Chapter 4

Results and Discussions

4.1. Introduction

From PVT reports for Sudan crude oil , 212 datasets were used in this research for analyzing bubble point pressure, and to know what is the best empirical among most popular empirical correlations by using the statistical analysis, then developed new correlation using 151 datasets (70% As train data) by using polynomial neural network PNN, and testing the model with 61 datasets (30% As test data) , and finally the comparison was done between the best common empirical correlations and the new PNN model.

Guide user interface (GUI) by MATLAB was created for bubble point pressure evaluation and converted to windows standalone application.

4.2. Data Collection

From PVT reports, the parameters that the bubble point pressure was depended on, (temperature, gas solubility, API gravity and gas specific gravity) were collected and filtered, and lastly a 212 datasets were selected as good data for bubble point pressure evaluation, those datasets shown in appendix (B), and the statistical description of it shown in table 4-1.

Table 4-1: statistical description of the datasets

Parameters	Units	Minimum	Average	Maximum
Measured P_b	psi	31	724.431	4155
Temperature, T	°F	107.6	178.4	244.0
Gas solubility R_s	SCF/STB	1.2	135.2	877.7
API gravity	°API	15.9	31.4	65
Gas specific gravity	dimensionless	0.5400	0.9	1.5300

4.3. Common Empirical Correlations

The common empirical correlations than mentioned in chapter three were applied to all data, the distributed of the calculated data vs the measured data is shown in 45 degree, then the best correlation for Sudan crude oil is identified by the statistical analysis that are expressed in chapter three.

4.3.1. Standing's Correlation

All the datasets were analyzed using this method Equation (3-1), this correlation gave a good result for Sudan crude oil, and the 45 degree shown a normal distributed for predicted values of bubble point pressure as shown in Figure (4-1) with correlation coefficient R^2 of 0.821133. the statistical analysis results shown in Table 4-2.

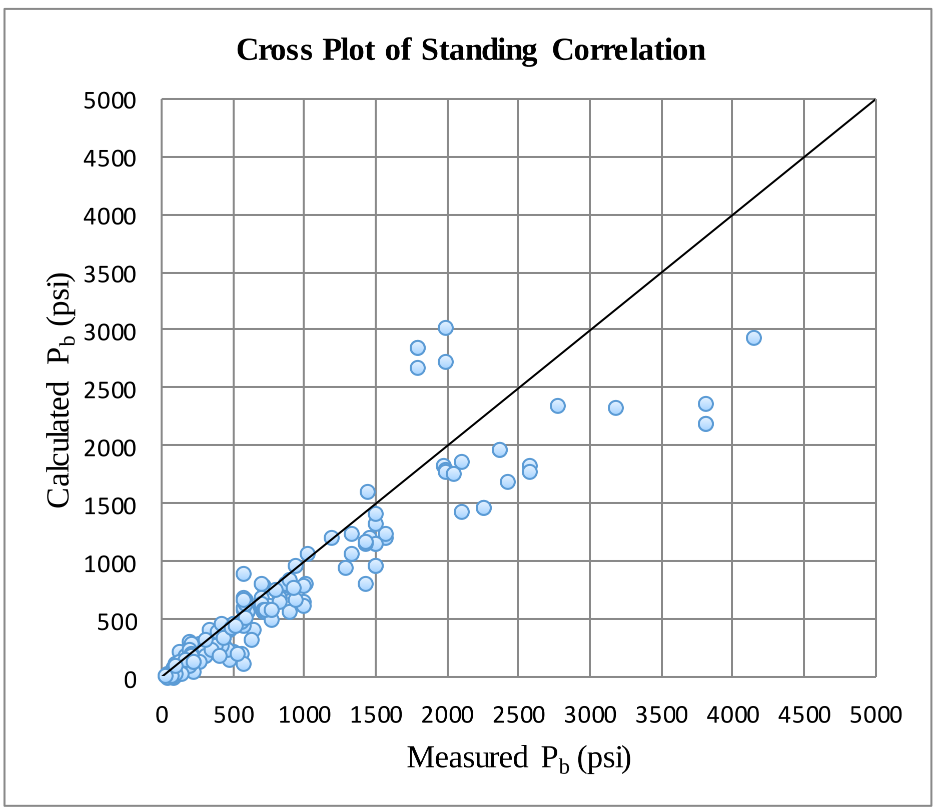


Figure 4-1: Measured P_b vs. Calculated P_b for Standing correlation

Table 4-2: Statistical Analysis Results for Standing's Correlation

RMSE	RRMSE	R^2
327.5768	0.422927	0.821133

4.3.2. Glaso's Correlation

After analyzing the all datasets using Equation (3-2), the 45 degree fitting method was plotted; (see Figure 4-2) and the statistical results were tabulated in Table (4-3). This correlation comes directly after Standing's correlation in accuracy with correlation coefficient R^2 of 0.809757.

