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Measurement of the Best Z-Factor Correlation Using Gas Well Inflow Performance Data in Niger-Delta

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Abstract

Gas compressibility has a long and important history for gas industries. The use of z-factor in real gas analysis is unavoidable; hence study of the effects of different z-factor correlations against real life data was carried out. This research establishes the need and a solution for a simple, robust and flexible technique requiring the use of different z-factor correlations. The most common sources of z-factor values are experimental measurement, equations of state method and empirical correlations. Necessity arises when there is no available experimental data for the required composition, pressure and temperature conditions. Presented here is a technique to predict z-factor values using Gas Well Inflow Performance data. The three gas correlations under study are Hall and Yarborough, Dranchuk, Abu and Kassem and Dranchuk, Purvis and Robbinson. The interest of the research was to show the best Z-Factor correlation for Niger Delta. The method or approach used was to review existing models, developed a computer program to evaluate numerically the three correlations and the best correlation is shown by running a statistical absolute average error for each of the calculated gas well performance against the history inflow performance data. Based on the study analysis performed using the Niger-Delta, the Hall and Yarborough is ranked first, followed by Dranchuk-purvis-Robbinson, while Dranchuk-Abu-Kaseem is recorded the last in the ranking model. Based on this study, it is recommended that the Hall and Yarborough gas deviation model is the best model for Niger Delta.

Keywords: Gas compressibility factor, Gas well, Gas Well Inflow Performance, Niger-Delta

INTRODUCTION

The accurate measurement of natural gas and natural gas related fluids is difficult. It requires care, experience, and insight to achieve consistently accurate measurements that meet stringent fiscal requirements. To understand and predict the volumetric behavior gas reservoirs as a function of pressure, knowledge of the physical properties of reservoir fluids must be gained. These fluid properties are usually determined by laboratory experiments performed on samples of actual reservoir fluids. In the absence of experimentally measured properties, it is necessary for the petroleum engineer to determine the properties from empirically derived correlations. It is particularly difficult to measure complex fluid mixtures that are exposed to a range of operating conditions, dynamic flow, fluid property behavior, and changing equipment conditions.

The magnitude of deviation of real gases from the conditions of the ideal gas law increases with increasing pressure and temperature and varies widely with the composition of the gas. Numerous equations-of-state have been developed in the attempt to correlate the pressure-temperature-volume variables for real gases with experimental data. In order to express a more exact relationship between the variables p, V, and T, z-factor must be introduced into the ideal gas equation to account for the departure of gases from ideality. It is hard to determine experimentally measured z-factor values for all compositions of gases at all ranges of pressures and temperatures. At the same time, this method is expensive and most of the time these measurements are made at reservoir temperatures only (Neeraj, 2004).

Schlumberger journal (2006) defined inflow performance relationship as the production engineer's shorthand description or the performance potential or a reservoir at a given average reservoir pressure. It is the relationship between the bottom-hole flowing pressure and flowrate and is the starting point in the analysis of a well. The journal presented some of the techniques currently used for calculating IPR's of gas wells, the basic assumptions made, and saw how IPR curves are applied in practice and these are in agreement with the work of (Ahmed, 2001). A flowing well never achieves its maximum pumped-off potential flow rate. Pressure losses in the tubing, chokes, and other surface equipment; make it impossible to get the pressure opposite the formation down to zero. The bottom-hole flowing pressure is equivalent to the backpressure exerted by the flowing column of fluid as it moves to the surface. This backpressure is usually quite large. The inflow rate that may exist against this backpressure is not a true reflection of what the flow rate of the well might be after installation of artificial lift because artificial lift unloads the fluid column, reduces the bottom-hole pressure, leading to the backpressure on the formation. It is important in the analysis of a well for an engineer to know the relationship that exists between the bottom-hole flowing pressure and flow rate even down to a very low pressure. For this reason the engineer must define the IPR and predict how it changes with time.

Determination of the flow capacity of a gas well requires a relationship between the inflow gas rate and the sand-face pressure or flowing bottom-hole pressure. This inflow performance relationship may be established by the proper solution of Darcy's equation. Solution of Darcy's law depends on the conditions of the flow existing in the reservoir or the flow regime.

Accurate information of compressibility factor values is necessary in engineering applications like gas metering, pipeline design, estimating reserves, gas flow rate, and material balance calculations. The most common sources of z-factor values are experimental measurement, equations of state method and empirical correlations. Necessity arises when there is no available experimental data for the required composition, pressure and temperature conditions. Presented here is a technique to predict z-factor values using Gas Well Inflow Performance data. Knowledge of accurate critical z-factor value for pure substances and mixtures is essential in the determination of accurate z-factor values.

