdy, Sharif (U. of Technology) (2007):

A set of conventional feed forward multilayer neural network have been proposed to predict dew point pressure of gas condensate reservoirs. The accuracy of the method is evaluated by its application for dew point pressure estimation of various reservoir fluids not used in the development of the model. Furthermore, the performance of the model is compared against the performance of other alternatives correlations reported as the most accurate and generality.

The network was developed using experimentally Constant Volume Depletion (CVD) measured condensate sample of south pars reservoir and collected data from literature of 111 gas condensate samples covering a wide range of gas properties and reservoir temperature.

- The network has an average absolute error of 2.573%, 3.832% and 2.612% for training, validation and test processes, respectively.

2.2.7 Bubble Point Pressure Correlation: J. A. LASATER (SPE)(1958):

A correlation of the bubble point pressure for black oil systems is developed using the standard physical-chemical equations of solutions. The correlation is based on 158 experimentally measured bubble point pressures of 137 independent systems and is expressed in terms of the usually measured .field parameters flash separation gas-oil ratio, tank oil gravity, total gas gravity, and reservoir temperature. The data were obtained on systems produced in Canada, Western and Mid-Continental United States, and South America. The average error (algebraic) in the representation is 3.8 per cent, and the maximum error encountered is 14.7 per cent.

2.3 THEORETICAL BACKGROUND:

2.3.1 MATLAB Introduction:

The name of MATLAB stands for **MAT**rix-**LAB**oratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects (Houcque, D., 2005).

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research (Houcque, D., 2005).

MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems. MATLAB is an interactive system which basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide.

Matlab is one of the most computer programs that used in programming especially at engineering; to design a computer program using Matlab you have to use a tool that called graphical user interface (GUI) as follow:

2.3.1.1 Introduction to Graphical User Interface (GUI):

The MATLAB® Graphical User Interface (GUI) development environment provides a set of tools for creating graphical user interfaces (GUIs) (Houcque, D., 2005). These tools greatly simplify the process of designing and building GUIs. And these GUIDE tools can be used to:

- **Lay out the GUI:**

A GUI can be easily laid out by a GUI lay out editor by clicking and dragging GUI components such as; buttons, panels, texts fields, sliders, menus, and others into the lay out area.

- **Program the GUI:**

GUIDE automatically generates an M-file that controls how the GUI operates. The M-file initializes the GUI and contains a framework for all the GUI callbacks are the commands that are executed when the user clicks a GUI component using the M-file editor. You can add a code to the callbacks to perform the functions needed.

The following sections provide an overview of creating GUIs with GUIDE:

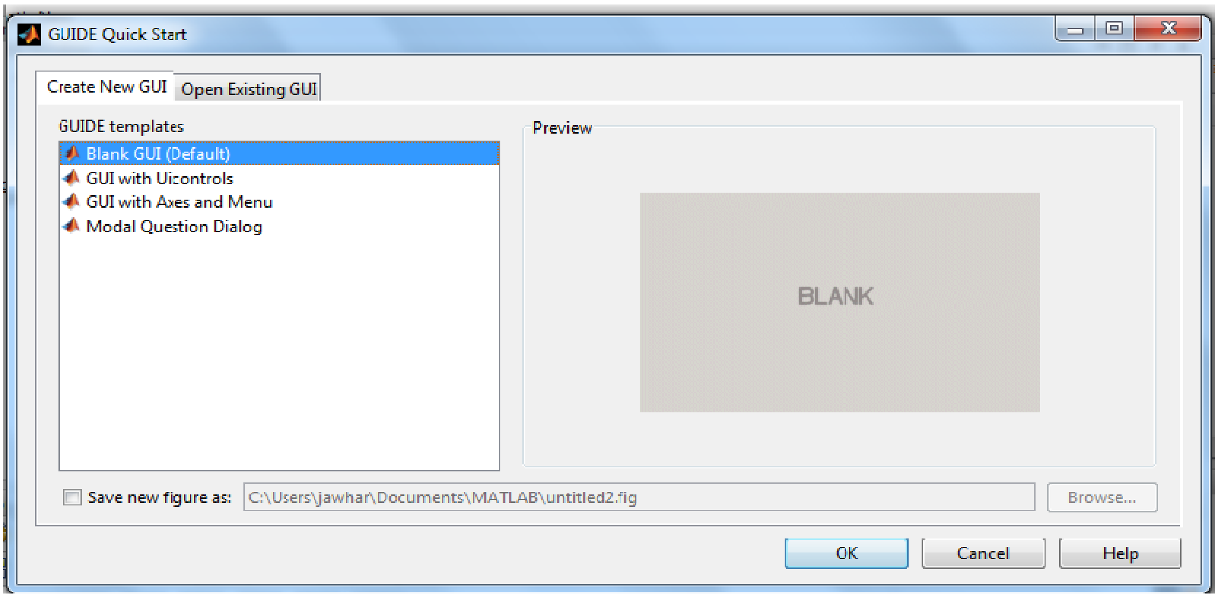


Figure (2.1): Guide Quick Start (Published with MATLAB® 7.10).

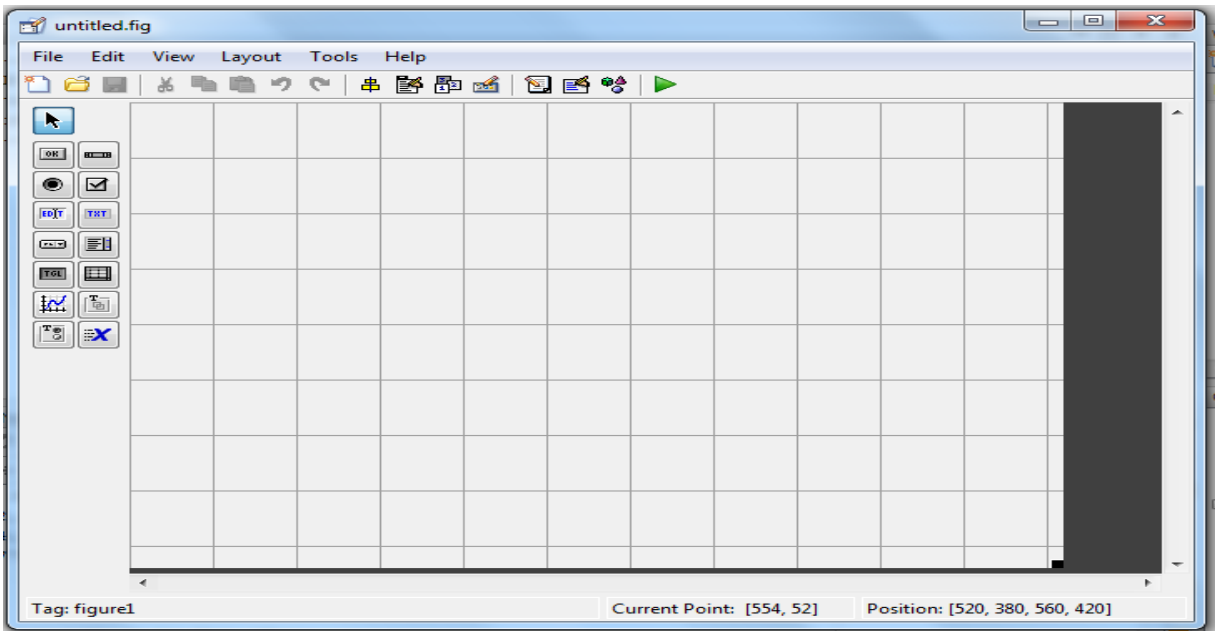


Figure (2.2): The Layout Editor (Published with MATLAB® 7.10).

2.3.1.2 How a Graphical User Interface Works:

A graphical user interface provides the user with a familiar environment to work. This environment contains pushbuttons, toggle buttons, lists, menus, text boxes, and so forth, all of which are already familiar to the user, so that; the user can concentrate on the using of the application rather than on the mechanism involved. However, GUIs are harder to the programmer because a GUI-based program must be prepared for mouse clicks (or possibly keyboard input) for any GUI element at any time. Such inputs are known as events, and a program that responds to events is said to be event driven.

- ❖ The three principal elements required to create a MATLAB Graphical User Interface are**:**

1. Components:

Each item on a MATLAB GUI (pushbuttons, labels, edit boxes, etc.) is a graphical component. The types of components include graphical controls (pushbuttons, edit boxes, lists, sliders, etc.), static elements (frames and text strings), menus, and axes.

Graphical controls and static elements are created by the function uicontrol, and menus are created by the functions uimenu and uicontextmenu. Axes, which are used to display graphical data, are created by the function axes.

1. Figures:

The components of a GUI must be arranged within a figure, which is a window on the computer screen. In the past, figures have been created automatically whenever we have plotted data. However, empty figures can be created with the function figure and can be used to hold any combination of components.

2. Callbacks:

There must be some way to perform an action if a user clicks a mouse on a button or types information on a keyboard. A mouse click or a key press is an event, and the MATLAB® program must respond to each event if the program is to perform its function. For example, if a user clicks on a button, that event must cause the

MATLAB code that implements the function of the button to be executed. The code executed in response to an event is known as a call back. There must be a callback to implement the function of each graphical component on the GUI. The basic GUI elements are summarized in Table 1.1, and sample elements are shown in Figure 1.1. We will be studying examples of these elements and then build working GUIs from them.

2.3.1.3 Creating and Displaying a Graphical User Interface:

MATLAB® GUIs are created using a tool called guide, the GUI Development Environment. This **tool** allows the programmer to layout the GUI, selecting and aligning the GUI components to be placed in it. Once the components are in place, the programmer can edit their properties: name, color, size, font, text to display, and so forth.

When guide saves the GUI, it creates working program including skeleton functions that the programmer can modify to implement the behavior of the GUI. When guide is executed, it creates the Layout Editor, shown in Figure 1.2. The large white area with grid lines is the *layout area,* where a programmer can layout the GUI. The Layout Editor window has a palate of GUI components along the left side of the layout area. A user can create any number of GUI components by first clicking on the desired component, and then dragging its outline in the layout area. The top of the window has a toolbar with a series of useful *tools* that allow the user to distribute and align GUI components, modify the properties of GUI components, add menus to GUIs, and so on.

2.3.2 Introduction to VariReg:

VariReg is a software tool for general purpose multidimensional regression modeling with the main emphasis on methods used in metamodelling / surrogate modeling. VariReg is primarily intended for use on small and moderately-sized numerical data sets; it was developed by GINTS JEKABSONS at the Riga Technical University.

The tool provides means for creating “full” polynomial regression models (also called Response Surface models), sparse polynomial models (also called partial polynomial models) employing subset selection algorithms, such as Sequential Forward Selection (SFS; also known as Forward Selection or Forward Stepwise Selection), Steepest Descent Hill Climbing (SDHC), Random Restart Hill Climbing (RRHC), and Sequential Floating Forward Selection (SFFS), as well as different other regression modeling techniques – Adaptive Basis Function Construction (ABFC), Locally Weighted Polynomials (LWP), k-Nearest Neighbours (k-NN), Radial Basis Function (RBF) interpolation, Kriging interpolation, Multivariate Adaptive Regression Splines (MARS), and Polynomial Neural Networks (PNN) induced by Group Method of Data Handling (GMDH).

In the methods, the model evaluation and hyperparameter selection is done using one of the following criteria:

- F-test.
- Corrected Akaike's Information Criterion (AICC).
- Schwarz's Bayesian Information Criterion (BIC).
- Generalized Cross-Validation (GCV).
- *v*-fold Cross-Validation (CV).
- Leave-One-Out Cross-Validation (LOOCV).
- A simple Hold-Out.

The modeling methods (or models generated by them) can be evaluated using *v*-fold Cross-Validation or Hold-Out. The full and sparse polynomial models can also be represented in a "spreadsheet-friendly" way.

VariReg also enables all the implemented regression modeling methods to be combined together using a number of model averaging techniques:

- Simple unweighted averaging.
- Averaging weighted by LOOCV error.
- LOOCV error variance.
- LOOCV error correlation, as well as averaging by Stacking.

All the VariReg's regression modeling methods, including model averaging, can also be put to work from:

- A command line using in configuration files.

- Matlab environment using wrapper functions provided together with VariReg.

The figure below shows the general shape of VariReg software:

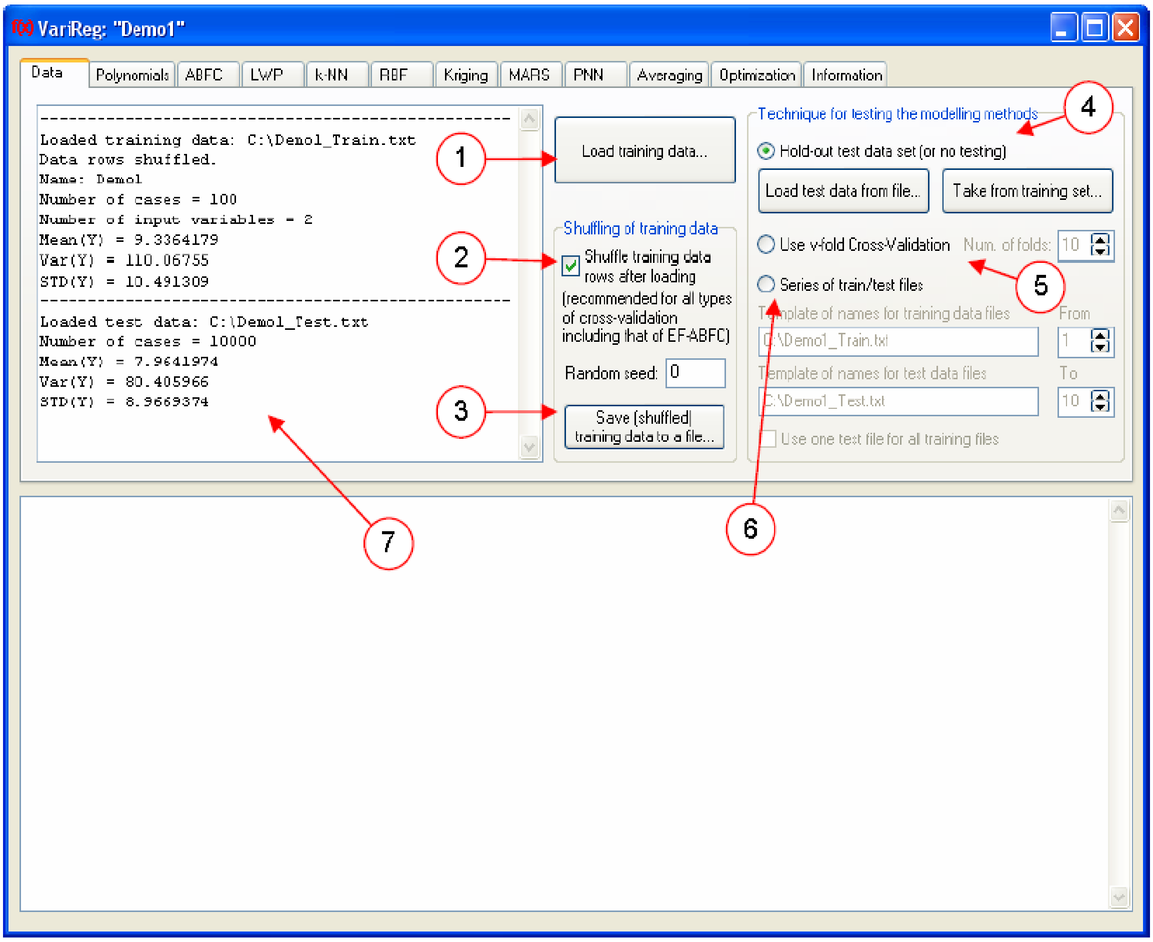


Figure (2.3): shows the general shape of VariReg software.

❖ **Note:**

The implementations of regression modeling methods in VariReg can be considerably faster (even orders of magnitude) than the same methods scripted in Matlab.

In the context of metamodelling / surrogate modeling, VariReg can be employed for building metamodels / surrogate models for evaluation and comparison of the different techniques as well as for further use in what-if analysis, design optimization, design space exploration etc, VariReg also provides means for optimization of the values of output variables using the built regression models as objective functions. In the current version of VariReg the following optimization algorithms are implemented: Particle Swarm Optimization (PSO) and a simple Grid Search (GS).

This user's manual provides a very brief overview of the implemented regression modeling methods as well a short guide to VariReg's input file format, user's interface, and access from command line and Matlab environment.

Note that the current version of VariReg is implemented as single-threaded and the software tool may appear as hung-up while performing some longer model building, prediction, or optimization operations.

2.3.2.1 Some applications of VariReg software:

1- Aerospace	2-Automotive
3-Credit Card Activity Checking	4-Banking
5-Defence	6- Electronics
7-Entertainment facilities	8-Financial
9-Industrial structures	10-Insurance
11-Oil & Gas industry	12-Robotic

2.3.2.2 User's interface:

VariReg user's interface consists of a window with tabs and a log; and these tabs are:

- Tab **"Data"** – manipulation of training and test data sets as well as Cross-Validation for evaluation of the modeling methods.
- Tab **"Polynomials"** – full and sparse polynomials built by subset selection methods.
- Tab **"ABFC"** – modeling using Adaptive Basis Function Construction.
- Tab **"LWP"** – modeling using Locally Weighted Polynomials.
- Tab **"k-NN"** – modeling using k-Nearest Neighbours.
- Tab **"RBF"** – modeling using Radial Basis Function interpolation.
- Tab **"Kriging"** – modeling using Kriging interpolation.
- Tab **"MARS"** – modeling using MARS.
- Tab **"PNN"** – modeling using Polynomial Neural Networks induced by Group Method of data handling.
- Tab **"Averaging"** – modeling using model averaging/ensembling/combining.