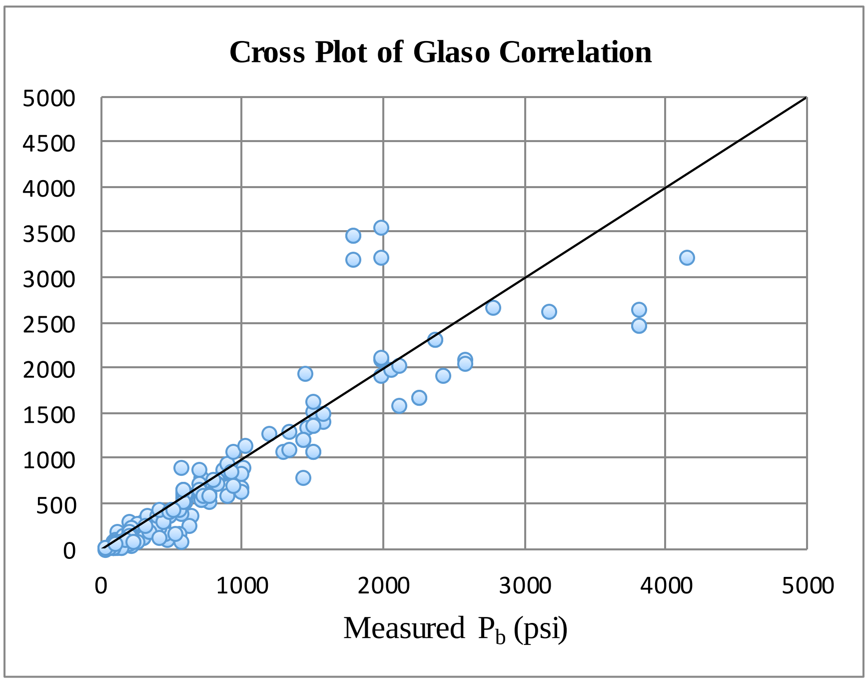


Figure 4-2: Measured P_b vs. Calculated P_b for Glaso correlation

Table 4-3: Statistical Analysis Results for Glaso Correlation

RMSE	RRMSE	R^2
337.8329	0.436168	0.809757

4.3.2. Al-Marhoun's Correlation

After analyzing the all datasets using Equation (3-3), the results had shown lower performance as per compared to above models .The 45 degree method shown in Figure (4-3) with correlation coefficient R^2 of 0.809757.The statistical result shown in Table (4-4).

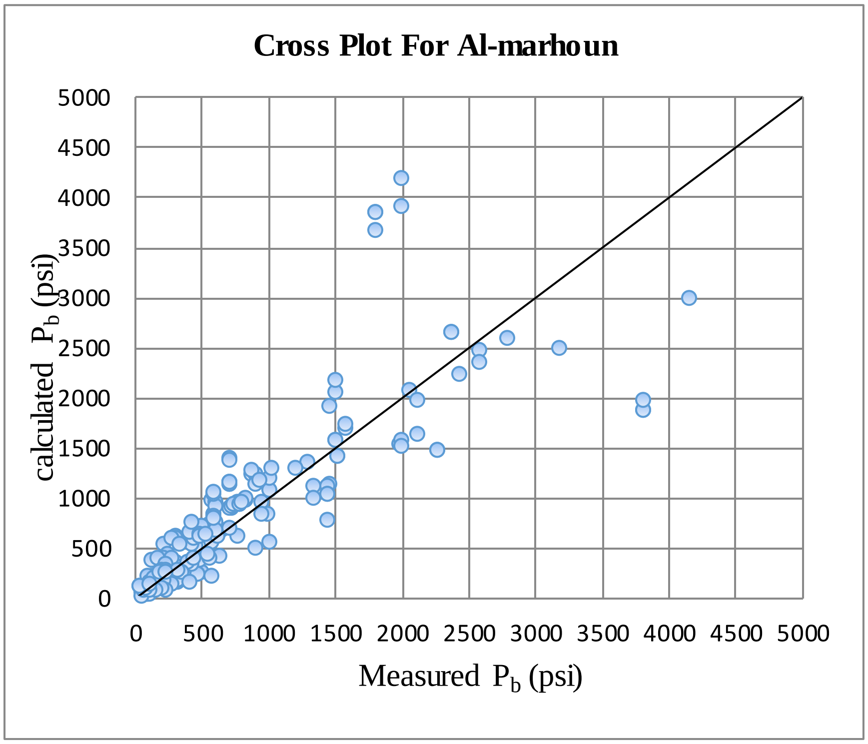


Figure 4-3: Measured P_b vs. Calculated P_b for Al-Marhoun's correlation

Table 4-4: Statistical Analysis Results for Al-Marhoun Correlation

RMSE	RRMSE	R^2
337.8329	0.436168	0.809757

4.3.4. Petroski and Farshed Correlation, (1993)

The Equation (3-4) had been evaluated using all datasets and the prediction result shown bad relationship between measured and calculated bubble point pressure. Most of the lower measured of P_b have a negative prediction result (see Figure 4-4).The statistical analysis results shown in Table (4-5)

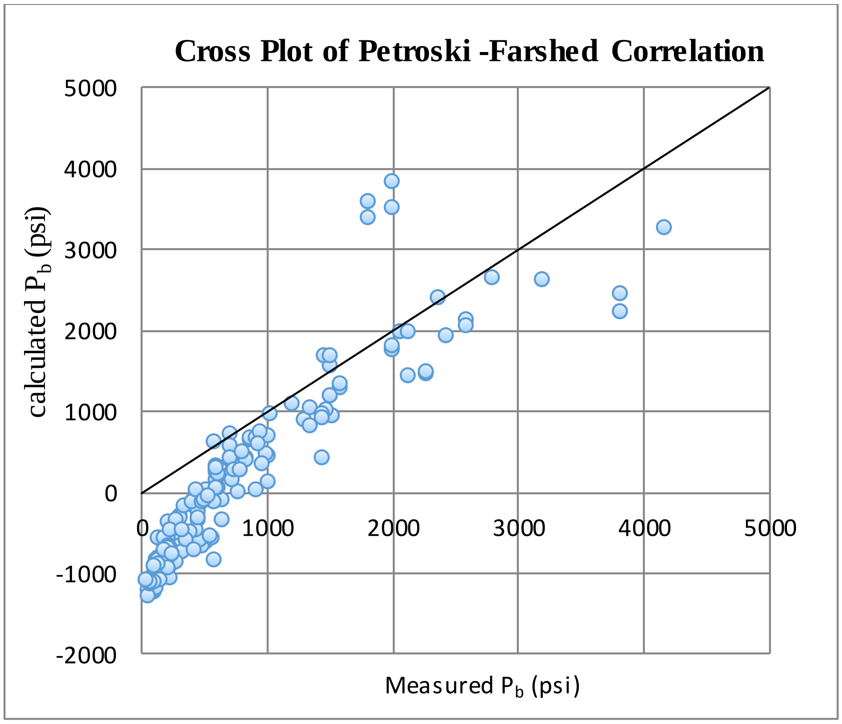


Figure 4-4: Measured P_b vs. Calculated P_b for Petroski-Farshed correlation

Table 4-5: Statistical Analysis Results for Petroski-Farshed Correlation

RMSE	RRMSE	R^2
838.9672	1.083171	-0.17326

4.3.5. Hanafy's Correlation

In this correlation, the bubble point pressure prediction depend only on the gas solubility R_S (see Equation 3-5).The 45 degree plotting show good prediction with correlation coefficient R^2 of 0.809757 (see Figure 4-5).The tabulated results of statistical analysis shown in Table (4-6).