Current Challenges

1. The use of Standing and Katz Z- factor chart can lead to a certain degree of error in measurement which can affect the fluid system calculation requiring the use of z-factor values. For example, frequent errors experience in the classroom when estimating z-factor for gas analysis as a result of analog nature of the chart. This research work considers the use of computer application to evaluate numerically various z-factor correlations.
2. The review of most soft-ware in oil and gas industries showed that the use of one Z-factor correlation as an inbuilt parameter for modeling system performance such as gas well; Most times leads to error since the Z-factor used may not be the best for the system under study or simulated. This is a great limitation; therefore, an improved model that will enhance flexibility and multiple choices is required. The basis of this research work is to measure the best z-factor correlation for the Niger-Delta using inflow performance relationship (IPR) history data as a yardstick.

The study considers the best Z-factor correlation for natural dry hydrocarbon gases in the Niger-delta. The computer model is an object oriented program. Only IPR was used as a yardstick to measure the best Z-factor in this study.

LITERATURE REVIEW

According to Ikoku (2006), an ideal gas was defined as a fluid that has insignificant volume when compared with the total volume of fluid contained in the system. He added that there is no molecular attraction between gas molecules and, between the molecules and the wall of the container. He further assumed that there is no loss in internal energy upon collision. Tarek (2001) had also stated the aforementioned assumptions by saying that for an ideal gas, the volume of these molecules is insignificant compared with the total volume occupied by the gas. And these molecules have no attractive or repulsive forces between them, and that all collisions of molecules are perfectly elastic. Based on the above behavioural assumptions of ideal gases, a mathematical equation called equation-of-state was derived to express the relationship existing between pressure P, volume V, and temperature T for a given quantity of moles of gas n.

However, in the actual sense, no gas behaves ideally. Different scientist came up with a relationship between a perfect gas and real gas. The theory that an ideal gas exist is from the assumption that real gases can behave ideally at a very low pressure. Tarek, (2001) submitted that the error in using ideal gas relationship for a higher pressure can be as great as 500%. It is also obvious that no reservoir can exist at atmospheric pressure; therefore, the need to develop an equation of state to match the relationship between perfect gases and real gases becomes imperative. To account for this deviation, a factor called gas deviation factor was introduced.

The question at this point is "how to account for the factor?" Among the existing method of determining z-factor values, experimental measurement is one of the most accurate methods. But, it is difficult to determine experimentally measured z-factor values for all compositions of gases at all ranges of pressures and temperatures. Also, this method is known to be expensive and these measurements are carried out at reservoir temperatures only; thus, **EMPIRICAL CORRELATION METHODS** are often used.

Empirical Correlation for Estimating Z-Factor

Standing and Katz (1942) present a generalized z-factor chart, for the evaluation of gas deviation factor. The chart is widely reliable for natural gas with minor amount of non-hydrocarbons. It had been one of the widely accepted correlations in the oil and gas industry for the past 50 decades. The chart represents compressibility factors of sweet natural gas as a function of pseudo-reduced pressure (p_{pr}) and pseudo-reduced temperature (T_{pr}).

Tarek (2001) corroborates the work of Standing and Katz (1942) by saying that gas compressibility factors for natural gases of various compositions have shown that compressibility factors can be generalized with sufficient accuracies for most

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engineering purposes when they are expressed in terms pseudo-reduced pressure and pseudo-reduced temperature. However, numerous methods have been suggested to predict Pseudo-critical properties of the gases as a function of their specific gravity. The point to be noted here is that these methods predict pseudo critical values which are evidently not accurate values of the gas mixtures. The existing methods fail to predict accurate values of pseudo-critical values when non-hydrocarbon components are present in significant amounts. The puzzle at this point is how the values of pseudo-critical temperature and pseudo-critical pressure of mixture of gases can be determined. Tarek (2001) said that in cases where the composition of a natural gas is not available, the pseudo-critical properties, P_{pc} and T_{pc}, can be predicted solely from the specific gravity of the gas.

To be able to predict z-factor using the Standing-Katz chart requires the appropriate reduced temperature and pressure. Information on the composition of the gas used to design the Standing-Katz chart are not provided. A close study and comparison of the experimental data with that of Standing-Katz chart values suggests that the Standing-Katz chart was developed based on the natural gas mixture without any significant amounts of non-hydrocarbon components.