- Tab **“Optimization”** – optimization of the values of output variables using the built regression models as objective functions.
- Tab **“Information”** – information about VariReg’s version, copyright, author’s contact e-mail and webpage address, as well as citations for references.

The tabs that will be used in the methodology of this research:

1. Tab “Data”:

Figure (2.4) demonstrates user’s interface of the tab:

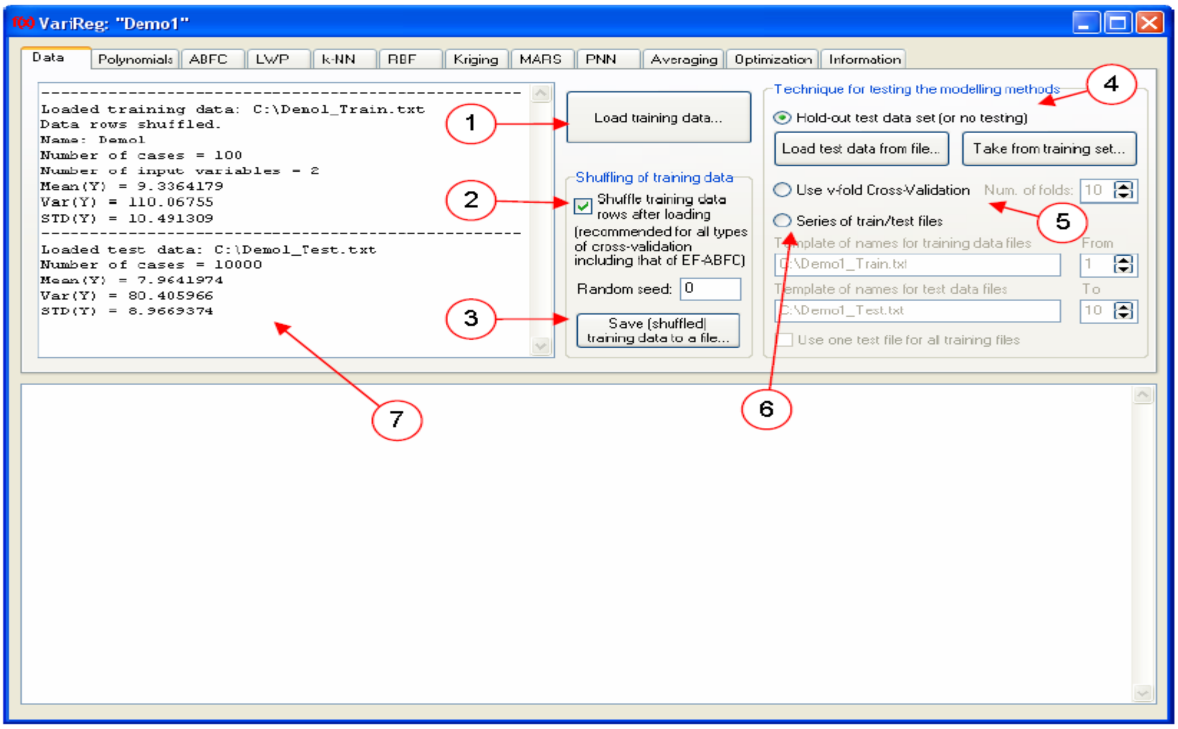


Figure (2.4): shows the Data modeling steps.

The numbers in the figure (3.8) above are illustrated below:

1. Button for loading training data set.
2. For all types of Cross-Validation it is important that the order of the data points in the whole training data set is uninformative (randomized).This checkbox provides the possibility to shuffle the order of the data points in the training data set right after loading it. The “random seed” enables the shuffling to be identical if multiple modeling methods are tested and the training data is reloaded.
3. Button for saving the (shuffled) training data set.

4. Radio button for selection of Hold-Out type of testing of modeling methods – in this case the user must load the test data set from additional file or take some percentage of data points from the training data set.
5. Radio button for selection of *v*-fold Cross-Validation type of testing of modeling methods –in this case the user must set the number of folds *v* for the Cross-Validation and each time when any modeling algorithm is started, the program will perform Cross-Validation (i.e. the modeling will be restarted *v* times) and the results will be stored in a user-chosen file which can be used for further calculations of averages, variances, standard deviations etc. Note that the Cross-Validation is done in the proper way – cross-validated are the modeling methods themselves not the models (i.e. the Cross-Validation loop is performed over the whole modeling method). The modeling process will be done *v* times. Note also that the models built during the Cross-Validation should not be used any further – to build models for further applications the “Hold-out test data set (or no testing)” radio button should be checked.
6. Radio button for selection of Hold-Out type of testing of modeling methods using a series of train/test files – in this case the user must supply template filenames (together with file paths) for the train and test files. When the modeling is started, a string “#.txt” (where # is the number of the file) will be added to these names automatically and the corresponding files will be loaded. This means that if the user has data files e.g. “train1.txt”, “train2.txt”, “train3.txt”, “test1.txt”, “test2.txt” and “test3.txt” on drive “C:”, then the templates must look like “C:\train” and “C:\test” and the values in fields “From” and “To” must be 1 and 3 correspondingly. In case the “Use one test file for all training files” is checked, for all the training data files a single one test data file will be used (and no additional symbols will be added to the file path, e.g. the entered string should look like “C:\test.txt”).
7. A small log for information on training data and testing data – file names, number of data points (data cases), number of input variables, mean value of *y*, variance of *y*, standard deviation of *y* etc.

2. Tab “PNN”:

Figure (3.6) demonstrates user’s interface of the tab:

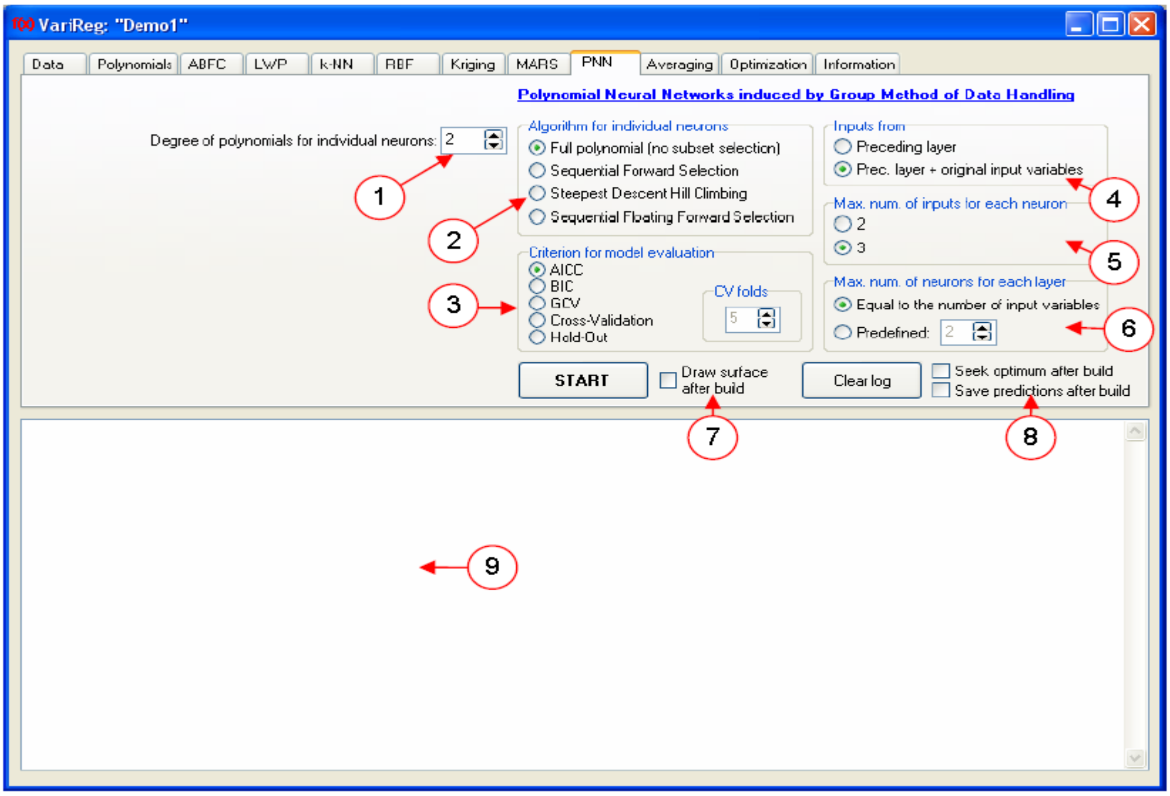


Figure (2.5): illustrates **PNN** tab modeling.

The numbers in the figure are shown below:

1. (Maximal) degree of polynomials in each neuron.
2. Radio buttons for selection of full polynomials (no subset selection) or one of the subset selection algorithms for generating neurons.
3. Radio buttons for selection of criterion for subset selection in each neuron as well as for deciding when to stop the building of the network.

4. Radio buttons for selection of whether the inputs to the neurons are taken only from the immediately preceding layer or also prom the original input variables.
5. Maximum number of inputs for each neuron.
6. Maximum number of neurons in each layer.
7. Draw surface of the model right after building it.

8. Checkboxes for seeking optimum of the output variable using the built model and saving the predictions (in the training and/or test data sets) of the built model to a file right after building it.

9. Information on the just built model:

- "Total number of generated layers" – the total number of the generated layers of the network (the last layer is discarded).
- "Number of layers" – the number of layers in the final network.
- "Used input variables" – the list of input variables used in the final network.
- "The number of used input variables" – the number of input variables used in the final network.
- "Crit value" – used criterion's value for the final network.

Chapter 3

Methodology

CHAPTER 3

METHODOLOGY

3.1 Introduction:

This chapter is considered as the most important part of this thesis that because it contains the steps of calculation of the bubble point pressure and dew point pressure as an application of equation of state; and using these steps to generate a computer program using MATLAB software.

Also it contains the explanation and details of the steps that will be used to generate new correlations of (P_b) and (P_d) including the way of data entering and how the required correlations developed using modified computer software called VariReg (Variable Regression) program using the same data.

3.2 Bubble and Dew Points Pressures calculations using Equations of State:

In oil industry in General when we aimed to determine the PVT properties such as bubble point pressure and dew point pressure in general we use either laboratories or calculate them using correlations; and in this thesis the correlations that have been developed using the applications of the equation of state will be programmed with a computer software (MATLAB) to simplify the stages of solution.

The steps of the calculations of both bubble point and dew point will be explained as follow:

3.2.1 Bubble point pressure calculation:

Assumptions:

$N_l = 1$ (mole fraction of liquid phase)

$N_v = 0$ (mole fraction of vapor phase)

$Z_i = x_i$

Steps of solution:

Step (1): Calculate the convergence pressure (p_k) using standing's equation:

$$P_k = 60M_{c_{7+}} - 4200 \quad \text{……………………………… (3.1)}$$

Step (2): Calculate P_c and T_c using Riazi and daubert: for C7+

$$T_c = 3.08 * 10^2[\exp((-1.3478 * 10^{-4} * M) - 0.61641 * S)] * M^{0.2998} * S^{1.0555} \quad \text{……………………………………………(3.2)}$$

$$P_c = 3.1166 * 10^2[\exp((-1.8078 * 10^{-3} * M) - 0.3084 * S)] * M^{-0.8063}S^{1.6015} \quad \text{… (3.3)}$$

Step (3): Calculate the accentric factor (ω) using demister equation: for C7+

$$\omega = [\frac{3\log(\frac{Pc}{14.7})}{7\left(\frac{Tc}{T_b}-1\right)} - 1\ ] \quad \text{………………………….. (3.4)}$$

Step (4): estimate P_b from:

$$P_b = \sum_{i=1}^{n}[Zi\ *\ P_{ci}\exp[5.73(1 + w_i)(1 - \frac{T_{c_i}}{T})]] \quad \text{…………… (3.5)}$$

Step (5): employing iterative procedure and using Whitson & Trop equation ratio:

$$K_i = \left(\frac{P_{ci}}{P_K}\right)^{A-1}\left(\frac{P_{ci}}{P}\right) \exp[5.73A(1 + w_i)(1 - \frac{T_{c_i}}{T})] \quad \text{..........(3.6)}$$

$$A = 1 - \left(\frac{P}{P_K}\right)^{0.7} \quad \text{.........................} \; (3.7)$$

Using the concept of **try and error** with appropriate accuracy that means with minimum error as follow:

Calculate K_i at $P =$ initial estimated (P_b) then K_iZi .

If $\sum K_i$Zi > 1 then the initial estimated (P_b) must be reduced ($P_b = P_b - 10$).

Else if $\sum K_i$Zi < 1 then the *initial estimated* P_b must be increased ($P_b = P_b + 10$).

Else $\sum K_i$Zi =1 the calculated $P_b =$ *estimated* P_b .

❖ The flow chart of P_b calculation will be as:

Flowchart of (P_b) Calculation:

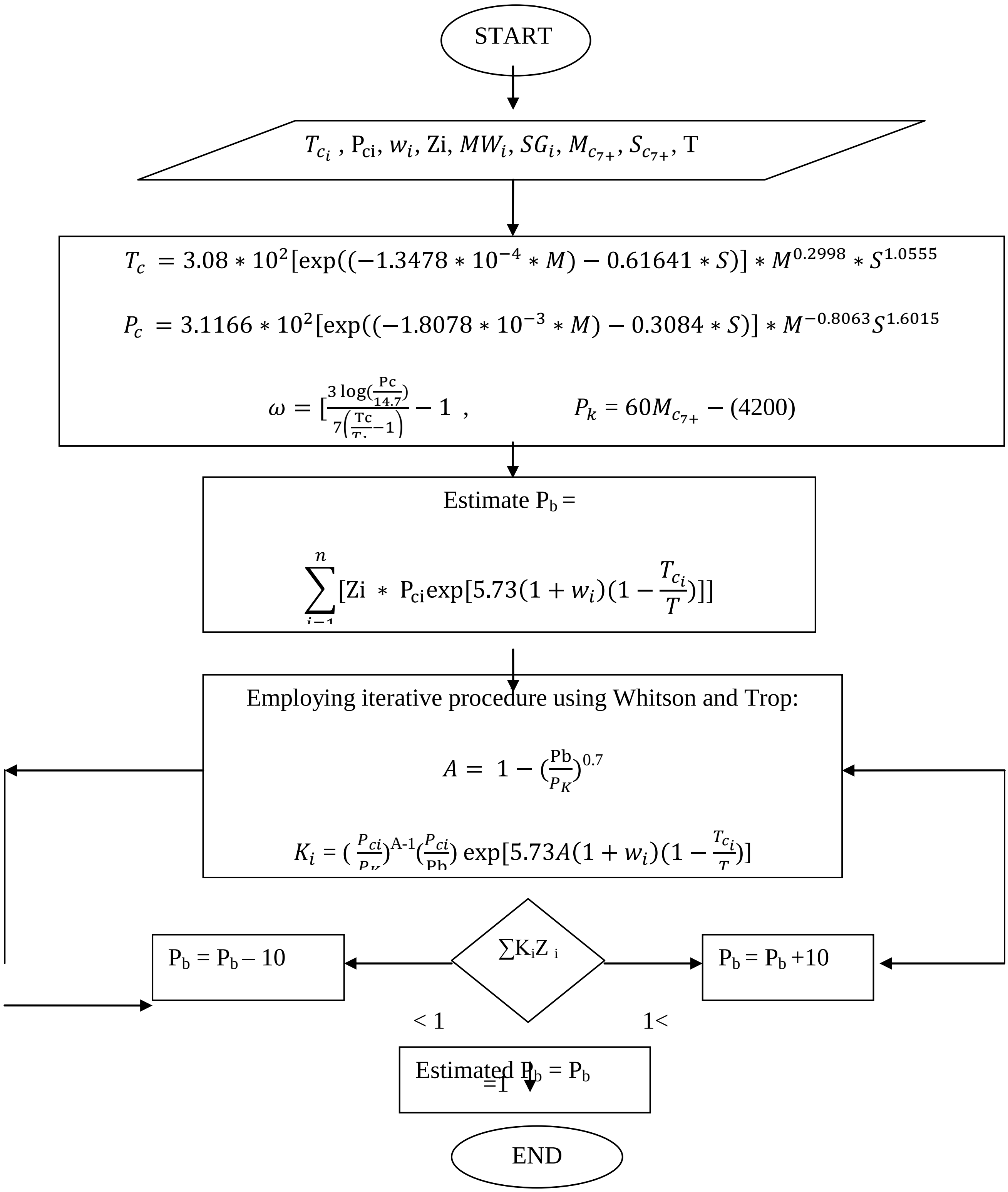


Figure (3.1): shows the flowchart of bubble-point pressure.