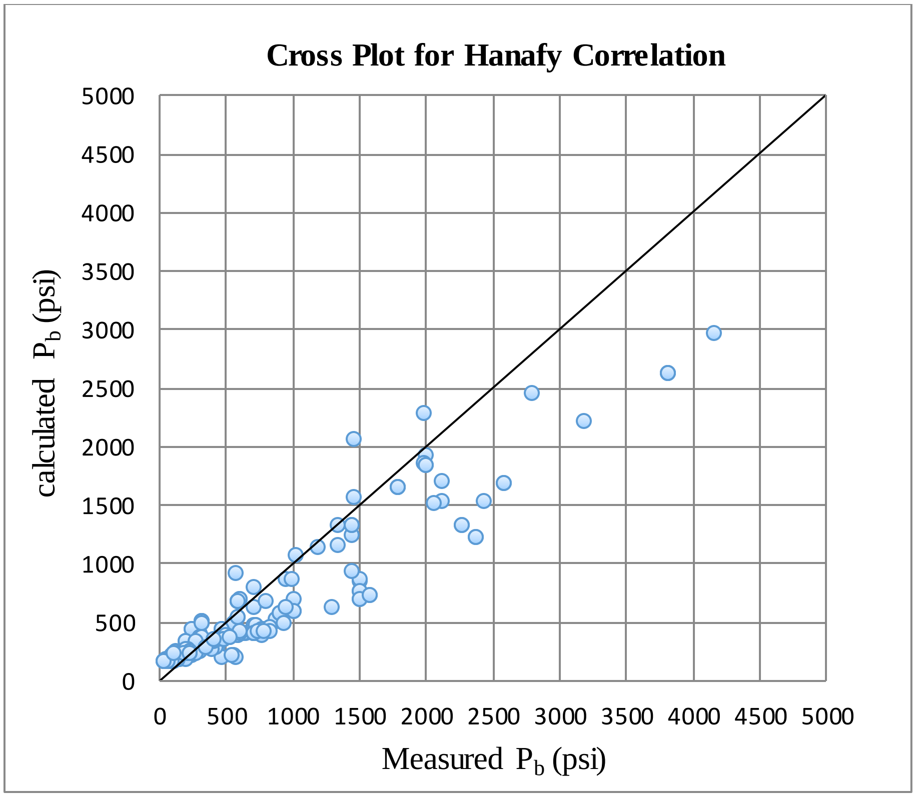


Figure 4-5: Measured P_b Vs Calculated P_b for Hanafy Correlation

Table 4-6: Statistical Analysis Results for Hanafy Correlation

RMSE	RRMSE	R^2
337.8329	0.436168	0.809757

4.3.6. Vasquez-Beggs Correlation

After evaluating of this correlation using Equation (3-6), the 45 degree plotting shown good performance with correlation coefficient R^2 of 0.8324 (see Figure 4-6). Statistical analysis results of this correlation shown in Table (4-7).

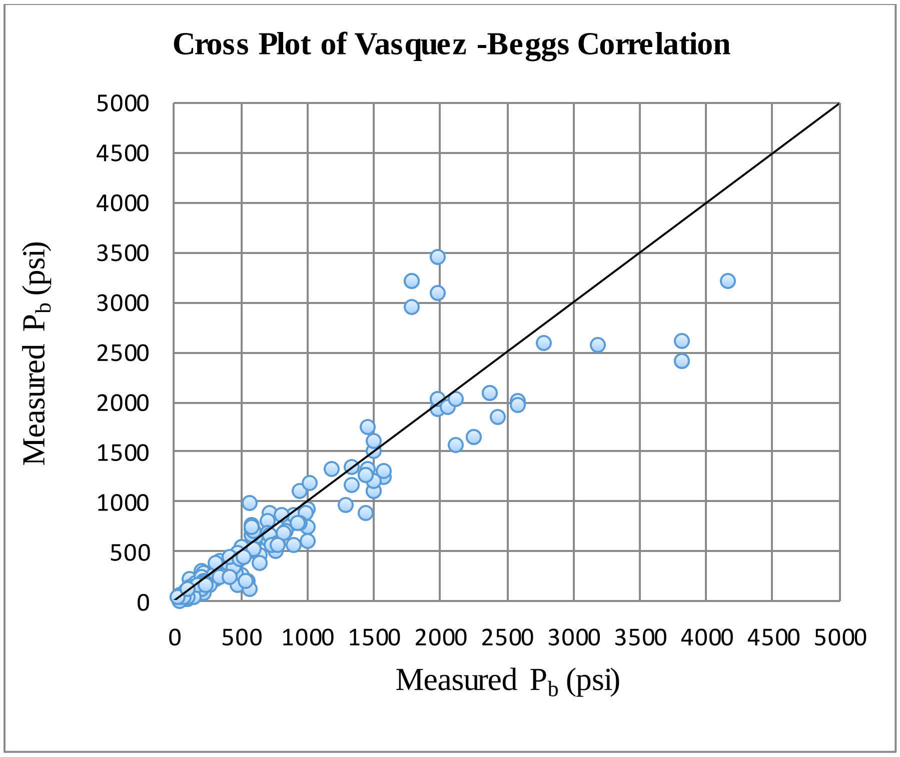


Figure 4-6: Measured P_b vs Calculated P_b for Vasques-Beggs Correlation.

Table 4-7: Statistical Analysis for Vasques-Beggs Correlation

RMSE	RRMSE	R^2
317.06	0.40935	0.8324

4.4. Comparison of Common Empirical Correlations

The comparisons of statistical analysis results between the common empirical correlations were carried out using bar chart plotting, see Figure (4-7) and summarized in Table (4-8).