Many correlation methods for compressibility factor have been developed by many authors. Generally, computation of compressibility factor can be done by empirical method, correlation method, corresponding state method and as well as use of equation of state. The position of gas deviation factor in today's gas industry is still a prominent one. Therefore, it becomes a necessity to have a simple and robust correlation(s) to be able to determine z-factor values accurately (Obuba et al., 2013).

METHODOLOGY

The three gas correlations under study are Hall and Yarborough, Dranchuk, Abu and Kassem and Dranchuk, Purvis and Robbinson. The interest of the research was to show the best Z-Factor correlation for Niger Delta. The method or approach used was to review existing models, developed a computer program to evaluate numerically the three correlations and the best correlation is shown by running a statistical absolute average error for each of the calculated gas well performance against the history inflow performance data.

The Computer Model Development

Due to the fact that the data point needed for this research study are large, there was need to automatically import data to a computer application just to avoid the stress of typing them manually, the Visual Basic.Net was used to develop the application that can do this task and we called it **Z-Factor Toolkit 2017**. Besides, the use of human brain to run the iterations in the objective functions defined above is very stressful if not impossible. Therefore, the **Z-Factor Toolkit 2017** application was developed to solve such problem. The application was equally designed to contain the estimated values of gas deviation factor for each of the correlation method and their respective production rate using the flowing bottom hole pressure values from the history data. This is to enable the user find the standard error between each of the gas Z-factor correlation calculated rate and the real life gas production rate at the same pressure. The production rate values are then used to compare with the history production data of gas wells.

Absolute Average Error

In this research study, absolute average error (AAE) was introduced to check how much the calculated production rate from **Z-Factor Toolkit 2017** differs from the gas production rate history for each of z-factor model. By definition, AAE is a measure of the dispersion in a distribution. It equals the absolute of the ratio of the square root of the arithmetic mean of the squares of the deviations from the mean. The average value of a set of numbers is called mean.

RESULTS AND DISCUSSION

The production history data is used to run the analysis, that is; the average reservoir pressure and flowing bottom hole pressure for the life of the wells in the field was used to evaluate the z- factor of each z- factor model, then the z- factor respectively is used to estimate the gas production rate. Finally, a statistical analysis is run to compare the fitness of the computed gas production rates with the history gas production rates.

The use of Z-Factor Toolkit 2017

Load the software by clicking at the icon on the desktop or from the program menu to display the figure shown below;

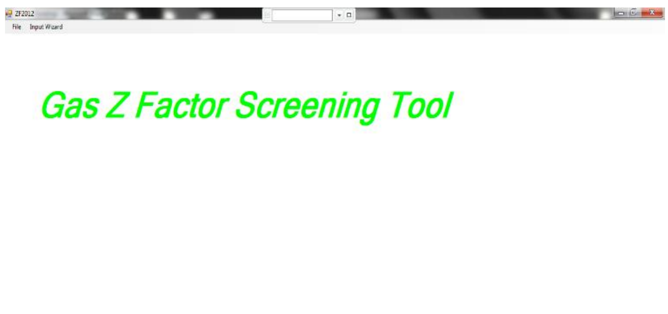
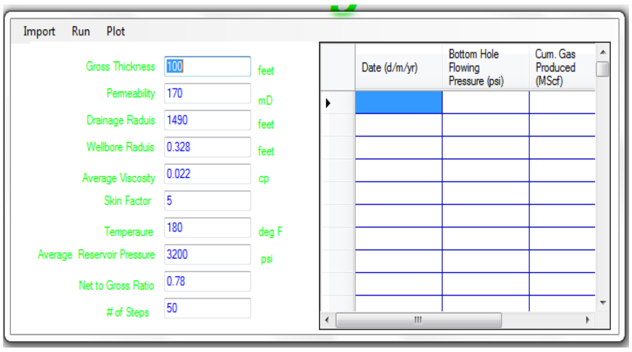


Figure 1: Main Section of the Software

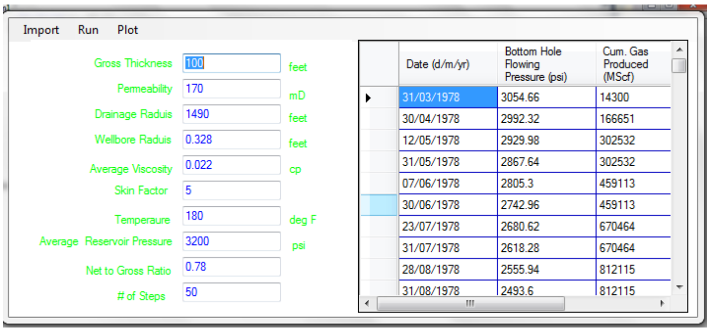
The main section contains menu items like File and input section. The software is called **Z-Factor Toolkit 2017**. To display the input section as shown in Table 1 below, click the Input wizard menu item.