3.2.2 Dew Point Pressure calculation:

Assumptions:

$N_l = 0$

$N_v = 1$

Then $y_i = z_i$

$$\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} \frac{z_i}{n_l + n_v(k_i)} = \sum_{i=1}^{n} \frac{z_i}{k_i} \quad \ldots\ldots (3.8)$$

$$\sum_{i=1}^{n} y_i = \sum_{i=1}^{n} \frac{(k_i)z_i}{n_l + n_v(k_i)} = 1 \text{ »» } \sum_{i=1}^{n} y_i = \sum_{i=1}^{n} z_i \text{ »» } \sum_{i=1}^{n} \frac{z_i}{k_i} = 1 \quad ..$$

(3.9)

Steps of Calculation:

Step (1) Assume a trial value of (p_d); using Wilson equation to calculate k_i to give:

$$\sum_{i=1}^{n} \left[\frac{z_i}{\frac{P_{c_i}}{P_d} \exp[5.73(1+w_i)(1-\frac{T_{c_i}}{T})]} \right] = 1 \quad \ldots\ldots\ldots\ldots (3.10)$$

Solving for P_d yields:

$$\text{Initial } P_d = \left(\frac{1}{\sum_{i=1}^{n} \left[\frac{z_i}{P_{c_i} \exp[5.73(1+w_i)(1-\frac{T_{c_i}}{T})]} \right]} \right) \quad \ldots\ldots (3.11)$$

Another simplified approach for estimating P_d is to treat the H.C mixture as an ideal system with K_i as:

$$K_i = \frac{P_{v_i}}{P} \quad \text{………………..……… (3.12)}$$

By substituting:

$$\sum_{i=1}^{n} [z_i (\frac{P_d}{P_{v_i}})] = 1 \quad \text{………………………… (3.13)}$$

Solving for P_d yields:

$$\text{Initial } P_d = \frac{1}{\sum_{i=1}^{n} (\frac{z_i}{P_{v_i}})} \quad \text{……………. (3.14)}$$

Step (2) Using the assumed P_d to calculate K_i for each component

Step (3) Compute new dew point pressure as:

$$P_d = \left(\frac{1}{\sum_{i=1}^{n} [\frac{z_i}{P_{c_i} \exp[5.73(1+w_i)(1-\frac{T_{c_i}}{T})]}]} \right) \quad \text{……………..… (3.15)}$$

If sum < 1 repeat steps 2&3 using high initial value of pressure ,if not then the correct value of P_d when sum=1

❖ The flowcharts of P_d calculation will be as:

Flowchart of (P_d) Calculation

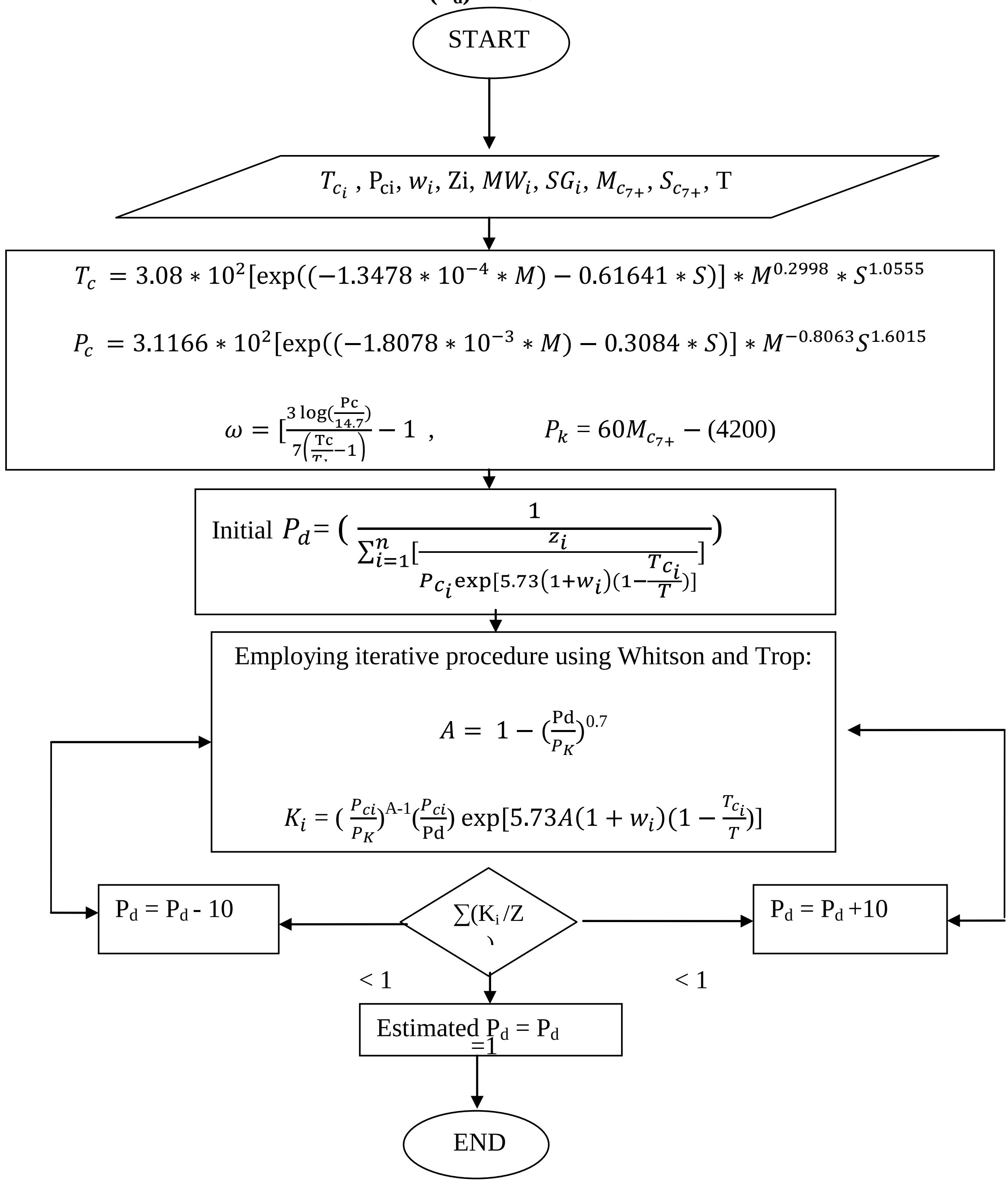


Figure (3.2): shows the flowchart of dew-point pressure.

3.3 Computer Program Using Matlab:

3.3.1 Program design procedures:

1) Creating program flow charts:

The flow charts are shown in figures (3.1) and (3.2) with the steps of equation of state, input data and general output; the Matlab program is designed based on this flow chart.

2) Writing M-files:

The M-file is a conversion of flow charts into a MATLAB code by using special command in MATLAB language. In this program there are six M-files of this program consist of thousands of programming lines.

3) Creating the program Graphical User Interface (GUI):

This can be achieved by using the layout editor as shown in figure (2.2) and this program consists of six GUIs.

4) Testing (Validity Check) of the program by comparing its results with solved case with known empirical correlations; in this thesis the comparison will be between Standing, Glasso, Marhoun, Petrosky and Farshad empirical correlations, and EOS.

3.4 Development of New Correlations Using VariReg Program:

VariReg (Variable Regression) is a software tool for general purpose multidimensional regression modeling and it is primarily intended for use on small and moderately-sized numerical data sets. The most important parts to generate new correlations with this software are:

- How to input a training data.
- How to handle with the user's interface.

Explained as follow:

3.4.1 Input file format:

The figures below illustrate VariReg's input format for training data and test data it is possible also to take some percentage of data points from the training data set as Hold-Out data for testing or use the data with Cross-Validation after loading of training data set.

```
Demo
3 100

y
x1
x2

0.45 0.69 0.63
0.73 0.03 0.4
...
data
 0.34 0.02 0.76
```

Name of the data set

Number of input variables plus 1 for *y* (*d*+1) and number of data points in the file (*n*)

Name for output variable followed by the names of input variables one in each line

Data. Each row corresponds to one point with value of output variable followed by the values of input variables separated by one or more spaces or one tab or (the values must be in simple fixed-point in standard scientific format; the only recognized decimal separator is the point)

Figure (3.3): input file format- the training data.

```
100


0.45 0.69 0.63
0.73 0.03 0.41
...
0.34 0.02 0.76
```

Number of data points in the file (the number of variables is assumed to be equal to that in the training data set file)

Data

Figure (3.4): input file format- the test data.

In this thesis a model that called polynomial neural network (PNN) will be used to generate new correlations using VariReg program and the general procedures that will be followed are:

1. Input the data required for training data and test data consequently in a notepad as a text.
2. The data will be divided usually into 75% for training and 25% for testing before loading them into the software.
3. Then load the training data using the (Data) button then (load training data) button .
4. We choose the tab that we are going to use; in this thesis (P-NN).
5. Then tab the (START) button; the correlation will be created in this first run; and this run will be saved.
6. Next we will change in the GMDH (Group Method of Data Handling) every run; some items will be changed and others not.
7. Two factors must be observed and recorded, the correlation factor (R^2) and Relative Root of Mean Squared Error (RRMSE) and the major factors of the inputs every run.
8. We will stop running program when:
   - R^2 is near to 1.
   - RRMSE is lower as possible.
   - And the major factors are found (all or most) in the created correlation.

➢ The figure (3.5) below shows the example of GMDH polynomial neural network structure (Gints Jekabsons, 2010):

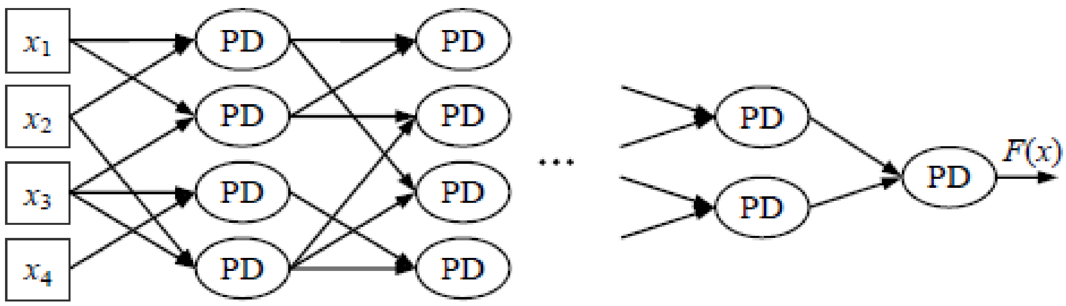


Figure (3.5): shows an example of GMDH (PNN) structure.

3.4.2 Errors and correlation factor that used:

1. Sum of Squared Error (SSE):

$$\textbf{SSE} = \sum_{i=1}^{n}((Y_{(i)}) - F(X_i))^2 \quad \dots\dots\dots\dots (3.16)$$

Where:

$Y_{(i)}$ = bubble point pressure from laboratories

$F(X_i)$ = bubble point pressure from prediction

2. Mean of Squared Error (MSE):

$$\textbf{MSE} = \frac{\textbf{SSE}}{\textbf{n}} = \frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - F(X_i))^2 \quad \dots.. (3.17)$$

Where:

$Y_{(i)}$ = bubble point pressure from laboratories

$F(X_i)$ = bubble point pressure from prediction

3. Relative Mean of Squared Error (RMSE):

$$\textbf{RMSE} = \sqrt{\boldsymbol{MSE}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - Y^{-})^2} \quad \dots\dots\dots. (3.18)$$

Where:

$Y_{(i)}$ = bubble point pressure from laboratories

n = number of data.

Y^{-} = statistical average.

4. Standard Deviation (STD):

$$\textbf{STD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - \bar{Y})^2} \quad \text{........ (3.19)}$$

Where:

$Y_{(i)}$ = bubble point pressure from laboratories.

$\bar{Y}$ = statistical average.

n = number of data.

5. Relative Root of Mean Squared Error (RRMSE):

$$\textbf{RRMSE} = \frac{RMSE}{STD} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - F(X_i))^2}}{\frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - \bar{Y})^2} \quad \text{........ (3.20)}$$

Where:

RMSE = Relative Mean of Squared Error.
STD = Standard Deviation.

$Y_{(i)}$ = bubble point pressure from laboratories

$F(X_i)$ = bubble point pressure from prediction

n = number of data

6. Variance (VAR):

$$\textbf{VAR} = \frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - \bar{Y})^2 \quad \text{............ (3.21)}$$

Where:

$F(X_i)$ = bubble point pressure from prediction.

Y^{-} = statistical average.

n = number of data.

7. Correlation factor:

$$\boldsymbol{R^2} = 1 - \frac{MSE}{VAR} = 1 - \frac{\frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - F(X_i))^2}{\frac{1}{n}\sum_{i=1}^{n}((Y_{(i)}) - Y^{-})^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.22)$$

Where:

R^2 = Correlation factor.

MSE = Mean of Squared Error.

VAR = Variance.

$Y_{(i)}$ = Bubble point pressure from laboratories.

$F(X_i)$ = Bubble point pressure from prediction.

Y^{-} = Statistical average.

n = Number of data.

Chapter 4

Results and Discussions

CHAPTER4

Results and Discussion

4.3Introduction:

This chapter contains the procedures and steps of building and creating the MATLAB® program that used to calculate the bubble point pressure and dew-point pressure using the application of equation of state and other empirical known correlations.

Also contains in details the stages of creating new correlation for bubble point pressure using software called VariReg that depends on the principal of neural network.

In addition to show a case study from Sudanese oil fields specially; including data sets to be used in both programs as inputs and laboratory outputs for the same data, also this chapter includes the results of MATLAB® program, results from manual calculations and the generated bubble point pressure correlation of VariReg.

The MATLAB® program will be validated using calculations of a case study; lastly this chapter includes the comparison between laboratory results, results from MATLAB® program and the outputs of VariReg correlations.

4.2 Data details:

4.2.1 Data Area of oil fields:

The data that used in this thesis was collected from Sudanese oil fields that generally located under ALMOGLAD western Sudan basin which contains the following types of formations that illustrated in the table **(4.1)** below:

Table (4.1): shows the general formations with depth in ALMOGLAD basin.

Formation name	**Depth, m**
Nayil	159
Amal	251
Barka	507

Formation name	Depth, m
Ghazal	662
Zarga	762
Ardeiba upper shale	916
Ardeiba lower shale	1112
Ardeiba E	1279
Bentiu 1A	1301
Bentiu 2A	1372
Bentiu 3A	1449

4.2.2 Data Description:

The data that used in this thesis were taken from ALMOGLAD basin in western Sudan including blocks (2, 4 and 6) from 69 reports of bubble point pressure, including main factors that affect the measuring of bubble point pressure; the table (4.2) below shows the data used and their ranges minimum, maximum and average.

Table (4.2): shows the ranges of data.

Parameter	Maximum	Minimum	Mean
Measured Bubble point(P_b), psi	3362	42	1086.292
Oil gravity (γ_o), API	47.16	19.3	36.30949
gas specific gravity (γ_g)	1.752	0.6181	1.172413
Solution gas(R_s),SCF/STB	1292	0.0001	322.6495
Temperature(T),C°	117.78	15.55	84.26928

4.3 Developed MATLAB® program:

❖ The program that has been designed using the codes that illustrated in (appendix B) is shown below:

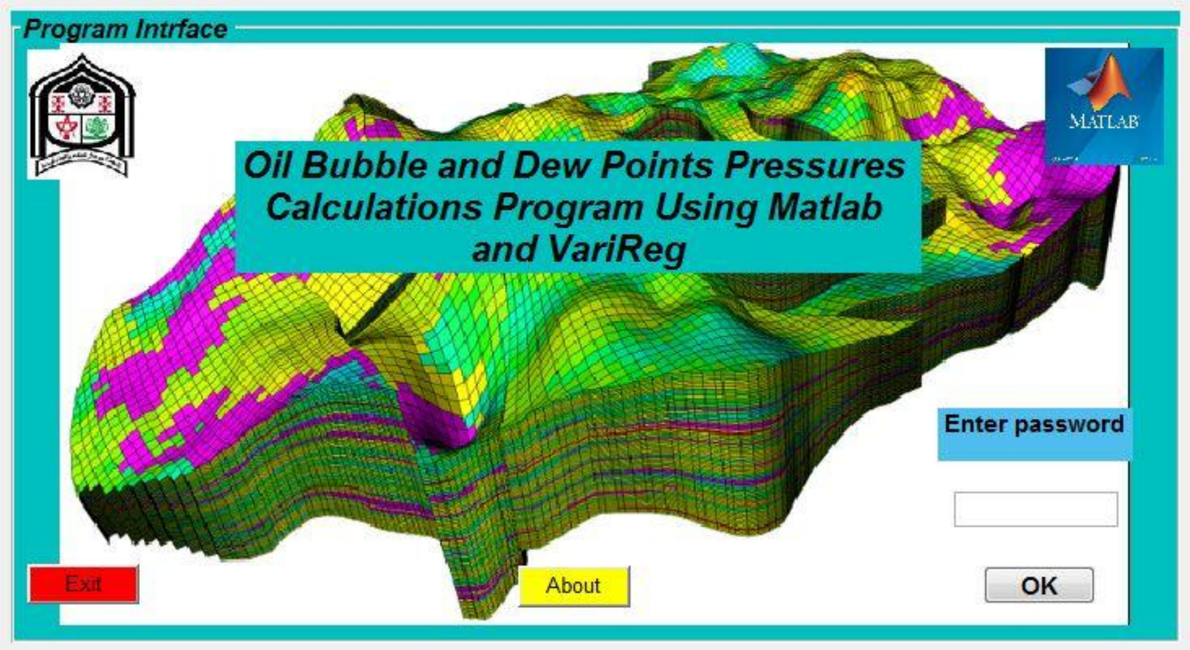


Figure (4.1): shows the window of the program interface.