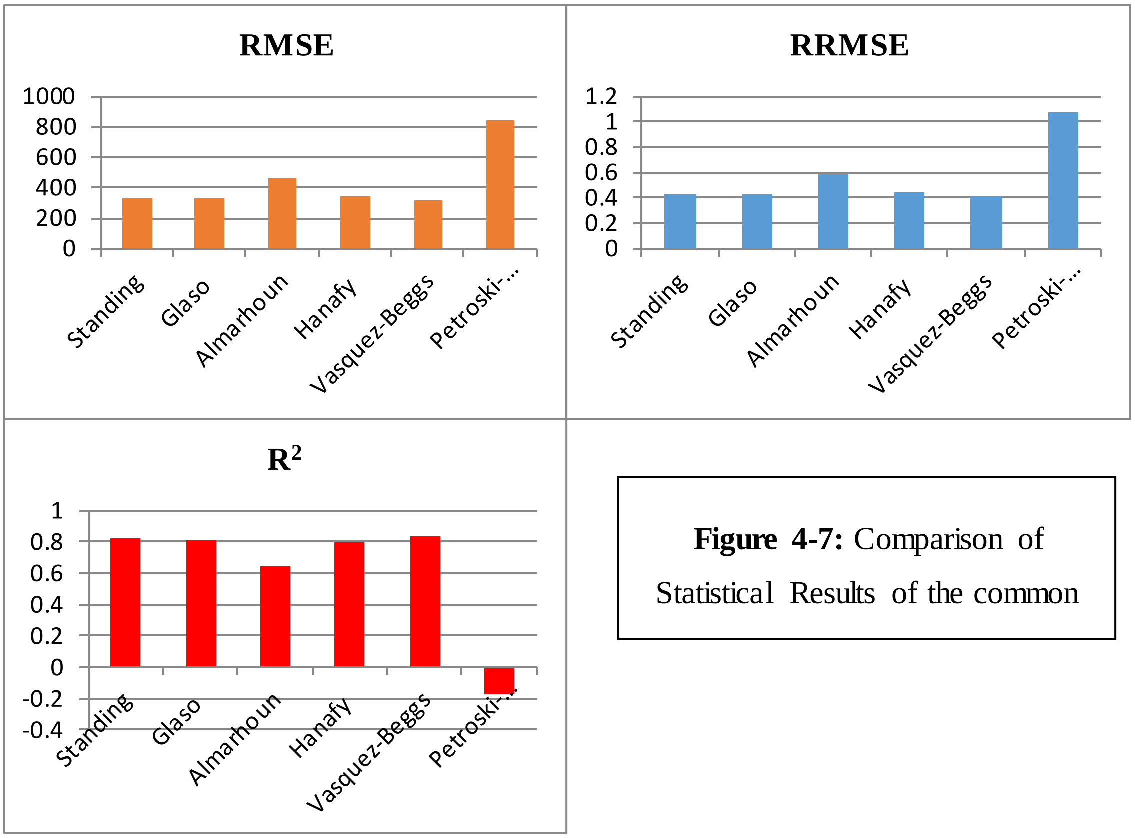


Figure 4-7: Comparison of Statistical Results of the common

Table 4-8: Summary of Statistical Results of the Common Empirical Correlations.

Correlation	RMSE	RRMSE	R^2
Standing	**327.5768**	**0.422927**	**0.821133**
Glaso	337.8329	0.436168	0.809757
Almarhoun	457.3507	0.590475	0.651339
Hanafy	344.4835	0.444755	0.802193
Vasquez-Beggs	**317.0618**	**0.40935**	**0.832432**
Petroski-Farshed	838.9672	1.083171	-0.17326

Vasquez-Beggs then Standing correlations have the biggest correlation coefficient R^2, lower errors results – RMSE and RRMSE - (See Table 4-8) and very good performance of predictive data in 45 degree method comparing to the others correlations. It can be used as a quick solution for Sudan oilfields for bubble point pressure prediction.

4.5. The New Developed Model by using Polynomial Neural Network

By using the PNN method in VariRig software that mentioned in chapter 3, a new predictive model was developed after trying many scenarios using 151 datasets as train data. The Final conditions which adjusted to achieve this model are: the degree of the new model is 4, the steepest descent hill climbing algorithm was used, the criterion for model evaluation is generalized cross validation (GCV) and the maximum number of input in each neuron is equal two. The new developed model for predicting of bubble point pressure is:

$$P_b = 0.5574 * A + 0.4511 * B \qquad (4-1)$$

$$A = 179.24 + 24.9318 * R_s - 0.02703 * {R_s}^2 - 0.0001035 * {R_s}^3 + 3.4328E-8 * {R_s}^4 - 46.62 * R_s * \gamma_g + 0.1360 * {R_s}^2 * \gamma_g + 6.2364E-5 * {R_s}^3 * \gamma_g + 23.5435 * R_s * {\gamma_g}^2 - 0.0939 * {R_s}^2 * {\gamma_g}^2 - 42.4064 * {\gamma_g}^4$$

$$B = 25.3128 * R_s - 0.0934 * {R_s}^2 + 3.3602E-8 * {R_s}^4 - 0.6338 * R_s * API + 0.00434 * {R_s}^2 * API - 1.3543E-6 * {R_s}^3 * API - 3.43598E-5 * {R_s}^2 API^2 + 7.6619E-5 * API^4$$

After justify the above Equation (4-1) the new form will be equation (4-2):

$$P_b = A * {R_S}^4 + B * {\gamma_g}^4 + C * API^4 + 99.914044 \qquad (4-2)$$

$$A = \frac{25.3166493}{{R_S}^3} - \frac{0.057216293}{{R_S}^2} - \frac{5.773274 * 10^{-5}}{R_S} + 3.429148 * 10^{-8}$$

$$B = \frac{D}{\gamma g^3} - \frac{E}{\gamma g^2} - 23.637987$$

$$D = 3.4763118 * 10^{-5} * {R_S}^3 + 0.0758274 * {R_S}^2 - 25.986304 * R_S$$

$$E = 13.12353 * R_S - 0.0523475 * {R_S}^2$$

$$C = \frac{F}{API^3} - \frac{1.5500635 * 10^{-5} * {R_S}^2}{API^2} + 3.4565019 * 10^{-5}$$

$$F = 0.00198117 * {R_S}^2 - 0.285913948 * R_S - 6.109709512 * 10^{-07} * {R_S}^3$$

Where:

p_b = bubble point pressure, psi

γ_g = gas specific gravity

R_s = gas solubility, SCF/STB

API=oil gravity in API degree

The prediction result of the train datasets shown in Figure (4-8) with correlation coefficient R^2 of 0.9572.