Table 1: Input Section of the Software



The input section contains input parameters like Gross Thickness, Permeability, Drainage Radius, Wellbore Radius, Average Viscosity, Skin Factor, Temperature, Average Reservoir Pressure and Net to Gross Ratio. There is also room for the user to upload history data such as Date, Bottom Hole Flowing Pressure and Cum. Gas Produced, provided the history data has been arranged and saved in a text file in any directory, for example; My Document, click the main menu item called Import to open a dialog box, navigate to the location of the file in your computer and click open after selecting it. Then the table below displays on the screen.

Table 2: The Input section showing the imported data



To display the section that runs the production and statistical analysis simultaneously, click the Run menu item on the menu bar. The result section is displays as shown in the CASE STUDIES.

Data Used For Analysis

Table 3 to Table 5 shows Production and Lithology Data from four different Niger-Delta fields with different reservoir properties and inflow performance.

Table 3: Gas Field 3 of Niger-Delta Production History Data

Gross Thickness (ft)		100	
Net to Gross		0.78	
Drainage Radius (ft)		1490	
Wellbore Radius (ft)		0.328	
Reservoir Temperature deg F)		180	
Average Reservoir Pressure (psi)		3200	
Date	**Bottom Hole Flowing Pressure (psi)**	**Cum. Gas Produced (Mscf)**	**Gas Production Rate (Scf/day)**
31/03/1978	3136	14300	19230.43
30/04/1978	3072	166651	19185.47
12/5/1978	3008	302532	19117.61
31/05/1978	2944	302532	19030.21
7/6/1978	2880	459113	18921.46
30/06/1978	2816	459113	18791.57
23/07/1978	2752	670464	18640.78
31/07/1978	2688	670464	18469.36
28/08/1978	2624	812115	18277.59
31/08/1978	2560	812115	18065.76
20/09/1978	2496	936496	17834.21
30/09/1978	2432	936496	17583.28
31/10/1978	2368	1162743	17313.34
30/11/1978	2304	1376590	17024.79
13/12/1978	2240	1554412	16718.07
31/12/1978	2176	1554412	16393.63

11/1/1979	2112	1743053	16051.96
31/01/1979	2048	1743053	15693.57
19/02/1979	1984	1888930	15319.03
28/02/1979	1920	1888930	14928.9
31/03/1979	1856	2045551	14523.81
30/04/1979	1792	2195795	14104.38
31/05/1979	1728	2331890	13671.28
30/06/1979	1664	2458046	13225.22
31/07/1979	1600	2581691	12766.89
31/08/1979	1536	2723559	12297.05
30/09/1979	1472	2859218	11816.43
31/10/1979	1408	2997902	11325.8
15/11/1979	1344	3160564	10825.94
30/11/1979	1280	3160564	10317.61
1/12/1979	1216	3324917	9801.587
10/12/1980	1152	3324917	9278.646
31/12/1982	1088	3324917	8749.548

Table 4: Gas Field 11 of the Niger- Delta Production History Data

Gross Thickness (ft)	80		
Net To Gross Ratio	0.58		
Drainage Radius (ft)	1359		
Well Bore Radius (ft)	0.425		
Reservoir Temperature (deg F)	212		
Average Reservoir Pressure (psi)	3117		
Date	**Bottom Hole Flowing Pressure (psi)**	**Cum. Gas Produced (Mscf)**	**Gas Production Rate (Scf/day)**
31/03/1978	3054.66	580326.00	11135.8471
30/04/1978	2992.32	580326.00	11069.56988
12/05/1978	2929.98	707084.00	1018.864375
31/05/1978	2867.64	707084.00	9921.825919
07/06/1978	2805.3	813579.00	9805.920174
30/06/1978	2742.96	933737.00	9668.838829
23/07/1978	2680.62	933737.00	9511.284932
31/07/1978	2618.28	1045121.00	9333.969447
28/08/1978	2555.94	1045121.00	9137.60796
31/08/1978	2493.6	1081355.00	8922.917612
20/09/1978	2431.26	1167457.00	8690.614313
30/09/1978	2368.92	1167457.00	8441.410288
31/10/1978	2306.58	1308942.00	8176.011953
30/11/1978	2244.24	1308942.00	7895.118135
13/12/1978	2181.9	1446312.00	7599.418608
31/12/1978	2119.56	1535377.00	7289.592941
11/01/1979	2057.22	1535377.00	6966.309604
31/01/1979	1994.88	1634264.00	6630.225318
19/02/1979	1932.54	1634264.00	6281.984602
28/02/1979	1870.2	1767232.00	5922.219501
31/03/1979	1807.86	1767232.00	5551.549442
30/04/1979	1745.52	1883598.00	5170.581209