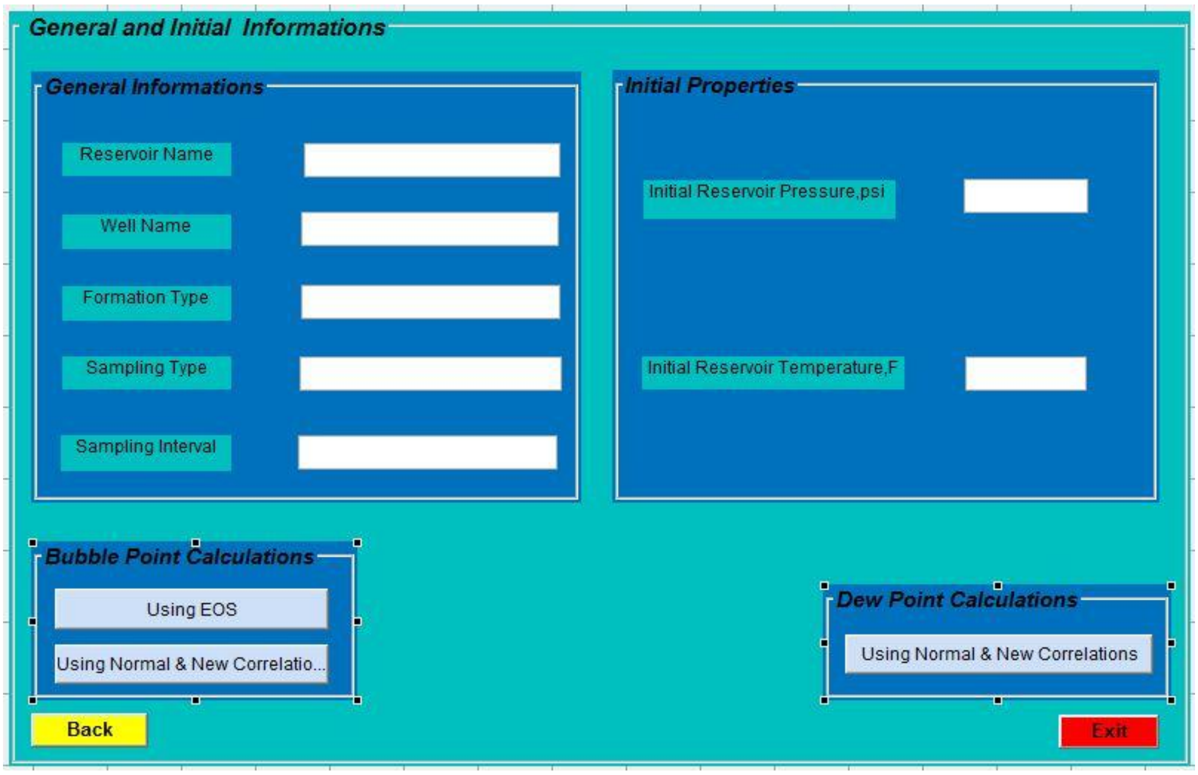


Figure (4.2): shows the window of General and Initial Information.

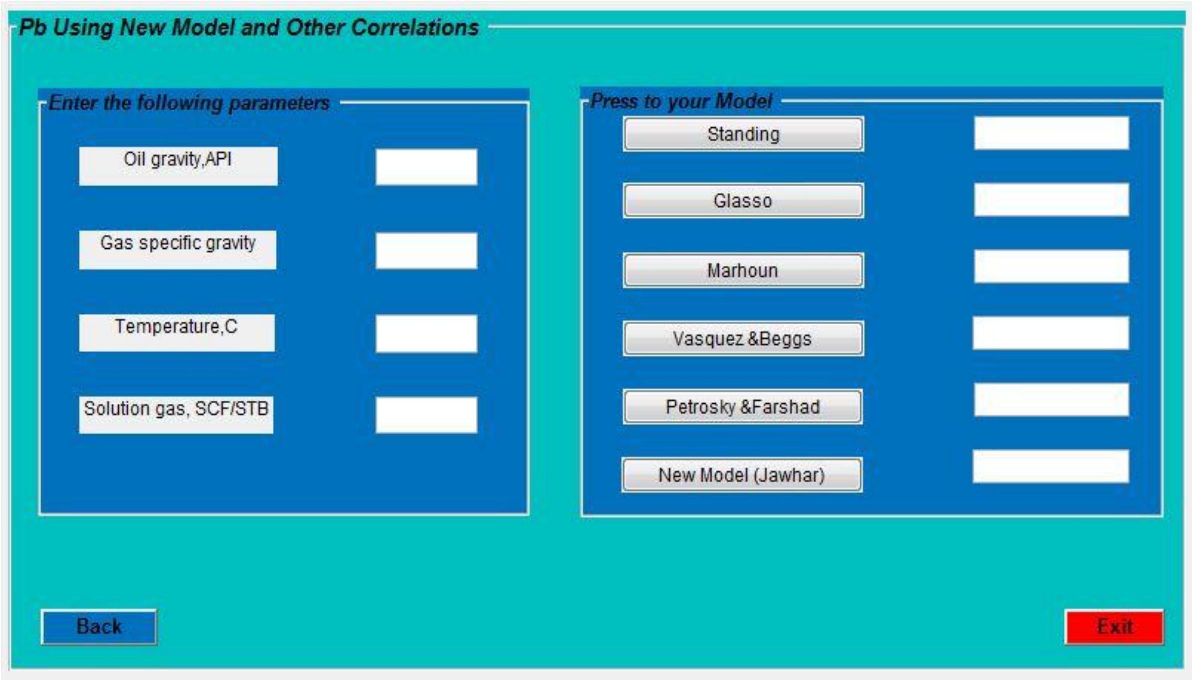


Figure (4.3): shows the window of P_b calculation using new model and others correlations.

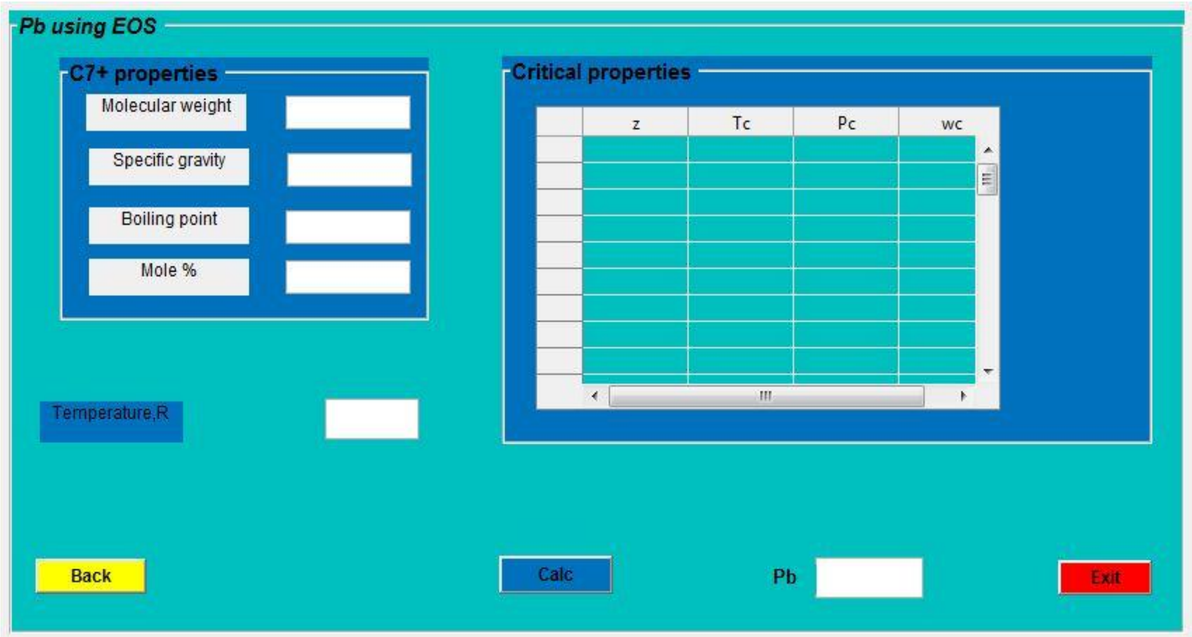


Figure (4.4): shows the window of P_b calculation using EOS.

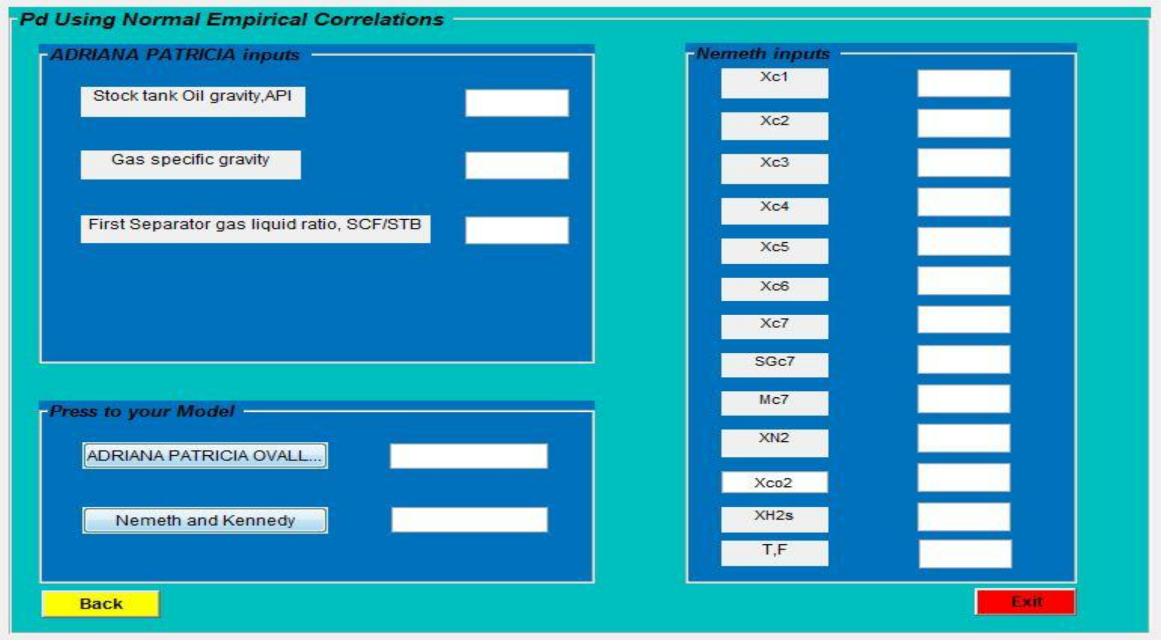


Figure (4.5): shows the window of P_d calculation using normal empirical correlations.

4.3.1 General properties of developed MATLAB program:

All the GUIs that mentioned above were converted to Windows Standalone Application (exe extension file) and in this case, MATLAB® software is not required to be installed just MATLAB® compiler is needed. Figure (4-6) shows the main icon of the software (Pb and Pd software) on the desktop.

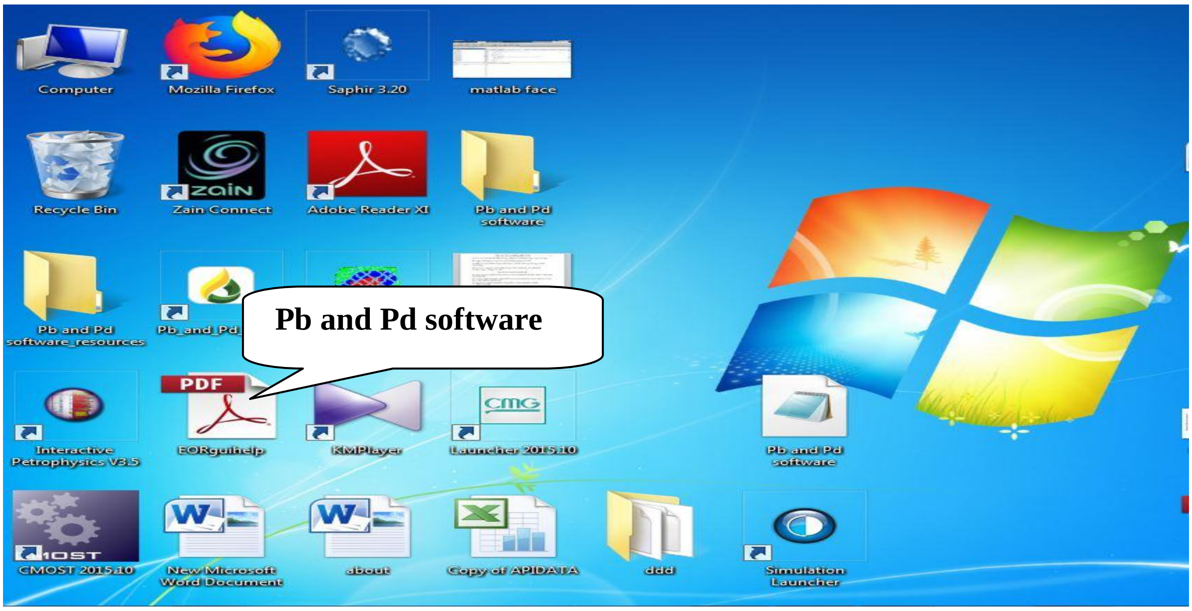


Figure (4.6): shows the icon of Pb and Pd software on the desktop.

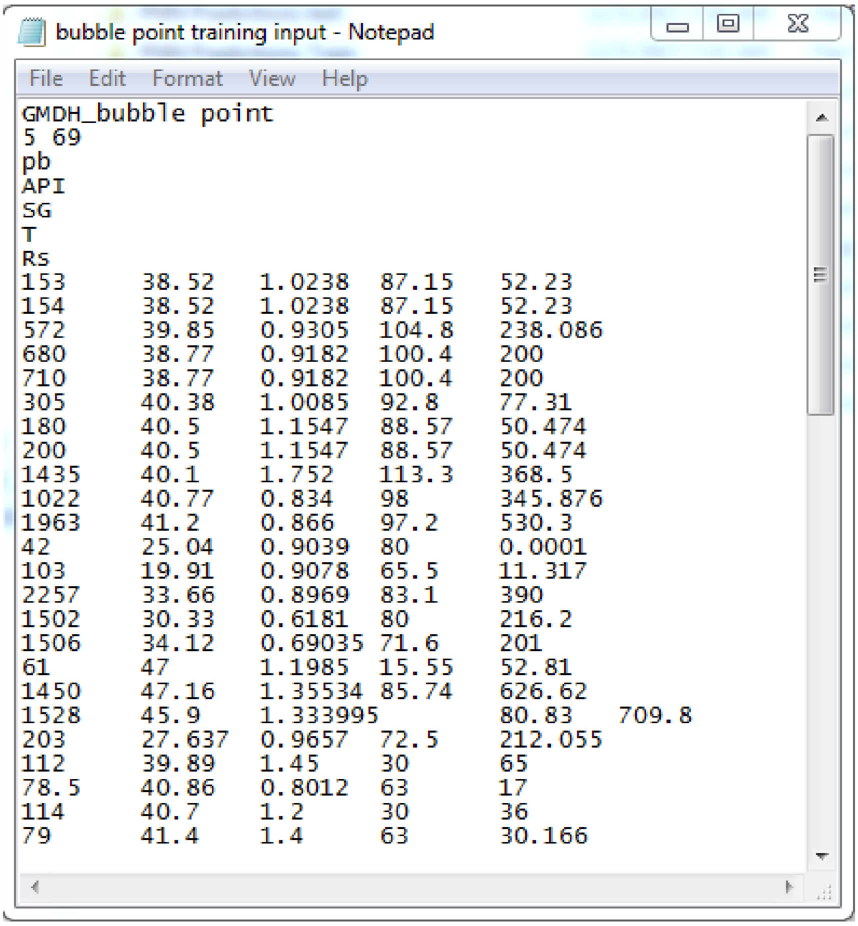
The general features of Pb and Pd software are shown below:

Table (4.3): illustrates the general properties of Pb and Pd software.

Software name	Pb and Pd software
Software size	1.4MB
Setup package size	634.5MB
System requirements	Windows 7, 8, 10 with RAM 1GB at least

4.4 Model developed using polynomial neural network (PNN):

The model developed using PNN in VariReg software used (69) data points for training data and (30) data points for test data (Appendix A) as shown in figures (4.7) and (4.8) below and figure (4.9) shows the general properties of data inputs.




```
GMDH_bubble point
5 69
pb
API
SG
T
Rs
153     38.52   1.0238  87.15   52.23
154     38.52   1.0238  87.15   52.23
572     39.85   0.9305  104.8   238.086
680     38.77   0.9182  100.4   200
710     38.77   0.9182  100.4   200
305     40.38   1.0085  92.8    77.31
180     40.5    1.1547  88.57   50.474
200     40.5    1.1547  88.57   50.474
1435    40.1    1.752   113.3   368.5
1022    40.77   0.834   98      345.876
1963    41.2    0.866   97.2    530.3
42      25.04   0.9039  80      0.0001
103     19.91   0.9078  65.5    11.317
2257    33.66   0.8969  83.1    390
1502    30.33   0.6181  80      216.2
1506    34.12   0.69035 71.6    201
61      47      1.1985  15.55   52.81
1450    47.16   1.35534 85.74   626.62
1528    45.9    1.333995        80.83   709.8
203     27.637  0.9657  72.5    212.055
112     39.89   1.45    30      65
78.5    40.86   0.8012  63      17
114     40.7    1.2     30      36
79      41.4    1.4     63      30.166
```

Figure (4.7): shows input formula of training data used.

bubble point test data - Notepad

File Edit Format View Help

30				
153	38.52	1.0238	87.15	52.23
572	39.85	0.9305	104.8	238.086
710	38.77	0.9182	100.4	200
1435	40.1	1.752	113.3	368.5
1022	40.77	0.834	98	345.876
1963	41.2	0.866	97.2	530.3
42	25.04	0.9039	80	0.0001
2257	33.66	0.8969	83.1	390
61	47	1.1985	15.55	52.81
79	41.4	1.4	63	30.166
2440.7	40.64	1.17451	92.37	441.87
112	39.89	1.45	30	65
43.5	24.68	1.5235	95.8	456.352
305	40.38	1.0085	92.8	77.31
180	40.5	1.1547	88.57	50.474
1502	30.33	0.6181	80	216.2
78.5	40.86	0.8012	63	17
114	40.7	1.2	30	36
1790	26.8	1.2425	71.6	484.025
2426	40.64	1.20734	92.37	494.4
594	40.2	1.52258	98.5	172.638
3362	44	0.948	106.1	1292
383	19.3	1.1634	87.94	48
56.25	29.11	1.2425	20	484.025
1997	34.65	1.019	85	553.84
232	25.89	1.44671	88	52.93
2581	41.83	1.20798	92.37	494.4
56.25	29.11	1.2425	20	484.025
200	40.5	1.1547	88.57	50.474
1190	38.19	1.45426	106	323.642

Figure (4.8): shows input formula of test data.