The developed model was tested using 61 of datasets (30 %) and the results were shown in Figure (4-9) with correlation coefficient R^2 of 0.9593.

The statistical analysis results for training and testing the new model are summarized in Table (4-9).

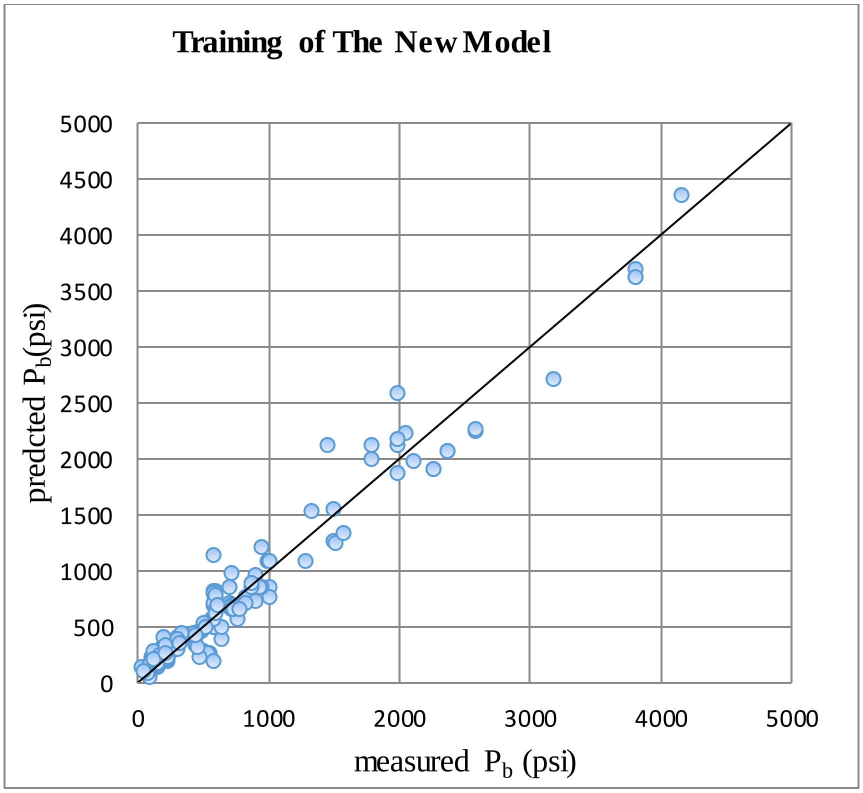


Figure 4-8: Measured P_b vs Calculated P_b for training data.

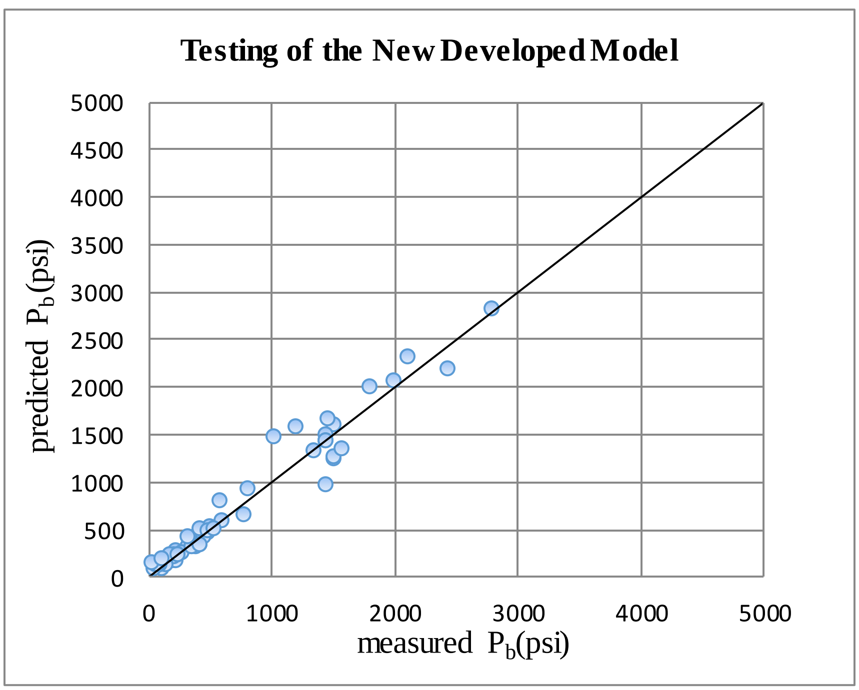


Figure 4-9: Measured P_b vs Predicted P_b for the New Model using Test Data

Table (4-9): Statistical Analysis Results of the New Model using Train and Test data

	RMSE	RRMSE	R^2
Trained Model	167.3167	0.206778	0.957243
Tested Model	136.3617	0.201667	0.959330

4.6. Compassion between the New Developed Model and the Best Common Empirical Correlations

The test data was applied to the best common empirical correlations which were achieved in this research (Vasquez-Beggs and Standing correlations). The result of these correlations was compared to the new developed model (see Table 4-9) . The statistical analysis results shown in Table (4-10) and Figure (4-9)

Table 4-10: Statistical Analysis Results Using Test data.