31/05/1979	1683.18	1883598.00	4779.909013
30/06/1979	1620.84	2005578.00	4380.114621
31/07/1979	1558.5	2005578.00	3971.767547
31/08/1979	1496.16	2087892.00	3555.425274
30/09/1979	1433.82	2087892.00	3131.633508
31/10/1979	1371.48	2182450.00	2700.926449
15/11/1979	1309.14	2182450.00	2263.827074
30/11/1979	1246.8	2275413.00	1820.847418
01/12/1979	1184.46	2275413.00	1372.488871
10/12/1979	1122.12	2365070.00	919.2424563
31/12/1979	1059.78	2365070.00	461.5891189

Table 5: Gas Field 8 of Niger- Delta Production History Data

Gross Thickness (ft)		95	
Net To Gross Ratio		0.67	
Drainage Radius (ft)		1247	
Well Bore Radius (ft)		0.396	
Reservoir Temperature (deg F)		230	
Average Reservoir Pressure (psi)		3082	
Date	**Bottom Hole Flowing Pressure (psi)**	**Cum. Gas Produced (Mscf)**	**Gas Production Rate (Scf/day)**
31/03/1983	3020.36	1419973.00	10138.8471
30/04/1985	2958.72	1534474.00	10089.56988
12/05/1988	2897.08	1648475.00	10015.86437
31/05/1989	2835.44	1765476.00	9921.825919
07/06/1992	2773.8	1906077.00	9805.920174
30/06/1994	2712.16	2116978.00	9668.838829
23/07/1996	2650.52	2254379.00	9511.284932
31/10/1998	1356.08	2426580.00	2700.926449
15/11/2000	1294.44	2569281.00	2263.827074
30/11/2003	1232.8	2656881.00	1820.847418
01/12/2005	1171.16	2707124.00	1372.488871
10/12/2008	1109.52	2788924.00	919.2424563
31/12/2010	1047.88	2905425.00	461.5891189

Case Study 1: Gas Filed HFL3

This is a case of a gas well that produced from 31st March, 1978 to 20th January, 1986. The initial flowing bottom hole pressure is 3136 psi and the flowing bottom hole pressure at 20th January, 1986 was 1024 psi. The gross thickness of the reservoir is 100 feet while the non-shale ratio of the pay zone is 0.78. The permeability of the formation is 170 md, drainage radius is 1490 feet, well bore radius is 0.328 feet, gas viscosity is 0.022, skin factor is 5, isothermal reservoir temperature is 180 and average reservoir pressure is 3200 psi. The data at a glance can be seen in Table 6.

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Table 6: Input section showing the imported data for case 1

Import Run Plot

Parameter	Value	Unit
Gross Thickness	100	feet
Permeability	170	mD
Drainage Raduis	1490	feet
Wellbore Raduis	0.328	feet
Average Viscosity	0.022	cp
Skin Factor	5	
Temperaure	180	deg F
Average Reservoir Pressure	3200	psi
Net to Gross Ratio	0.78	
# of Steps	50	

Date (d/m/yr)	Bottom Hole Flowing Pressure (psi)	Cum. Gas Produced (MScf)
31/03/1978	3136	14300
30/04/1978	3072	166651
12/05/1978	3008	302532
31/05/1978	2944	302532
07/06/1978	2880	459113
30/06/1978	2816	459113
23/07/1978	2752	670464
31/07/1978	2688	670464
28/08/1978	2624	812115
31/08/1978	2560	812115

To run the production and statistical analysis, the menu item called Run is clicked. This displays the interface shown in table 4.9 below. Here the user runs the analysis by clicking on the Run menu item. The Results in the table shows in array format the date, flowing bottom hole pressure, calculated z-factor for HALL-YARBOROUGH correlation and its corresponding gas production rate, calculated z-factor for DRANCHUK-ABU-KASSEM correlation and its corresponding gas production rate, calculated z-factor for DRANCHUK-PURVIS-ROBINSON correlation and its corresponding gas production rate, the absolute average residual error in that order. The summarized statistical results are also displayed in Table 7 and Figure 2 - 5 showing the plot of rate of different z- factor correlations against bottom hole pressure at the same time.