After many runs; the properties of the best chosen run as shown in figure (4.10) are:

- The maximum degree is (4).
- Algorithm for individual neurons is (full polynomial).
- The inputs from preceding layers and original input variables.
- The number of used input variables equal (3).
- Maximum number of inputs for each neuron is (predefined 4).
- Maximum number of neurons for each layer is equal to the number of input variables.
- Criterion for model evaluation is Cross-Validation (CV).
- Test R^2 equals (0.996).
- Test MSE equals (4102.056).
- Test RRMSE equals (0.066).

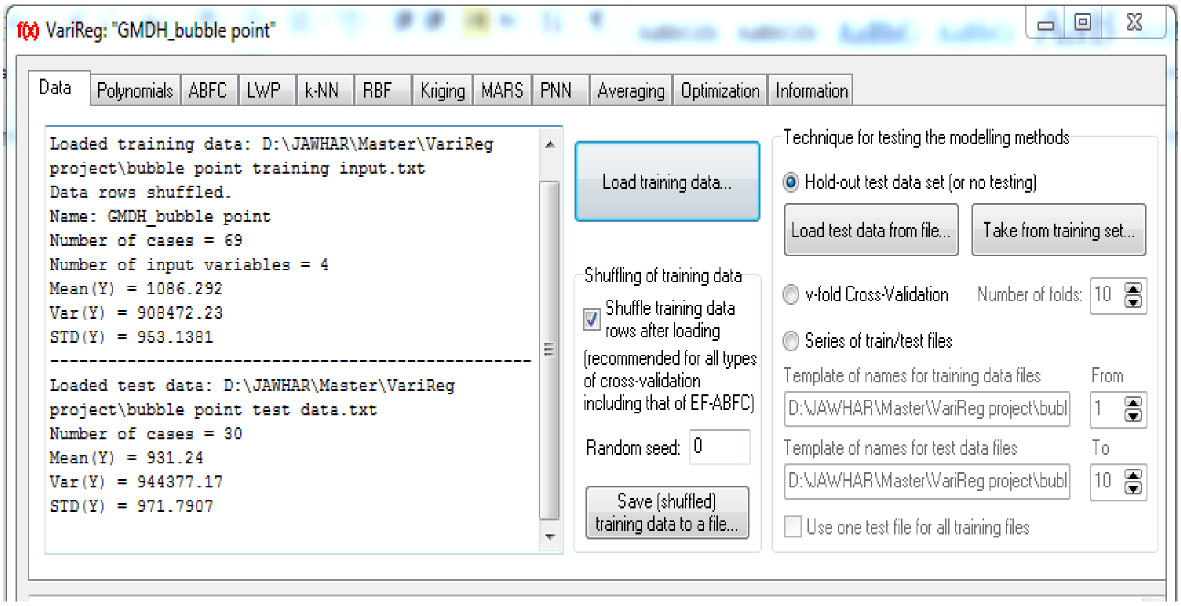


Figure (4.9): shows the general properties of loaded data.

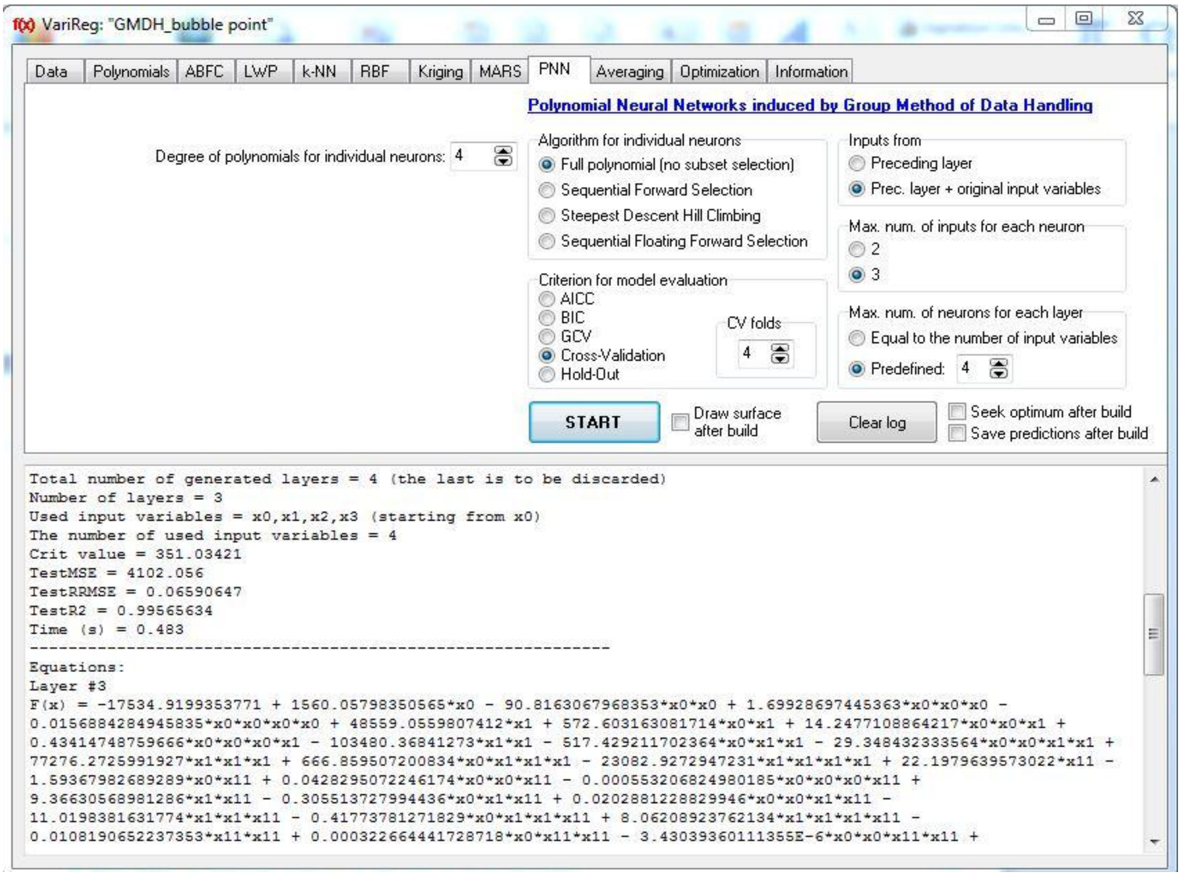


Figure (4.10): shows the best chosen run.

- The new developed model for prediction bubble point pressure is:

$$\mathbf{Pb} = X_{11}^2*E\text{-}3*A+API*B+API^2*C+D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

A = X_{11} *10^-4*(6.468+901API-6.32* γ_g) + API*(32-3430API-0.111γ_g) + γ_g(7.6-0.51γ_g)

B = (γ_g(573+667(γ_g)^2-517γ_g)+ X_{11} (-1.6-0.306γ_g-0.418(γ_g)^2)+1560

C =API*(1.7-0.016*API+0.434γ_g-5.53E-4 X_{11}) + (-90.82+14.25*γ_g*-29.34γ_g^2+0.043 X_{11}+0.02γ_g)

D = X_{11} (22.2 + γ_g(9.37-11.02+8.06γ_g^2)- X_{11} (0.011+4.9E-11γ_g^2))+ γ_gE4(4.86-10.3γ_g+7.73γ_g^2-2.31γ_g^3)-1.75E4

$$\mathbf{X_{11}} = X_7^2E\text{-}2*E+X7*F+G+X_4^2*H \quad \ldots\ldots\ldots\ldots\ldots (4.2)$$

E = X_7E-7(1320-25.5API-4350 X_4-19.8 X_7)+(-1.8+0.124API-0.00195API^2-768 X_4+1.66E-5API X_4+9.49E-8 X_4^2

F = 1.62-0.21API+0.007API^2-7.48E-5API^3+0.042 X_4-0.0029API X_4+4.63E-5 API^2 X_4+1.35E-5 X_4^2-3.35E-7API X_4^2-9.92E-10 X_4^3

G = X_4(26.78-2.35API+0.068API^2-6.47E-4API^3) +1.86E4-2.6E3API+129API^2-2.73API^3+0.021API^4

H = (0.0012API-0.017-2.01E-5API^2) + X_4E-8(13.9API-645+0.0535 X_4)

$$\mathbf{X_7} = R_s^2*I+ R_s*J+T^2*K+L \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

I = R_sE-5(4.4γ_g-16.2+1.14-29E-5R_s)+(-0.031γ_g+0.02γ_g^2 -0.0012T-5.2E-4γ_gT+6.07E-6T^2+1.32)

J =30.49-392.1+376γ_g^2 -87γ_g^3+3.51T-0.71γ_gT-γ_g^2T-0.032T^2+0.018γ_g T^2

K =T (-0.077+0.017γ_g+2.3E-4T) +9.04-3.15γ_g-0.095γ_g^2

L = T (-1970+4200γ_g-3460γ_g^2+991.5γ_g^3) + γ_gE5 (2.08γ_g-2.53) + γ_g^3E4 (0.367γ_g-5.1) +1.04E5

$$\mathbf{X_4} =M*T^2 +\gamma_g^2*N+T*O+P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

M =T(6.3E-4API-0.77+0.33γ_g+1.07E-3T) + (157.4+0.574API-0.016API^2-130.58γ_g+ 0.48APIγ_g

N = $(-2.34E5+2.28E4API-57.4API^2-14.2APIT) + \gamma_g E3 (58.2-4.86API-7.76\gamma_g+1.08T)$

O = $-2.5E4-605API-11.45API^2+0.071API^3+2.57E4\gamma_g-447.3API\gamma_g+5.71API^2\gamma_g-6110\gamma_g{}^2)$

P =$API (3770-4.91E4\gamma_g) + API^2 (1.26E3\gamma_g-22.01)-API^3 (6.54+15.94\gamma_g) +4.93E5+0.156API^4-3.55E4\gamma_g$

Where:

P_b = bubble point pressure, psi.

API = oil gravity, API.

T = system temperature, C°.

γ_g = gas specific gravity.

R_s = gas Solubility, SCF/STB.

The relationships between predicted model and measured model for both training and testing are shown below in figures (4.11) & (4.12):

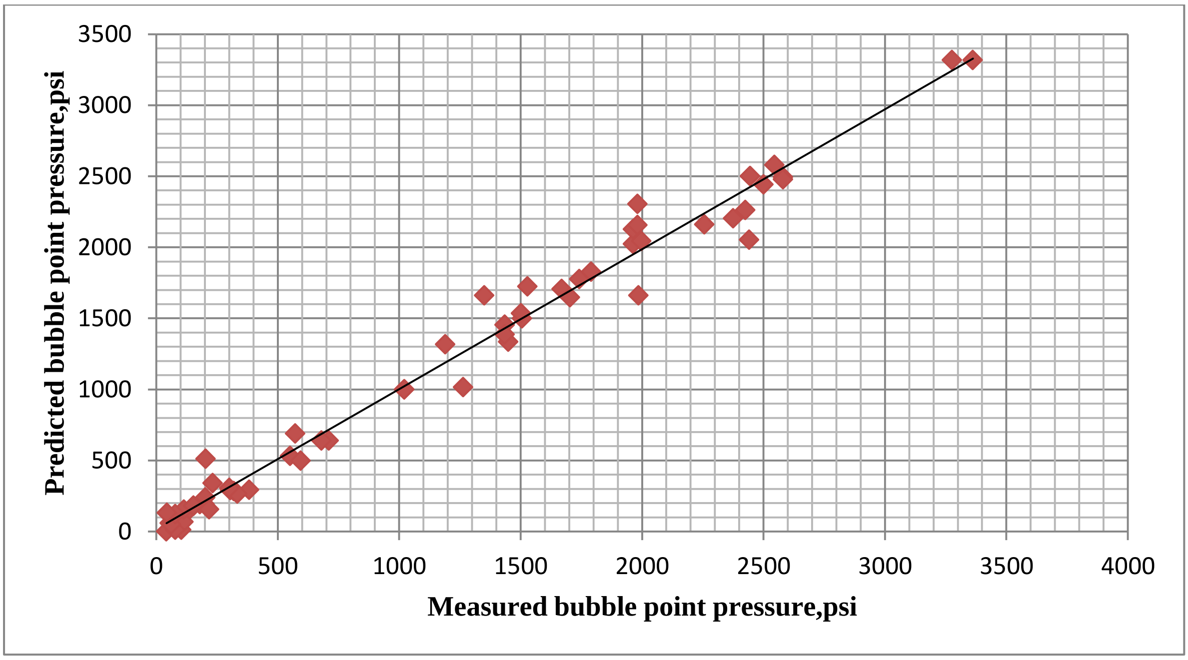


Figure (4.11): Measured P_b vs. predicted P_b for the training data.

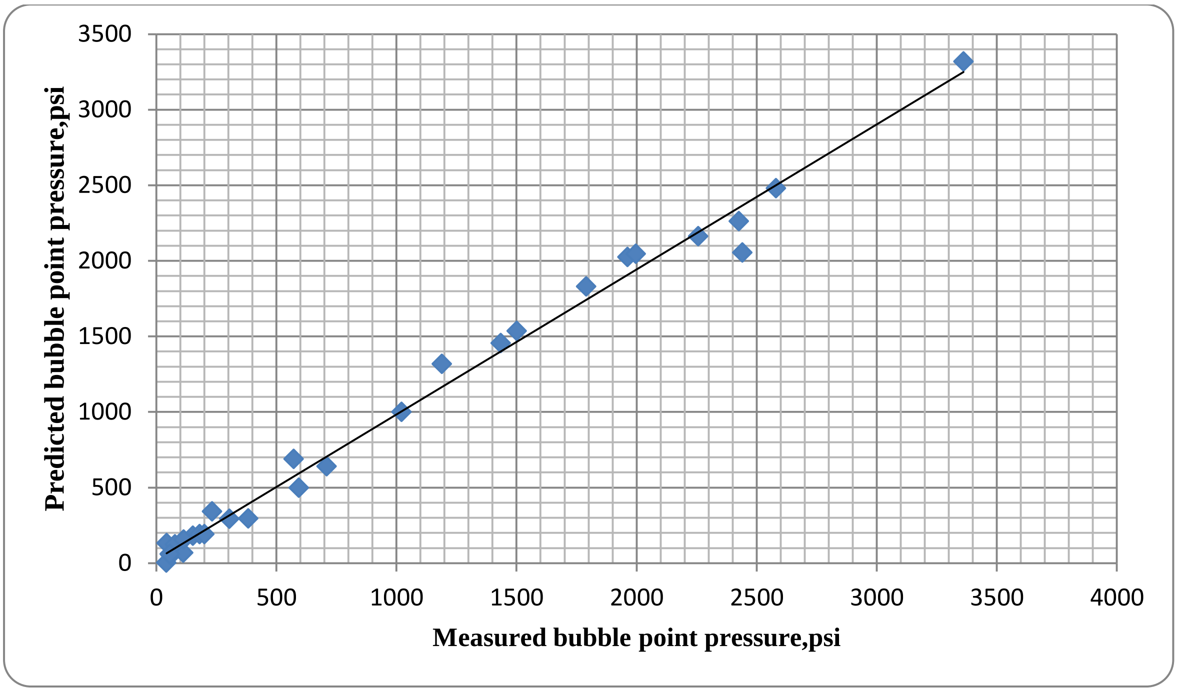


Figure (4.12): Measured P_b vs. predicted P_b for the testing data.

4.5 The statistical errors of the new developed model:

The statistical results from the new developed model are shown in the table (4.4) below:

Table (4.4): shows the new developed model results.

Model	SSE	MSE	RMSE	STD	RRMSE	R^2	VAR
New Model	950996.8	4102.056	64.047	971.79	0.066	0.996	944377.8

4.6 Statistical errors from Others Known Correlations:

The following table illustrates the statistical errors of the others correlations that mentioned in chapter3; and the comparison using the statistical errors that explained in chapter3.

Table (4.5): shows the results of statistical errors of the others known correlations.