Correlation	RMSE	RRMSE	R^2
Standing	256.4604	0.379283	0.856144
Vasquez-Beggs	277.5448	0.410465	0.833342
New developed model	**136.3617**	**0.201667**	**0.95933**

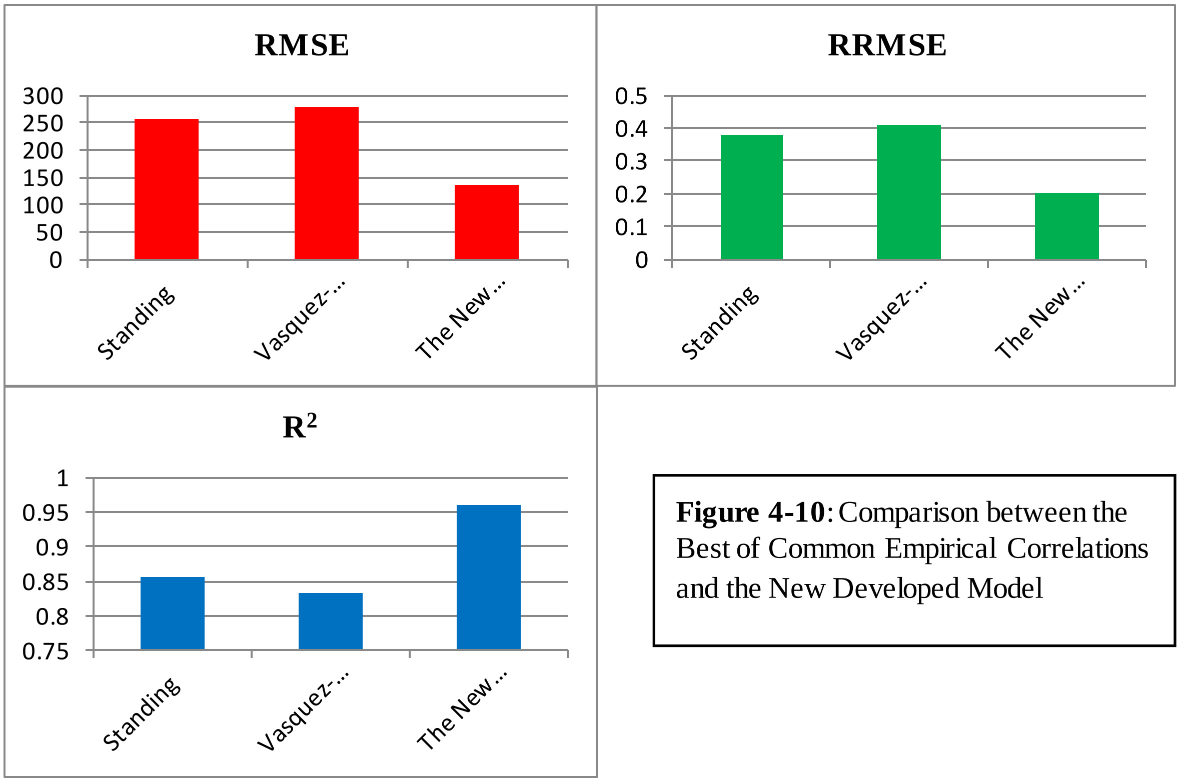


Figure 4-10: Comparison between the Best of Common Empirical Correlations and the New Developed Model

From above Figure (4-10) and Table (4-10), the new developed model has a biggest correlation coefficient R^2 and lowest error parameters comparing with the best common Correlations.

4.7. Summary of the Results

From this study Vasquez-Beggs and Standing correlations are the best common empirical correlations of bubble point pressure (P_b) for Sudan oilfields with correlation coefficient R^2 of 0.832432 and 0.821133 respectively using all datasets (0.833342 and 0.856144 respectively using test data).

The new developed model (Equation 4-1) was built using polynomial neural network (PNN) method (151 datasets as train data). The correlation coefficient of this model is 0.957243.

The new developed model has a good prediction performance of bubble point pressure comparing with best common correlations. From statistical evaluation this model has correlation coefficient of 0.95933 using Test data.

It should be noted that the new developed model has limitations for being used in Sudan oilfields depend on datasets ranges (see Table 4-1).

4.8. Creating Guide User Interfaces (GUIs) Using MATLAB Software

All the common empirical correlations as well as the developed new model were programmed using MATLAB codes (see Appendix C) and were validated; these codes were used for evaluation bubble point pressure inside GUI which was created.

Guide user interfaces (GUIs) had been generated to cover the evaluation workflow which mentioned in chapter 3 (Figure 3-4).

The first GUI is the main page includes the software name (PbSOFT) and the main command buttons for Methods Evaluation and bubble point pressure P_b Calculations - see Figure (4-11). The second GUI is Load page for loading and quick QC data from excel template file (see Figure 4-12). The third GUI for Methods Evaluation using 45 degree plotting method, see Figure (4-13). The fourth GUI for Statistical Analysis (see chapter 3) and displaying the final results. The last GUI for bubble point pressure prediction calculation using the all methods of this research (see Figure 4-14).