Table 7: Result section showing statistical analysis of case 1

Results

Back Run Plot

Date (d/m/yr)	Flowing Bottom Hole Pressure (psi)	Hall-Yarborough Z Factor	Hall-Yarborough Gas Flow Rate (scf/day)	Dranchuk-Abu-Kas Z Factor	Dranchuk-Abu-Kas Gas Flow Rate (scf/day)	Dranchuk-Purvis-R Z Factor	Dranchuk-Purvis-R Gas Flow Rate (scf/day)	History Gas Production Rate (Scf/day)	Hall-Yarborough AAE	Dranchuk-Abu-Kas AAE	Dranchuk-Purvis-R AAE
31/03/1978	3136	0.900797650930...	11718.49852729...	0.867	10138.84710405...	0.7714	11391.96303826...	19230.43115	0.390627363688...	0.896707875426...	0.688070009129...
30/04/1978	3072	0.895186770049...	11670.66886536...	0.869	10089.56987673...	0.7733	11336.59536711...	19185.47127	0.391692354015...	0.901515278093...	0.692348597503...
12/05/1978	3008	0.889628802617...	11598.476147826	0.871	10015.86437467...	0.7755	11253.78019626...	19117.61011	0.393309305865...	0.908732925572...	0.698772303759...
31/05/1978	2944	0.884202815547...	11505.50240780...	0.874	9921.825918600...	0.7780	11148.11900966...	19030.2148	0.395408694609...	0.918015389115...	0.707033696312...
07/06/1978	2880	0.878918557877...	11389.80438271...	0.877	9805.920174189...	0.7808	11017.88783616...	18921.45865	0.398048290388...	0.929595419286...	0.717339923164...
30/06/1978	2816	0.873786484332...	11251.62133984...	0.881	9668.838829095...	0.7839	10863.86385291...	18791.56659	0.401240908470...	0.943518443337...	0.729731414569...
23/07/1978	2752	0.868817764923...	11091.21066468...	0.885	9511.284931673...	0.7873	10686.83700187...	18640.78056	0.405002884456...	0.959859334875...	0.744274808039...
31/07/1978	2688	0.864024286646...	10908.84929944...	0.889	9333.969446732...	0.7909	10487.60611992...	18469.36087	0.409354261025...	0.978725233182...	0.761065457532...
28/08/1978	2624	0.859418645756...	10704.83523853...	0.893	9137.607960218...	0.7947	10266.9752362	18277.58766	0.414319031720...	1.000259558034...	0.780231006650...
31/08/1978	2560	0.855014128679...	10479.48906456...	0.897	8922.9176117439	0.7987	10025.75012555...	18065.76225	0.419925441309...	1.024647434402...	0.801936216618...
20/09/1978	2496	0.850824679308...	10233.15550431...	0.902	8690.614312937...	0.8030	9764.735183076...	17834.20871	0.426206361565...	1.052122907289...	0.826389387487...
30/09/1978	2432	0.846864849982...	9966.204977990...	0.907	8441.410288072...	0.8074	9484.730660755...	17583.27521	0.433199739015...	1.082978389860...	0.853850766975...
31/10/1978	2368	0.843149733152...	9679.035109908...	0.912	8176.011953420...	0.8120	9186.530284741...	17313.33554	0.440949140762...	1.117577082645...	0.884643603554...
30/11/1978	2304	0.839694870446...	9372.072161671...	0.918	7895.1181346314	0.8167	8870.919252394...	17024.79036	0.449504401317...	1.156369299316...	0.919168676392...
13/12/1978	2240	0.836516135871...	9045.772342754...	0.923	7599.418607897...	0.8215	8538.672593143...	16718.06853	0.458922403235...	1.199914150357...	0.957923593817...
31/12/1978	2176	0.833629590122...	8700.622946832...	0.929	7289.592940984...	0.8265	8190.553866274...	16393.6281	0.469268004998...	1.248908578671...	1.001528635017...
11/01/1979	2112	0.831051303690...	8337.143256583...	0.934	6966.309604098...	0.8316	7827.314161908...	16051.95719	0.480615157522...	1.304226786095...	1.050761839625...
31/01/1979	2048	0.828797147620...	7955.885155564...	0.940	6630.225317506...	0.8368	7449.691367984...	15693.57458	0.493048246273...	1.3669745488984	1.106607348519...
19/02/1979	1984	0.826882552507...	7557.4333838906	0.946	6281.984602231...	0.8420	7058.409665428...	15319.02991	0.506663709889...	1.438565338819...	1.170323151549...
28/02/1979	1920	0.825322238583...	7142.405375950...	0.952	5922.219501335...	0.8474	6654.179214983...	14928.90359	0.521572007422...	1.5208291564732	1.243537949261...
31/03/1979	1856	0.824129922373...	6711.450623897...	0.958	5551.549441658...	0.8528	6237.696001863...	14523.80612	0.537900012679...	1.616171624270...	1.328392745600...
30/04/1979	1792	0.823318008348...	6265.249521048...	0.964	5170.581208974...	0.8582	5809.641807836...	14104.37708	0.555793957754...	1.727812698409...	1.427753301584...
31/05/1979	1728	0.822897276758...	5804.511654748...	0.970	4779.909012892...	0.8637	5370.6842841488	13671.28349	0.575423064045...	1.8601555914821	1.545538476419...
30/06/1979	1664	0.822876581264...	5329.973538437...	0.977	4380.114621250...	0.8693	4921.477102529...	13225.21766	0.596984059131...	2.019377071968...	1.687245594052...
31/07/1979	1600	0.823262571529...	4842.395796829...	0.983	3971.767547020...	0.8749	4462.660165191...	12766.89458	0.620706839358...	2.214411324141...	1.860826078486...
31/08/1979	1536	0.824059456372...	4342.559844543...	0.989	3555.425273686...	0.8805	3994.859858074...	12297.04879	0.646861623573...	2.458671704060...	2.078217816613...
30/09/1979	1472	0.825268822145...	3831.264125223...	0.996	3131.633507768...	0.8861	3518.68933457098	11[illegible]16.43081	0.675768073555...	2.773248300188...	2.358190987167...
31/10/1979	1408	0.826889518576...	3309.320002719...	1.002	2700.926449388...	0.8918	3034.748819537...	11325.80334	0.707807039962...	3.1933031321773	2.7320397876378
15/11/1979	1344	0.828917620682	2777.547415787	1.008	2263.827073801	0.8975	2543.6259256193	10825.9371	0.743435843924	3.782139601247	3.256104245109