Model	SSE	MSE	RMSE	STD	RRMSE	R^2	VAR
Standing	27822585.65	403225.879	635.001	2.04E+12	3.106E-10	0.718	1429862.4
Glaso	30933681.38	448314.223	669.563	5.5E+11	1.217E-09	0.396	741711.519
Marhoun	34093778.45	494112.731	702.932	1.89E+11	3.714E-09	-0.136	435047.614
Petrosky & Farshad	271932686	3941053.42	1985.209	2.73E+13	7.276E-11	0.246	5223426.2

Where:

SSE = Summation of Squared Error.

MSE = Mean of Squared Error.

RMSE = Relative Mean of Squared Error.

RRMSE = Relative Root of Mean Squared Error.

STD = Standard Deviation.

VAR = Variance.

R^2 = Correlation factor.

One of the data of the case study above used to determine the bubble point pressure and the other used to determine the dew-point pressure

The statistical results of table (4.5) will be shown in figures as:

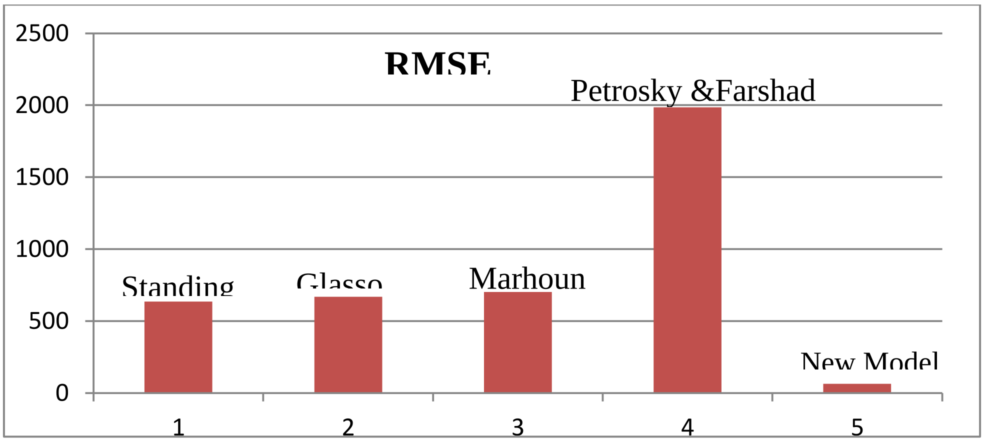


Figure (4.13): show the **(RMSE)** comparison between general correlations and new one

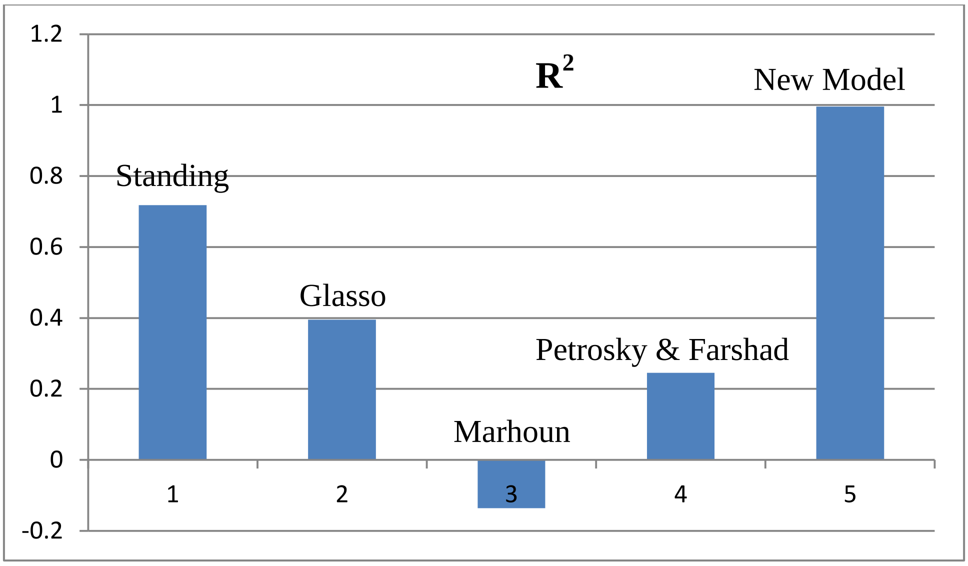


Figure (4.14): show the (R^2) comparison between general correlations and new one

4.7 Details of the wells reports that have been used in the comparison:

4.7.1 Details of bubble point pressure:

The general information and properties of the well tested for bubble point pressure are shown below:

Table (4.6): shows the general information of tested well (Azrag C-1).

*** Reservoir and well information:**	
Well Name Formation Reservoir fluid Reservoir Pressure (Psia) Reservoir Temperature (°F ,°C) Test Number	Azraq C-1 DST -4 AbuGabra BOTTOM HOLE OIL SAMPLE 1550 176°F , 80°C DST-4
*** Sampling Information:**	

Sampling Time Sample Volume (cc] Testing interval Sampling Depth Bubble point Pressure @ reservoir temperature Opening Pressure @ 21°C (Psig) Sampling Company	05:20/09-29-2009 600 1550.0-1665.0 mkb 1548.0 mkB 1502 3700 CNLC

Table (4.7): shows the general properties of the well (Azrag C-1) that used in study for bubble point pressure.

GOR	Oil gravity, API	γ_g
220.92	30.33	0.6181

Table (4.8): shows the compositional analysis of well (Azrag C1) that has been tested for bubble point pressure.

Component	z_i	Tc	Pc	wc
NITROGEN	0.024845	227.49	493.1	0.0403
CARBON DIOXIDE	0.020161	547.91	1071	0.2276
METHANE	0.901866	343.33	666.4	0.0108
ETHANE	0.046127	549.92	706.5	0.099
PROPANE	0.002138	666.06	616	0.1517
ISOBUTANE	0.002566	734.46	527.9	0.177
N-BUTANE	0.000408	765.62	550.6	0.1931
ISOPENTANE	0.000626	829.1	490.4	0.2275
N-PENTANE	0.000102	845.8	488.6	0.2486
HEXANES	0.000113	1012.22	710.4	0.2108
M-C-C5	0.000242	959.35	548.9	0.2302
Benzene	0.000017	1012.22	710.4	0.2108

Table (4.9): shows the properties of Heptane plus for the well (Azrag C1) that used in study for bubble point pressure.

C_7+	
Mole%	0.00581398
Molecular Weight (g mol^{-1})	172.5532314
Density at 60°F (g cm^{-3})	0.82333175

4.7.2 Details of dew point pressure:

The general information and properties of the well tested for bubble point pressure are shown below:

Table (4.10): shows the general information of the well (Azrag R-1) that used in study for Dew point pressure.

*** Reservoir and well information:**	
Well Name	Azraq R-1 DST-1a
Formation	AbuGabra
Reservoir fluid	Gas Condensate
Reservoir Pressure (Psia)	3434.6
Reservoir Temperature (°F)	179.6
Test Number	DST-4
*** Sampling Information:**	
BH pressure, psi	3434.6
BH temperature, F	179.6
Testing interval	2032.5-2039
Dew point Pressure @ reservoir temperature	2053
Type of sample	BHS
Sampling Company	CNLC

Table (4.11): shows the general properties of the well (Azrag R-1) that used in study for dew point pressure.

GOR (first separator)	Oil gravity, API	γ_g
60666.465	58.96	0.7368

Table (4.12): shows the compositional analysis of well (Azrag R-1) tested for Dew point pressure.

Component	z_i	**Tc**	**Pc**	**wc**
NITROGEN	0.007	227.49	493.1	0.0403
CARBON DIOXIDE	0.00459	547.91	1071	0.2276
METHANE	0.80226	343.33	666.4	0.0108
ETHANE	0.08319	549.92	706.5	0.099
PROPANE	0.058	666.06	616	0.1517
ISOBUTANE	0.007	734.46	527.9	0.177
N-BUTANE	0.0191	765.62	550.6	0.1931
ISOPENTANE	0.00427	829.1	490.4	0.2275
N-PENTANE	0.00648	845.8	488.6	0.2486
HEXANES	0.00493	1012.22	710.4	0.2108
Me-Cyclo-Pentane	0.00049	959.35	548.9	0.2302
Benzene	0.00025	1012.22	710.4	0.2108
Cyclo-hexane	0.00069	1456.7	591	0.2149

Table (4.13): shows the properties of Heptane plus for the well (Azrag R-1) that used in study for Dew point pressure.

C_7+	
Mole%	0.00176
Molecular Weight (g mol^{-1})	101.793
Density at 60°F (g cm^{-3})	0.736

4.8 The Results:

4.8.1 Results using reference calculations:

Example (15.5) from" Ahmed_Tarig –reservoir engineering handbook –fourth Edition" explained as follow:

Reservoir temperature is 200 ^{o}F and a composition as given below:

Component	x_i
C_1	0.42
C_2	0.05
C_3	0.05
i-C_4	0.03
n-C_4	0.02
i-C_5	0.01
n-C_5	0.01
C_6	0.01
C_{7+}	0.4

$M_{c_{7+}}$ = 216

$\gamma_{c_{7+}}$ = 0.8605

$T_{b\,c_{7+}}$ = 977^{o} R

Solution:

Step (1): Calculate the convergence pressure of the system by using Standing's correlation Equation (3.1):

P_k = (60)*(216) – (4200) = **8760** psia.

Step (2): Calculate the critical pressure and temperature by the Riazi and Daubert's equations (3.2) and (3.3) to give:

$$T_c = 3.08 * 10^2[\exp((-1.3478 * 10^{-4} * M) - 0.61641 * S)] * M^{0.2998} * S^{1.0555}$$

=**1279.8^{o}** R.

$P_c = 3.1166 * 10^2[\exp((-1.8078 * 10^{-3} * M) - 0.3084 * S)] * M^{-0.8063} S^{1.6015}$

=**230.4** psia.

Step (3): Calculate the accentric factor by employing the Edmister correlation Equation (3.4) to yield:

$$\omega = [\frac{3\log(\frac{230.4}{14.7})}{7\left(\frac{1279.8}{977}-1\right)} - 1 \qquad = \mathbf{0.653}$$

Step (4) Estimate the bubble-point pressure from Equation (3.5) to give:

$$P_b = \sum_{i=1}^{n}[Z_i * P_{ci}\exp[5.73(1+w_i)(1-\frac{T_{c_i}}{T})]]$$

= **3924** psia.

Step (5): Employing the iterative procedure outlined previously and using the Whitson and Trop equilibrium ratio correlation gives:

Component	z_i	K_i @3924 psia	$z_i K_i$	K_i @3924 psia	$z_i K_i$	K_i @3924 psia	$z_i K_i$
C_1	0.42	2.257	0.9479	2.242	0.9416	2.0430	0.8581
C_2	0.05	1.241	0.06205	2.137	0.0619	1.1910	0.0596
C_3	0.05	0.79	0.0395	0.7903	0.0395	0.793	0.0397
$i\text{-}C_4$	0.03	0.5774	0.0173	0.5786	0.0174	0.5977	0.0179
$n\text{-}C_4$	0.02	0.521	0.0104	0.5221	0.0104	0.5445	0.0109
$i\text{-}C_5$	0.01	0.3884	0.0039	0.3902	0.0039	0.418	0.0042
$n\text{-}C_5$	0.01	0.3575	0.0036	0.3593	0.0036	0.3878	0.0039
C_6	0.01	0.2530	0.0025	0.2549	0.0025	0.2840	0.0028
C_{7+}	0.4	0.227	0.0091	0.0232	0.00928	0.032	0.00138
$\sum$			1.09625		1.09008		1.0099

The calculated bubble-point pressure is **4,330** psia.

Then the same data above will be applied using the MATLAB® program to validate the program code.

4.8.2 The Results of bubble point pressure:

Table (4.14): shows the results of P_b of various methods.

Method of Measurement	**Bubble point pressure**
Laboratory	**1502**
EOS	6177
Standing	1157
Glasso	13573
Marhoun	1728
Petrosky and Farshad	1428
New developed model	**1486**

4.8.3 The Results of dew point pressure:

The results of dew point pressure using equation of state and other empirical correlations are shown below:

Table (4.15): shows the results of P_d of various methods.

Method of Measurement	**Dew point pressure**
Laboratory	**2053**
EOS	**1910**
ADRIANA PATRICIA	3059
NEMETH and KENNEDY	2738

4.9 Discussions:

The results of bubble and dew points pressures that shown in tables (4.14) and 4.15) are computed using EOS as illustrated in details in appendix A (tables (A.5) and (A.6)) and some of other empirical correlations in addition to our new developed model for P_b and P_d, the reference results that will be used in the comparison is the laboratory results.

For P_b we notice that the nearest value to the laboratory result (1502) is the result of new developed model (1486) comparing with the other results.

For P_d we notice that the nearest value to the laboratory result (2053) is the result of EOS (1910) comparing with the other results.

The results of new developed model are more accurate because this model has the biggest correlation factor (R^2) and lowest errors comparing to the other models; as clarified in tables (4.4) and (4.5).

Chapter 5

Conclusions and Recommendations

CHAPTER 5

Conclusions and Recommendations

5.1 Conclusions:

Based upon the literature review and work performed in this thesis the following conclusions were drawn:

1. A reasonably accurate correlation to predict bubble point pressure (Pb) has been developed based on Sudanese oil fields data.

2. A computer program has been developed using MATLAB software to:
   - Simplify the steps of Pb calculation with the concept of EOS using try and error.
   - Coding some of the general correlations for both bubble and dew-points pressures to make the calculations easy.
   - Also; coding the new correlation that has been generated with VariReg.

3. A comparison study between Pb using new correlation, Pb with EOS and some of Pb published correlations with experimental Pb from laboratory are performed.

4. A comparison study between Pd with EOS and other of Pb published correlations with experimental Pd from laboratory are performed.

5.2 Recommendations:

This research was carefully conducted and our results represent our best efforts to generate the new model and to generate a computer program that can be distributed easily. In conclusion, the following points are recommended as possible as extensions of this research:

1. The new developed model is recommended to be used specially for Sudanese oil fields due to the high correlation factor R^2 (0.996) and lower errors RRMSE (0.066) comparing with the others published empirical correlations.

2. As already known the bubble and dew points pressures are ones of the most difficult properties to correlate accurately; the research recommends increasing the control of the oil composition to get more accurate results.

3. The tolerance of the models that developed using the neural network depends on the number of data sets; we recommend increasing the tolerance by increasing the number of data sets.

4. The research recommends using the new developed model as further quality control method in the PVT laboratories for Sudanese crude oil fields.

5. The new model for dew point pressure was difficult to be developed using the neural network concept because the tolerance of the new developed model depends mainly on the number of data sets; and here in the SUDAN there are not data enough to generate the model (few of condensate wells), we recommend to use another concept to develop new model for dew point pressure.

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Appendices

Appendix A

Data, best run and Excel sheet calculations

A.1 Data used in this thesis:

A.1.1 Training data:

Table (A.1): shows the training data.

Pb,psi	API	ɣg	T,C	Rs
153	38.52	1.0238	87.15	52.23
154	38.52	1.0238	87.15	52.23
572	39.85	0.9305	104.8	238.086
680	38.77	0.9182	100.4	200
710	38.77	0.9182	100.4	200
305	40.38	1.0085	92.8	77.31
180	40.5	1.1547	88.57	50.474
200	40.5	1.1547	88.57	50.474
1435	40.1	1.752	113.3	368.5
1022	40.77	0.834	98	345.876
1963	41.2	0.866	97.2	530.3
42	25.04	0.9039	80	0.0001
103	19.91	0.9078	65.5	11.317
2257	33.66	0.8969	83.1	390
1502	30.33	0.6181	80	216.2
1506	34.12	0.69035	71.6	201
61	47	1.1985	15.55	52.81
1450	47.16	1.35534	85.74	626.62
1528	45.9	1.333995	80.83	709.8
203	27.637	0.9657	72.5	212.055
112	39.89	1.45	30	65
78.5	40.86	0.8012	63	17
114	40.7	1.2	30	36
79	41.4	1.4	63	30.166
2440.7	40.64	1.17451	92.37	441.87
2581	41.83	1.20798	92.22	494.4
1997	34.65	1.019	85	553.84
333.5	28.7	1.33478	98	69.951
232	25.89	1.44671	88	52.93
319	27.45	1.39696	98	64.41
217.5	25.3	1.5767	88	52.028
2501	37.14	0.7804	96.1	543
111	23.55	0.9829	78	25.894

1742	26.32	0.7804	75	253
Pb,psi	**API**	**ɣg**	**T,C**	**Rs**
1670	25.377	0.902	73.3	250
1264	26.64	0.8853	69	199.79
43.5	24.68	1.5235	95.8	456.352
3362	44	0.948	106.1	1292
3276	44	0.948	106.1	1292
301	31.489	1.5117	82.2	720.51
2545	43.6	1.0491	99.9	956.519
1982	39.6	1.312	93.3	509.8
1022	40.77	0.834	98	345.876
202	23.69	1.5039	75.5	814.034
1790	26.8	1.2425	71.6	484.025
1703.7	32.81	1.4769	73.72	533.795
112	38.89	1.6007	30	171.6
78.5	40.86	1.2716	63	110.365
114	40.7	1.291	30	173.472
79	41.4	1.5259	63	124.057
2426	40.64	1.20734	92.37	494.4
594	40.2	1.52258	98.5	172.638
2581	41.83	1.20798	92.37	494.4
2375	35.042	1.4108	108	447.677
56.25	29.11	1.2425	20	484.025
551	39.37	1.3029	72.2	91.709
1190	38.19	1.45426	106	323.642
2445	38.8	1.4273	106	542.911
2445	38.8	1.4273	106	542.911
1982	39.6	1.058	93.28	509.8
1350	38.5	1.009	117.78	337.1
1985	38.5	1.009	117.78	337.1
1435	40.1	1.752	113.3	368.5
153	38.52	1.0238	87.15	52.23
154	38.52	1.0238	87.15	52.23
1022	40.77	0.834	98	345.876
1435	40.1	1.752	113	368.5
1963	41.2	1.2359	97.39	530.2
383	19.3	1.1634	87.94	48

A.1.2 Testing data:

Table (A.2): shows the testing data.