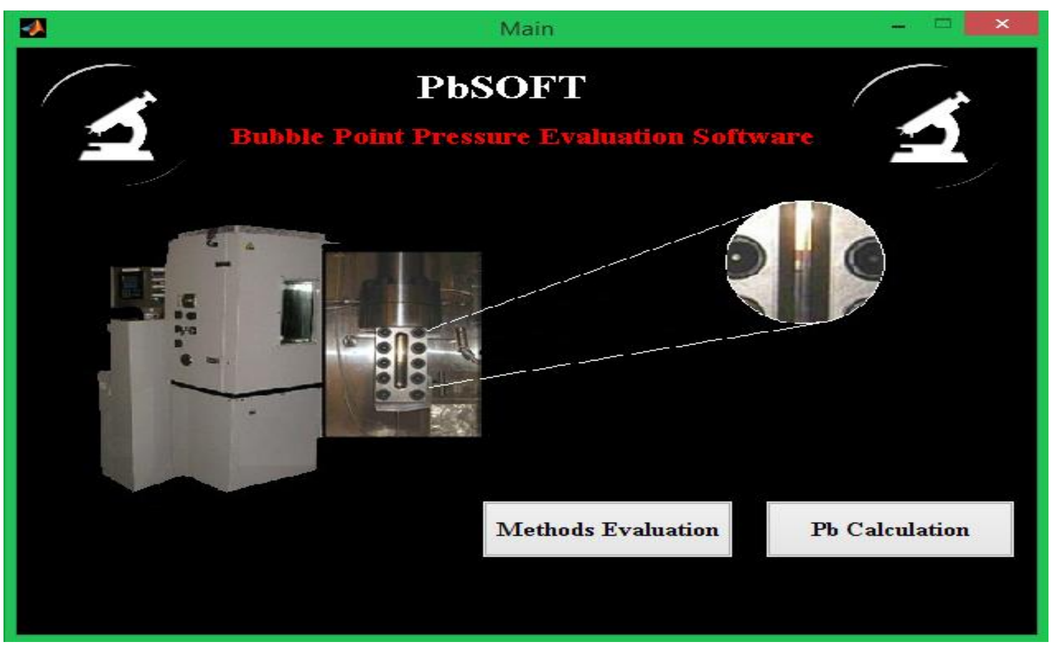
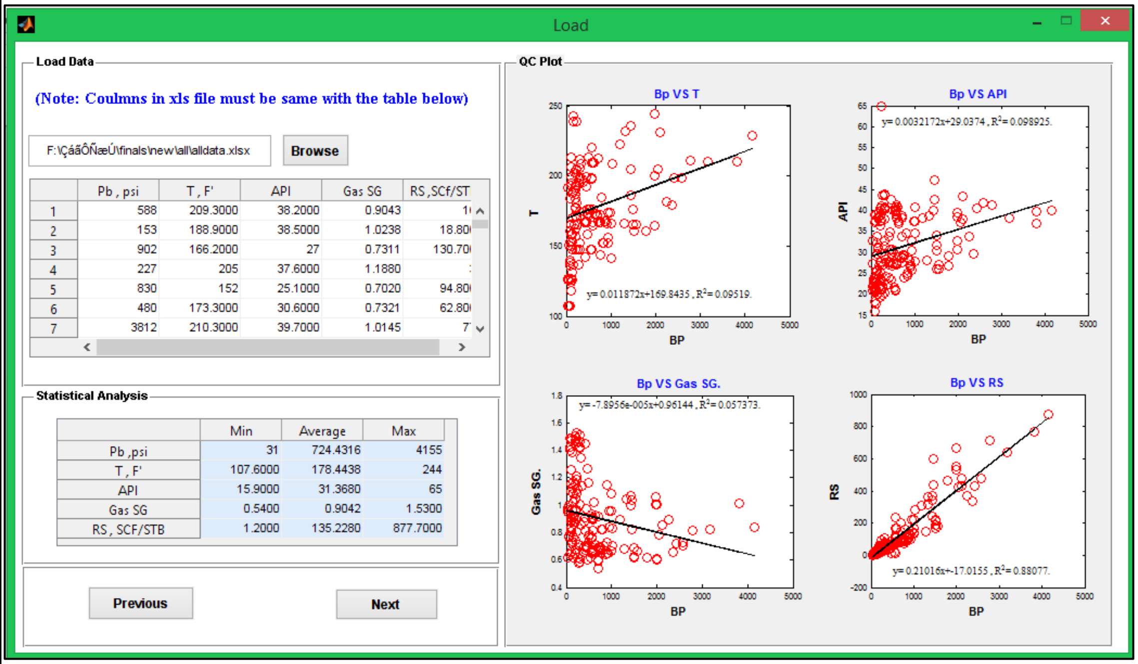


Figure 4-11: The First GUI as Main Page.



	A	B	C	D	E	F
1	Measured Pb ,psi	Temprature F'	API	Gas Specific Gravity	Rs SCF/STB	
2	588	209.3	38.2	0.9043	165	
3	153	188.9	38.5	1.0238	18.8	
4	902	166.2	27	0.7311	130.7	
5	227	205	37.6	1.188	30	
6	830	152	25.1	0.702	94.8	
7	480	173.3	30.6	0.7321	62.8	
8	3812	210.3	39.7	1.0145	770	

Figure 4-12: The Second GUI for Loading Data and QC and Example of Template File.

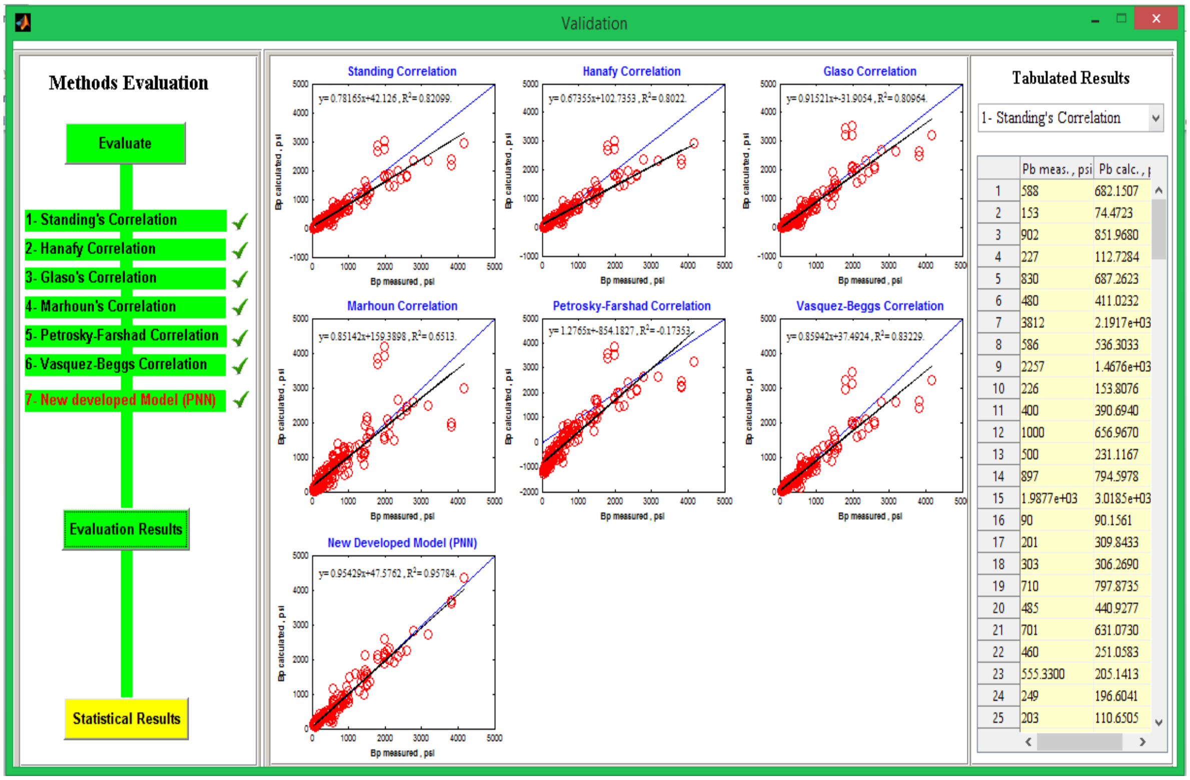


Figure 4-13: The Third GUI for Methods Evaluation.