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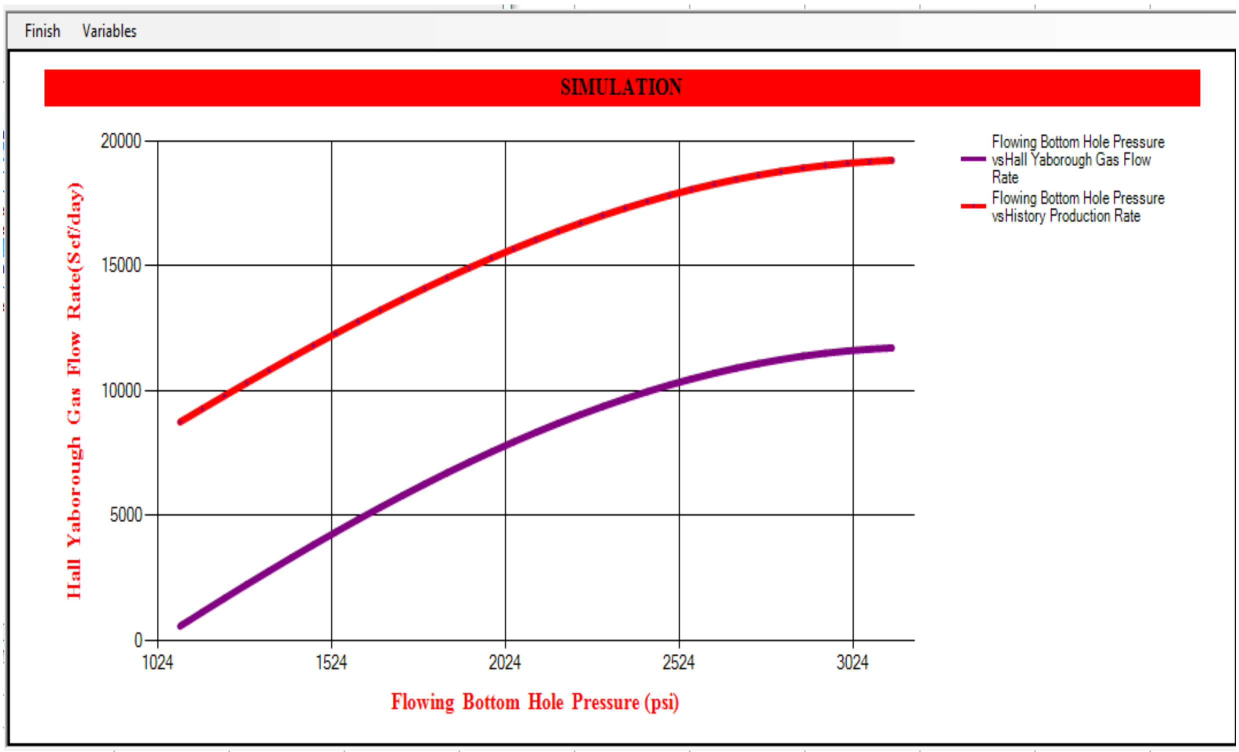