Pb,psi	API	ɣg	T,C	Rs
153	38.52	1.0238	87.15	52.23
572	39.85	0.9305	104.8	238.086
710	38.77	0.9182	100.4	200
1435	40.1	1.752	113.3	368.5
1022	40.77	0.834	98	345.876
1963	41.2	0.866	97.2	530.3
42	25.04	0.9039	80	0.0001
2257	33.66	0.8969	83.1	390
61	47	1.1985	15.55	52.81
79	41.4	1.4	63	30.166
2440.7	40.64	1.17451	92.37	441.87
112	39.89	1.45	30	65
43.5	24.68	1.5235	95.8	456.352
305	40.38	1.0085	92.8	77.31
180	40.5	1.1547	88.57	50.474
1502	30.33	0.6181	80	216.2
78.5	40.86	0.8012	63	17
114	40.7	1.2	30	36
1790	26.8	1.2425	71.6	484.025
2426	40.64	1.20734	92.37	494.4
594	40.2	1.52258	98.5	172.638
3362	44	0.948	106.1	1292
383	19.3	1.1634	87.94	48
56.25	29.11	1.2425	20	484.025
1997	34.65	1.019	85	553.84
232	25.89	1.44671	88	52.93
2581	41.83	1.20798	92.37	494.4
56.25	29.11	1.2425	20	484.025
200	40.5	1.1547	88.57	50.474
1190	38.19	1.45426	106	323.642

A.2 The best chosen run:

Starting GMDH

Building layer #1...

Number of neurons in this layer = 4

Total number of neurons tried = 4

TrainMSE of the best neuron = 251568.96

Crit value (MSE) of the best neuron = 10903230

Building layer #2...

Number of neurons in this layer = 4

Total number of neurons tried = 52

TrainMSE of the best neuron = 27526.134

Crit value (MSE) of the best neuron = 387941.48

Building layer #3...

Number of neurons in this layer = 4

Total number of neurons tried = 52

TrainMSE of the best neuron = 12559.918

Crit value (MSE) of the best neuron = 123225.02

Building layer #4...

Number of neurons in this layer = 4

Total number of neurons tried = 52

TrainMSE of the best neuron = 5267.0937

Crit value (MSE) of the best neuron = 132713.61

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Finished

Total number of generated layers = 4 (the last is to be discarded)

Number of layers = 3

Used input variables = x0,x1,x2,x3 (starting from x0)

The number of used input variables = 4

Crit value = 351.03421

TestMSE = 4102.056

TestRRMSE = 0.06590647

TestR2 = 0.99565634

Time (s) = 0.421

Equations:

Layer #3

F(x) = -17534.9199353771 + 1560.05798350565*x0 - 90.8163067968353*x0*x0 + 1.69928697445363*x0*x0*x0 - 0.0156884284945835*x0*x0*x0*x0 + 48559.0559807412*x1 + 572.603163081714*x0*x1 + 14.2477108864217*x0*x0*x1 + 0.43414748759666*x0*x0*x0*x1 - 103480.36841273*x1*x1 - 517.429211702364*x0*x1*x1 - 29.348432333564*x0*x0*x1*x1 + 77276.2725991927*x1*x1*x1 + 666.859507200834*x0*x1*x1*x1 - 23082.9272947231*x1*x1*x1*x1 + 22.1979639573022*x11 - 1.59367982689289*x0*x11 + 0.0428295072246174*x0*x0*x11 - 0.000553206824980185*x0*x0*x0*x11 + 9.36630568981286*x1*x11 - 0.305513727994436*x0*x1*x11 + 0.0202881228829946*x0*x0*x1*x11 - 11.0198381631774*x1*x1*x11 - 0.41773781271829*x0*x1*x1*x11 + 8.06208923762134*x1*x1*x1*x11 - 0.0108190652237353*x11*x11 + 0.000322664441728718*x0*x11*x11 - 3.43039360111355E-6*x0*x0*x11*x11 + 0.00761636072127989*x1*x11*x11 - 0.000111277278176648*x0*x1*x11*x11 - 0.000509385124517567*x1*x1*x11*x11 + 6.46778675552719E-7*x11*x11*x11 + 9.00934645067932E-9*x0*x11*x11*x11 - 6.32362816318111E-7*x1*x11*x11*x11 - 4.89373817232466E-11*x11*x11*x11*x11

Layer #2

x11 = 18551.290732823 - 2591.45762765547*x0 + 129.092810712215*x0*x0 - 2.72809015657204*x0*x0*x0 + 0.0207987972572486*x0*x0*x0*x0 + 26.7864075513505*x4 - 2.35400738712354*x0*x4 + 0.0678491050271633*x0*x0*x4 - 0.000647262972365956*x0*x0*x0*x4 - 0.0169880646666794*x4*x4 + 0.00124844961462689*x0*x4*x4 - 2.01202192671441E-5*x0*x0*x4*x4 - 6.44630094263908E-6*x4*x4*x4 + 1.38611622508188E-7*x0*x4*x4*x4 + 5.35011006115544E-10*x4*x4*x4*x4 + 1.62412873480223*x7 - 0.205507198223639*x0*x7 + 0.00700059313620309*x0*x0*x7 - 7.47682350170073E-5*x0*x0*x0*x7 + 0.0419188058968634*x4*x7 - 0.00287311848994221*x0*x4*x7 +

4.63169673467121E-5*x0*x0*x4*x7 + 1.3485892221433E-5*x4*x4*x7 - 3.34989494086437E-7*x0*x4*x4*x7 - 9.91792719584248E-10*x4*x4*x4*x7 - 0.017549533029551*x7*x7 + 0.00123876731341113*x0*x7*x7 - 1.95316229061459E-5*x0*x0*x7*x7 - 7.67596558175033E-6*x4*x7*x7 + 1.66096048050233E-7*x0*x4*x7*x7 + 9.48535879723386E-10*x4*x4*x7*x7 + 1.32095236050938E-6*x7*x7*x7 - 2.55463828235471E-8*x0*x7*x7*x7 - 4.35368772624498E-12*x4*x7*x7*x7 - 1.97717179117303E-10*x7*x7*x7*x7

Layer #1

x4 = 492704.230478212 + 3772.70604519114*x0 - 22.0080800298289*x0*x0 - 6.54490724712956*x0*x0*x0 + 0.156133097972999*x0*x0*x0*x0 - 35487.5099590645*x1 - 49087.9664940001*x0*x1 + 1264.75740416562*x0*x0*x1 - 15.9424246455428*x0*x0*x0*x1 - 233841.209052916*x1*x1 + 22779.4851918582*x0*x1*x1 - 57.3941792018102*x0*x0*x1*x1 + 85199.2365168354*x1*x1*x1 - 4861.97582571882*x0*x1*x1*x1 - 7764.00540757765*x1*x1*x1*x1 - 25019.938433671*x2 + 604.88583822333*x0*x2 - 11.4527778356849*x0*x0*x2 + 0.0705261945003667*x0*x0*x0*x2 + 25724.9530168686*x1*x2 - 447.339052827235*x0*x1*x2 + 5.70779219055326*x0*x0*x1*x2 - 6105.91073312218*x1*x1*x2 - 14.1944727542897*x0*x1*x1*x2 + 1083.60931313841*x1*x1*x1*x2 + 157.429622557961*x2*x2 + 0.573802158744889*x0*x2*x2 - 0.016047074373626*x0*x0*x2*x2 - 130.584652718903*x1*x2*x2 + 0.477316918875978*x0*x1*x2*x2 + 14.1483340307823*x1*x1*x2*x2 - 0.773210076004282*x2*x2*x2 + 0.000628697535424597*x0*x2*x2*x2 + 0.332330314073033*x1*x2*x2*x2 + 0.00107483826081914*x2*x2*x2*x2

x7 = 104368.114647277 - 252959.095689539*x1 + 207812.119743382*x1*x1 - 51305.9566967706*x1*x1*x1 - 3669.65088412271*x1*x1*x1*x1 - 1974.12938215109*x2 + 4196.07523852387*x1*x2 - 3462.53748210706*x1*x1*x2 + 991.459274495242*x1*x1*x1*x2 + 9.03530806054725*x2*x2 - 3.15257020610311*x1*x2*x2 - 0.0947632262097901*x1*x1*x2*x2 - 0.0766145571620027*x2*x2*x2 + 0.0167073099402243*x1*x2*x2*x2 + 0.000228658314287472*x2*x2*x2*x2 + 30.4891501066485*x3 - 392.144956736398*x1*x3 + 375.959119752298*x1*x1*x3 - 86.9745701180325*x1*x1*x1*x3 + 3.51435169509722*x2*x3 - 0.7110209582719*x1*x2*x3 - 0.997573180060285*x1*x1*x2*x3 - 0.0310977237534942*x2*x2*x3 + 0.0184922591184227*x1*x2*x2*x3 + 2.12316045157012E-5*x2*x2*x2*x3 + 0.131654067261385*x3*x3 - 0.0310981630817903*x1*x3*x3 + 0.018856686074927*x1*x1*x3*x3 - 0.0012369986819281*x2*x3*x3 - 0.000515049241126642*x1*x2*x3*x3 + 6.06772924644421E-6*x2*x2*x3*x3 - 0.000161820089664189*x3*x3*x3 + 4.39592853121396E-5*x1*x3*x3*x3 + 1.14107904934427E-6*x2*x3*x3*x3 - 2.85339721674573E-9*x3*x3*x3*x3

A.3 The predicted training results:

Table (A.3): shows the Prediction train results.

API	SG	T	Rs	pb	Predicted
47.16	1.35534	85.74	626.62	1450	1334.76549991069324
41.83	1.20798	92.22	494.4	2581	2493.45547515684731
38.89	1.6007	30	171.6	112	136.082257515941303
38.77	0.9182	100.4	200	710	640.262979265180157
41.2	0.866	97.2	530.3	1963	2023.45086108872747
23.55	0.9829	78	25.894	111	129.606068255725325
41.2	1.2359	97.39	530.2	1963	2127.00101456977417
25.377	0.902	73.3	250	1670	1707.99416943744985
25.04	0.9039	80	0.0001	42	2.05088591756153877
34.65	1.019	85	553.84	1997	2045.01116203424949
40.7	1.291	30	173.472	114	116.002792534840947
40.38	1.0085	92.8	77.31	305	292.712621919593871
41.4	1.4	63	30.166	79	108.798222769360786
38.5	1.009	117.78	337.1	1350	1662.35041749410991
29.11	1.2425	20	484.025	56.25	59.7978247612107197
44	0.948	106.1	1292	3362	3318.12162447216658
38.8	1.4273	106	542.911	2445	2501.19768266693278
40.1	1.752	113.3	368.5	1435	1455.98363519272279
40.5	1.1547	88.57	50.474	200	192.102123008562001
39.6	1.312	93.3	509.8	1982	2157.27260087411562
41.4	1.5259	63	124.057	79	54.7407312737893062
38.19	1.45426	106	323.642	1190	1317.77658536729895
19.91	0.9078	65.5	11.317	103	12.9511517260088807
35.042	1.4108	108	447.677	2375	2203.20122116107748
19.3	1.1634	87.94	48	383	294.866309496918399
39.89	1.45	30	65	112	68.3187947689586514
38.5	1.009	117.78	337.1	1985	1662.35041749410991
26.64	0.8853	69	199.79	1264	1015.34717998531838
37.14	0.7804	96.1	543	2501	2443.13483886612635
40.5	1.1547	88.57	50.474	180	192.102123008562001
40.77	0.834	98	345.876	1022	999.926640408080289
39.37	1.3029	72.2	91.709	551	532.359940502119083
27.45	1.39696	98	64.41	319	286.062984997221019
26.8	1.2425	71.6	484.025	1790	1829.36349714032146
38.52	1.0238	87.15	52.23	154	181.32509607641946
28.7	1.33478	98	69.951	333.5	265.984922399708911
33.66	0.8969	83.1	390	2257	2161.5018831072138
40.7	1.2	30	36	114	154.136219490620314
41.83	1.20798	92.37	494.4	2581	2479.24200067103782
40.86	1.2716	63	110.365	78.5	11.8129932892157224
31.489	1.5117	82.2	720.51	301	308.303155845604743
40.77	0.834	98	345.876	1022	999.926640408080289
40.64	1.17451	92.37	441.87	2440.7	2053.83717479126955
40.1	1.752	113.3	368.5	1435	1455.98363519272279

API	SG	T	Rs	pb	Predicted
45.9	1.333995	80.83	709.8	1528	1725.38267827781847
25.89	1.44671	88	52.93	232	341.054395399576075
43.6	1.0491	99.9	956.519	2545	2579.84148694751845
34.12	0.69035	71.6	201	1506	1500.91699000178262
40.1	1.752	113	368.5	1435	1386.96405099766572
38.52	1.0238	87.15	52.23	154	181.32509607641946
47	1.1985	15.55	52.81	61	50.6735801392542702
38.8	1.4273	106	542.911	2445	2501.19768266693278
40.64	1.20734	92.37	494.4	2426	2261.52226137576584
40.77	0.834	98	345.876	1022	999.926640408080289
23.69	1.5039	75.5	814.034	202	238.881311300309258
38.52	1.0238	87.15	52.23	153	181.32509607641946
25.3	1.5767	88	52.028	217.5	156.089446811490966
27.637	0.9657	72.5	212.055	203	511.897903490356598
40.86	0.8012	63	17	78.5	123.187115749940618
44	0.948	106.1	1292	3276	3318.12162447216658
39.85	0.9305	104.8	238.086	572	689.352061715481476
32.81	1.4769	73.72	533.795	1703.7	1647.39342202286606
30.33	0.6181	80	216.2	1502	1535.66153421156354
38.77	0.9182	100.4	200	680	640.262979265180157
40.2	1.52258	98.5	172.638	594	498.68917049482666
39.6	1.058	93.28	509.8	1982	2306.38216249256794
38.52	1.0238	87.15	52.23	153	181.32509607641946
24.68	1.5235	95.8	456.352	43.5	132.116841208274784
26.32	0.7804	75	253	1742	1776.08331600775121

A.4 The predicted testing results:

Table (A.4): shows the Prediction test results.

API	SG	T	Rs	pb	Predicted
38.52	1.0238	87.15	52.23	153	181.32509607641946
39.85	0.9305	104.8	238.086	572	689.352061715481476
38.77	0.9182	100.4	200	710	640.262979265180157
40.1	1.752	113.3	368.5	1435	1455.98363519272279
40.77	0.834	98	345.876	1022	999.926640408080289
41.2	0.866	97.2	530.3	1963	2023.45086108872747
25.04	0.9039	80	0.0001	42	2.05088591756153877
33.66	0.8969	83.1	390	2257	2161.5018831072138
47	1.1985	15.55	52.81	61	50.6735801392542702
41.4	1.4	63	30.166	79	108.798222769360786
40.64	1.17451	92.37	441.87	2440.7	2053.83717479126955
39.89	1.45	30	65	112	68.3187947689586514
24.68	1.5235	95.8	456.352	43.5	132.116841208274784
40.38	1.0085	92.8	77.31	305	292.712621919593871
40.5	1.1547	88.57	50.474	180	192.102123008562001
30.33	0.6181	80	216.2	1502	1535.66153421156354
40.86	0.8012	63	17	78.5	123.187115749940618
40.7	1.2	30	36	114	154.136219490620314
26.8	1.2425	71.6	484.025	1790	1829.36349714032146
40.64	1.20734	92.37	494.4	2426	2261.52226137576584
40.2	1.52258	98.5	172.638	594	498.68917049482666
44	0.948	106.1	1292	3362	3318.12162447216658
19.3	1.1634	87.94	48	383	294.866309496918399
29.11	1.2425	20	484.025	56.25	59.7978247612107197
34.65	1.019	85	553.84	1997	2045.01116203424949
25.89	1.44671	88	52.93	232	341.054395399576075
41.83	1.20798	92.37	494.4	2581	2479.24200067103782
29.11	1.2425	20	484.025	56.25	59.7978247612107197
40.5	1.1547	88.57	50.474	200	192.102123008562001
38.19	1.45426	106	323.642	1190	1317.77658536729895

A.5 The Excel-sheet calculations of bubble and dew points pressures of Azrag C1:

Table (A.5): shows the Excel sheet calculations of bubble point pressure of Azrag C1.