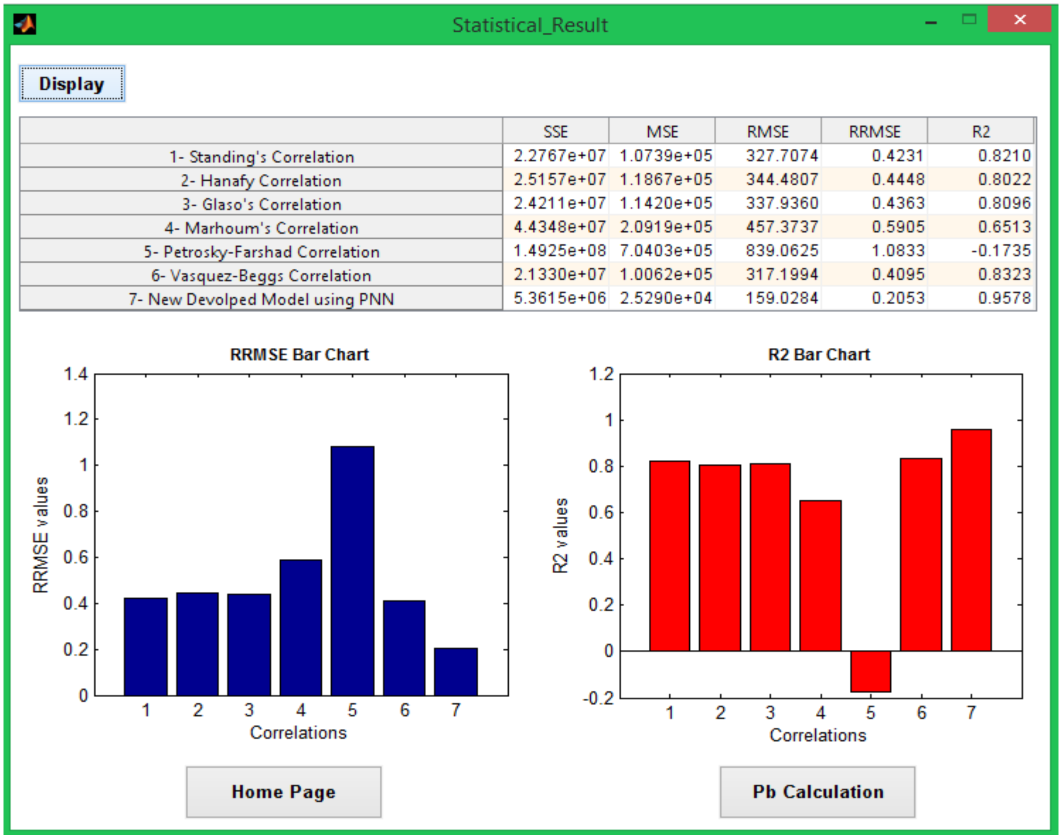


Figure 4-14: The Fourth GUI for Statistical Analysis.

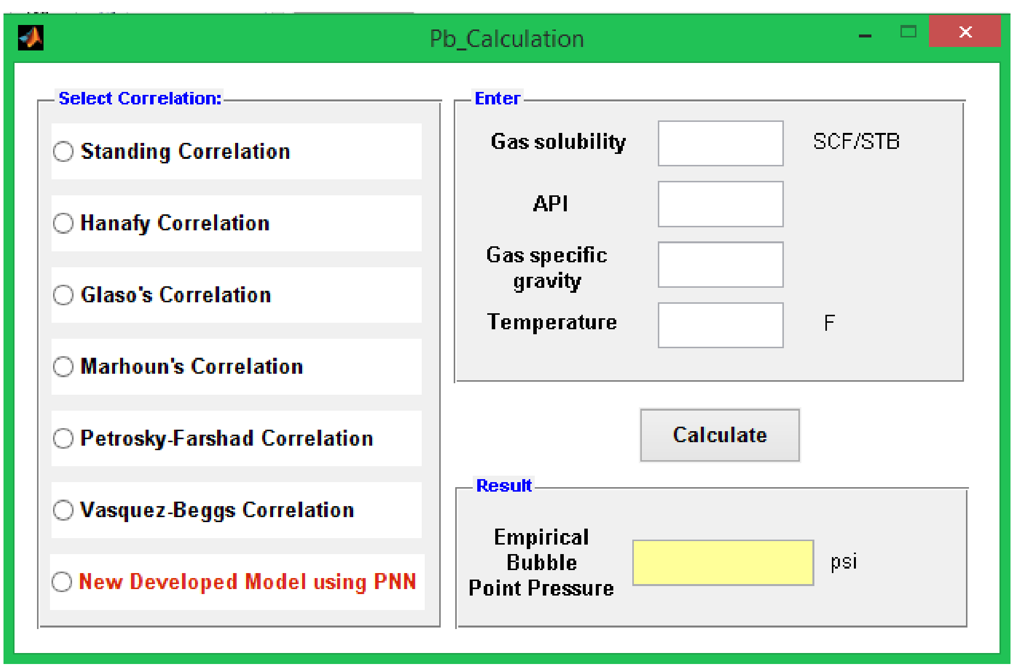


Figure 4-15: The Last GUI for Bubble Point Pressure Prediction Calculations

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 (4-16) is showing the main icon of the software (PbSOFT) on the desktop.

Figure 4-16: Icon of PbSOFT Software placed on the Desktop.

The main features of PbSOFT software shown on Table (4-11)

Table 4-11: Main Features of PbSOFT software

Software Name	PbSOFT
Software Size	4.32 MB
Setup Package Size	151 MB
System Requirements	Windows 10 ,Windows 8 ,Windows 7 512 MB RAM as minimum.