Comp	**zi**	**Pc**	**Tc**	**wc**	**pbi**	**A1**	**k_i**	**zk**	**ki2**	**A2**	**zk2**
N|2	0.0248	493.1	227.49	0.0403	443.115	-0.24	0.571	0.0142	0.9934	-0.0027	0.0247
Co2	0.0202	1071	547.91	0.2276	53.8071		0.899	0.0181	0.9984		0.0201
C_1	0.9019	666.4	343.33	0.0108	7305.76		0.69	0.6218	0.9955		0.8978
C_2	0.0461	706.5	549.92	0.099	72.4378		1.020	0.0471	0.9998		0.0461
C_3	0.0021	616	666.06	0.1517	0.98319		1.369	0.0029	1.0031		0.0021
i-C_4	0.0026	527.9	734.46	0.177	0.50916		1.673	0.0043	1.0054		0.0026
n-C_4	0.0004	550.6	765.62	0.1931	0.06087		1.791	0.0007	1.0061		0.0004
i-C_5	0.0006	490.4	829.1	0.2275	0.04149		2.174	0.0014	1.0083		0.0006
n-C_5	0.0001	488.6	845.8	0.2486	0.00546		2.288	0.0002	1.0089		0.0001
C_6	0.0001	710.4	1012.2	0.2108	0.00171		3.093	0.0003	1.0123		0.0001
M-c-c5	0.0002	548.9	959.35	0.2302	0.00462		2.928	0.0007	1.0117		0.0002
Benzene	2E-05	710.4	1012.2	0.2108	0.00026		3.093	5E-05	1.0123		2E-05
C_{7+}	0.0058	1235.6	297.09	0.4687	480.377		0.396	0.0023	0.9893		0.0058
					8357.1			**0.7141**			**1.0007**

Table (A.6): shows the Excel sheet calculations of Dew-point pressure of Azrag R1.

Component	zi	Pc	Tc	wc	Pdi	A1	ki	z/k	ki2	A2	z/k2
N|2	0.007	493.1	227.5	0.0403	0.00063	0.925	321.96	2.2E-05	0.997	-9E-04	0.007023
Co2	0.00459	1071	547.9	0.2276	1.9E-05		56.651	8.1E-05	0.998		0.004597
C_1	0.80226	666.4	343.3	0.0108	0.01986		155.93	0.00514	0.997		0.804304
C_2	0.08319	706.5	549.9	0.099	0.00045		34.586	0.00241	0.999		0.083283
C_3	0.058	616	666.1	0.1517	0.00014		11.188	0.00518	1		0.058002
i-C_4	0.007	527.9	734.5	0.177	1.1E-05		5.1643	0.00136	1.001		0.006995
n-C_4	0.0191	550.6	765.6	0.1931	2.1E-05		3.9756	0.0048	1.001		0.019082
i-C_5	0.00427	490.4	829.1	0.2275	2.9E-06		1.8859	0.00226	1.002		0.004263
n-C_5	0.00648	488.6	845.8	0.2486	3.7E-06		1.5497	0.00418	1.002		0.006468
C_6	0.00493	710.4	1012	0.2108	4.4E-07		0.4868	0.01013	1.003		0.004916
M-c-c5	0.00049	548.9	959.4	0.2302	8.8E-08		0.6008	0.00082	1.003		0.000489
Benzene	0.00025	710.4	1012	0.2108	2.2E-08		0.4868	0.00051	1.003		0.000249
cyclo-hexane	0.00069	591	1457	0.2149	1.2E-09		0.0061	0.11258	1.007		0.000685
C_{7+}	0.00176	424.56	1014.3	0.3031	2.1E-07		0.2267	0.00776	1.004		0.001754
∑					**0.02114**			**0.15725**			**1.002109**
1/∑					**47.3145**						

Appendix B

Program Codes

B.1 Dew-point pressure Calculations Codes:

```
function pushbutton3_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a=str2num(get(handles.dew1,'string'));
b=str2num(get(handles.dew2,'string'));
c=str2num(get(handles.dew3,'string'));
y=(-0.01691*(log(c))^2 - 0.87528*(log(c))+ 9.8895);
z=0.00151*(a)^2-0.29709*(a)+11.7;
k=-0.81744*(b)^2-2.91450*b+ 3.5202;
x=y+z+k;
Pd=2.71828^(0.00477*x^2 + 0.32239*x + 8.48 );
set(handles.dew4,'string',Pd);

% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton4 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
xc1=str2num(get(handles.nem1,'string'));
xc2=str2num(get(handles.nem2,'string'));
xc3=str2num(get(handles.nem3,'string'));
xc4=str2num(get(handles.nem4,'string'));
xc5=str2num(get(handles.nem5,'string'));
xc6=str2num(get(handles.nem6,'string'));
xc7=str2num(get(handles.nem7,'string'));
SGc7=str2num(get(handles.nem8,'string'));
Mc7=str2num(get(handles.nem9,'string'));
xN2=str2num(get(handles.nem10,'string'));
xco2=str2num(get(handles.nem11,'string'));
xH2s=str2num(get(handles.nem12,'string'));
T=str2num(get(handles.nem13,'string'));
xx=-2.0623054*(xc2+xco2+xH2s+xc6+2*xc3+2*xc4);
yy=(xc5+0.4*xc1+xN2)+6.6259728*SGc7-4.4670559E-3*(xc1/(xc7+0.002));
zz=1.0448346E-4*(T+460)+3.2673714E-2*(xc7*Mc7)-3.6453277E-3*(xc7*Mc7)^2+7.42951E-
5*(xc7*Mc7)^3;
ll=-0.11381195*(Mc7/(SGc7+0.0001))+6.2476497E-4*(Mc7/(SGc7+0.0001))^2
```

```
mm=-1.0716866E-6*(Mc7/(SGc7+0.0001))^3+10.746622;
Pd=exp(xx+yy+zz+ll+mm);
set(handles.nemeth,'string',Pd);
```

B.2 Bubble point pressure Calculations Codes using EOS:

```
function pushbutton3_Callback(hObject, eventdata, handles)
% handles    structure with handles and user data (see GUIDATA)
pbtable=str2double(get(handles.pbtable,'data'));
z1=pbtable(:,1);
tc1=pbtable(:,2);
pc1=pbtable(:,3);
wc1=pbtable(:,4);
for j=1:length(pc1)
   if isnan(pc1(j))==1
       pc1(j)=0;
       tc1(j)=0;
       wc1(j)=0;
       z1(j)=0;
   end
end
z1=z1(z1>0);
tc1=tc1(tc1>0);
pc1=pc1(pc1>0);
wc1=wc1(wc1>0);
Mc7=str2double(get(handles.edit22,'string'));
Sc7=str2num(get(handles.edit12,'string'));
Tbc7=str2num(get(handles.edit13,'string'));
zc7=str2num(get(handles.edit14,'string'));
T=str2num(get(handles.edit15,'string'));
pcc7=(3.12281)*(10)^9*(Tbc7)^(-2.3125)*(Sc7)^(2.3201);
Tcc7=(24.27870)*(Tbc7)^(0.58848)*(Sc7^0.3596);
pc=[pc1',pcc7];
tc=[tc1',Tcc7];
z=[z1',zc7];
pk=60*Mc7-4200;
wc7=((3*(log10(pcc7/14.7)))/(7*(Tcc7/Tbc7-1)))-1;
wc=[wc1',wc7];
pbi=z.*pc.*exp((5.37+5.37*wc).*(1-(tc/T)));
spb=sum(pbi);
j=1;
kz=6;
pb(1)=spb;
while ((kz-1)>-0.002&&(kz-1)<0.002)~=1
```

```
    A=1-(pb(j)/pk)^(0.7)
    k=(pc/pk).^(A-1).*(pc/pb(j)).* exp(5.37*A.*(1+wc).*(1-(tc/T)));
    kz=sum(k.*z);
    kzi(j)=kz;
    if kz>1
        pb(j+1)=pb(j)+50;
    elseif kz<1
        pb(j+1)=pb(j)-50;
    end
    j=j+1;
end
pbcorrected=pb(j-1);
set(handles.pbcorrected,'string',pbcorrected);
```

B.3 Bubble point pressure Calculations Codes using new developed model and others known empirical Correlations:

```
function pushbutton3_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton3 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a=str2num(get(handles.edit7,'string'));
b=str2num(get(handles.edit8,'string'));
c=str2num(get(handles.edit9,'string'));
d=str2num(get(handles.edit10,'string'));
A=0.00091*(c)-(0.0125*a);
P=18.2*((d/b)^(0.83)*(10)^(A)-1.4);
set(handles.standing,'string',P);
% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton4 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a=str2num(get(handles.edit7,'string'));
b=str2num(get(handles.edit8,'string'));
c=str2num(get(handles.edit9,'string'));
d=str2num(get(handles.edit10,'string'));
A=0.816;
B=0.172;
C=-0.989;
Pbs = (d/b)^(A)*(c)^(B)*(a)^(C);
P=10^(1.7669+1.7447*log(Pbs)-0.30218*(log(Pbs))^2);
set(handles.glasso,'string',P);
% --- Executes on button press in pushbutton5.
```

```
function pushbutton5_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton5 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a=str2num(get(handles.edit7,'string'));
b=str2num(get(handles.edit8,'string'));
c=str2num(get(handles.edit9,'string'));
d=str2num(get(handles.edit10,'string'));
P=5.338088*10^(-3)*(d)^(0.715082)*(b)^(-
1.87784)*((141.5)/(a+131.5))^(3.1437)*(c+460)^(1.32657);
set(handles.marhoun,'string',P);
% --- Executes on button press in pushbutton6.
function pushbutton6_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a=str2num(get(handles.edit7,'string'));
b=str2num(get(handles.edit8,'string'));
c=str2num(get(handles.edit9,'string'));
d=str2num(get(handles.edit10,'string'));
x=7.916*(10)^(-4)*(a)^(1.5410)-4.561*(10)^(-5)*(c)^(1.3911);
P=(112.727*(d)^(0.577421))/((b)^(0.8439)*(10)^(x))-1391.051;
set(handles.petrosky,'string',P);

% --- Executes on button press in pushbutton7.
function pushbutton7_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a=str2num(get(handles.edit7,'string'));
b=str2num(get(handles.edit8,'string'));
c=str2num(get(handles.edit9,'string'));
d=str2num(get(handles.edit10,'string'));
x0=a;
x1=b;
x2=c;
x3=d;
x4 = 492704.230478212 + 3772.70604519114*x0 - 22.0080800298289*x0*x0 -
6.54490724712956*x0*x0*x0 + 0.156133097972999*x0*x0*x0*x0 -
35487.5099590645*x1 - 49087.9664940001*x0*x1 + 1264.75740416562*x0*x0*x1 -
15.9424246455428*x0*x0*x0*x1 - 233841.209052916*x1*x1 +
22779.4851918582*x0*x1*x1 - 57.3941792018102*x0*x0*x1*x1 +
85199.2365168354*x1*x1*x1 - 4861.97582571882*x0*x1*x1*x1 -
7764.00540757765*x1*x1*x1*x1 - 25019.938433671*x2 + 604.88583822333*x0*x2 -
11.4527778356849*x0*x0*x2 + 0.0705261945003667*x0*x0*x0*x2 +
```

25724.9530168686*x1*x2 - 447.339052827235*x0*x1*x2 + 5.70779219055326*x0*x0*x1*x2 - 6105.91073312218*x1*x1*x2 - 14.1944727542897*x0*x1*x1*x2 + 1083.60931313841*x1*x1*x1*x2 + 157.429622557961*x2*x2 + 0.573802158744889*x0*x2*x2 - 0.016047074373626*x0*x0*x2*x2 - 130.584652718903*x1*x2*x2 + 0.477316918875978*x0*x1*x2*x2 + 14.1483340307823*x1*x1*x2*x2 - 0.773210076004282*x2*x2*x2 + 0.000628697535424597*x0*x2*x2*x2 + 0.332330314073033*x1*x2*x2*x2 + 0.00107483826081914*x2*x2*x2*x2;

x7 = 104368.114647277 - 252959.095689539*x1 + 207812.119743382*x1*x1 - 51305.9566967706*x1*x1*x1 - 3669.65088412271*x1*x1*x1*x1 - 1974.12938215109*x2 + 4196.07523852387*x1*x2 - 3462.53748210706*x1*x1*x2 + 991.459274495242*x1*x1*x1*x2 + 9.03530806054725*x2*x2 - 3.15257020610311*x1*x2*x2 - 0.0947632262097901*x1*x1*x2*x2 - 0.0766145571620027*x2*x2*x2 + 0.0167073099402243*x1*x2*x2*x2 + 0.000228658314287472*x2*x2*x2*x2 + 30.4891501066485*x3 - 392.144956736398*x1*x3 + 375.959119752298*x1*x1*x3 - 86.9745701180325*x1*x1*x1*x3 + 3.51435169509722*x2*x3 - 0.7110209582719*x1*x2*x3 - 0.997573180060285*x1*x1*x2*x3 - 0.0310977237534942*x2*x2*x3 + 0.0184922591184227*x1*x2*x2*x3 + 2.12316045157012E-5*x2*x2*x2*x3 + 0.131654067261385*x3*x3 - 0.0310981630817903*x1*x3*x3 + 0.018856686074927*x1*x1*x3*x3 - 0.0012369986819281*x2*x3*x3 - 0.000515049241126642*x1*x2*x3*x3 + 6.06772924644421E-6*x2*x2*x3*x3 - 0.000161820089664189*x3*x3*x3 + 4.39592853121396E-5*x1*x3*x3*x3 + 1.14107904934427E-6*x2*x3*x3*x3 - 2.85339721674573E-9*x3*x3*x3*x3;

x11 = 18551.290732823 - 2591.45762765547*x0 + 129.092810712215*x0*x0 - 2.72809015657204*x0*x0*x0 + 0.0207987972572486*x0*x0*x0*x0 + 26.7864075513505*x4 - 2.35400738712354*x0*x4 + 0.0678491050271633*x0*x0*x4 - 0.000647262972365956*x0*x0*x0*x4 - 0.0169880646666794*x4*x4 + 0.00124844961462689*x0*x4*x4 - 2.01202192671441E-5*x0*x0*x4*x4 - 6.44630094263908E-6*x4*x4*x4 + 1.38611622508188E-7*x0*x4*x4*x4 + 5.35011006115544E-10*x4*x4*x4*x4 + 1.62412873480223*x7 - 0.205507198223639*x0*x7 + 0.00700059313620309*x0*x0*x7 - 7.47682350170073E-5*x0*x0*x0*x7 + 0.0419188058968634*x4*x7 - 0.00287311848994221*x0*x4*x7 + 4.63169673467121E-5*x0*x0*x4*x7 + 1.3485892221433E-5*x4*x4*x7 - 3.34989494086437E-7*x0*x4*x4*x7 - 9.91792719584248E-10*x4*x4*x4*x7 - 0.017549533029551*x7*x7 + 0.00123876731341113*x0*x7*x7 - 1.95316229061459E-5*x0*x0*x7*x7 - 7.67596558175033E-6*x4*x7*x7 + 1.66096048050233E-7*x0*x4*x7*x7 + 9.48535879723386E-10*x4*x4*x7*x7 + 1.32095236050938E-6*x7*x7*x7 - 2.55463828235471E-8*x0*x7*x7*x7 - 4.35368772624498E-12*x4*x7*x7*x7 - 1.97717179117303E-10*x7*x7*x7*x7;

P = -17534.9199353771 + 1560.05798350565*x0 - 90.8163067968353*x0*x0 + 1.69928697445363*x0*x0*x0 - 0.0156884284945835*x0*x0*x0*x0 + 48559.0559807412*x1 + 572.603163081714*x0*x1 + 14.2477108864217*x0*x0*x1 + 0.43414748759666*x0*x0*x0*x1 - 103480.36841273*x1*x1 - 517.429211702364*x0*x1*x1 - 29.348432333564*x0*x0*x1*x1 +

```
77276.2725991927*x1*x1*x1 + 666.859507200834*x0*x1*x1*x1 -
23082.9272947231*x1*x1*x1*x1 + 22.1979639573022*x11 -
1.59367982689289*x0*x11 + 0.0428295072246174*x0*x0*x11 -
0.000553206824980185*x0*x0*x0*x11 + 9.36630568981286*x1*x11 -
0.305513727994436*x0*x1*x11 + 0.0202881228829946*x0*x0*x1*x11 -
11.0198381631774*x1*x1*x11 - 0.41773781271829*x0*x1*x1*x11 +
8.06208923762134*x1*x1*x1*x11 - 0.0108190652237353*x11*x11 +
0.000322664441728718*x0*x11*x11 - 3.43039360111355E-6*x0*x0*x11*x11 +
0.00761636072127989*x1*x11*x11 - 0.000111277278176648*x0*x1*x11*x11 -
0.000509385124517567*x1*x1*x11*x11 + 6.46778675552719E-7*x11*x11*x11 +
9.00934645067932E-9*x0*x11*x11*x11 - 6.32362816318111E-7*x1*x11*x11*x11 -
4.89373817232466E-11*x11*x11*x11*x11
set(handles.jawhar,'string',P);
% --- Executes on button press in pushbutton8.
function pushbutton8_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton8 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a=str2num(get(handles.edit7,'string'));
b=str2num(get(handles.edit8,'string'));
c=str2num(get(handles.edit9,'string'));
d=str2num(get(handles.edit10,'string'));
if(a<=30)
C1=0.0362;
C2=1.0937;
C3=25.724;
P=(C1*b*2.71828^(C3*((141.5/(a+131.5)))/(c+459.67))/(d))^(C2);
else
C1=0.0178;
C2=1.187;
C3=23.931;
P=(C1*b*2.71828^(C3*((141.5/(a+131.5)))/(c+459.67))/(d))^(C2);
end
set(handles.vasquez,'string',P);
```