Figure 2: Model plot of BHP against Hall-Yarborough Z -factor correlation case1

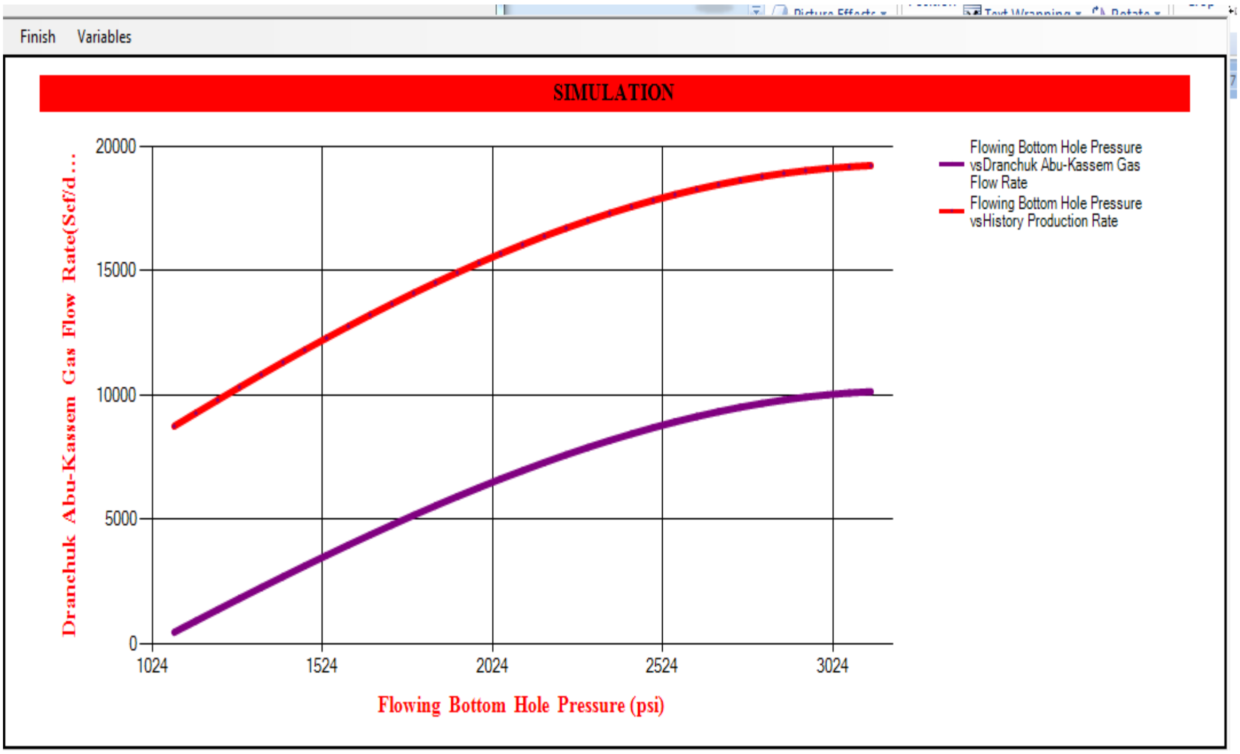

Figure 3: Model plot of BHP against Dranchuk-Abu-Kassem correlation

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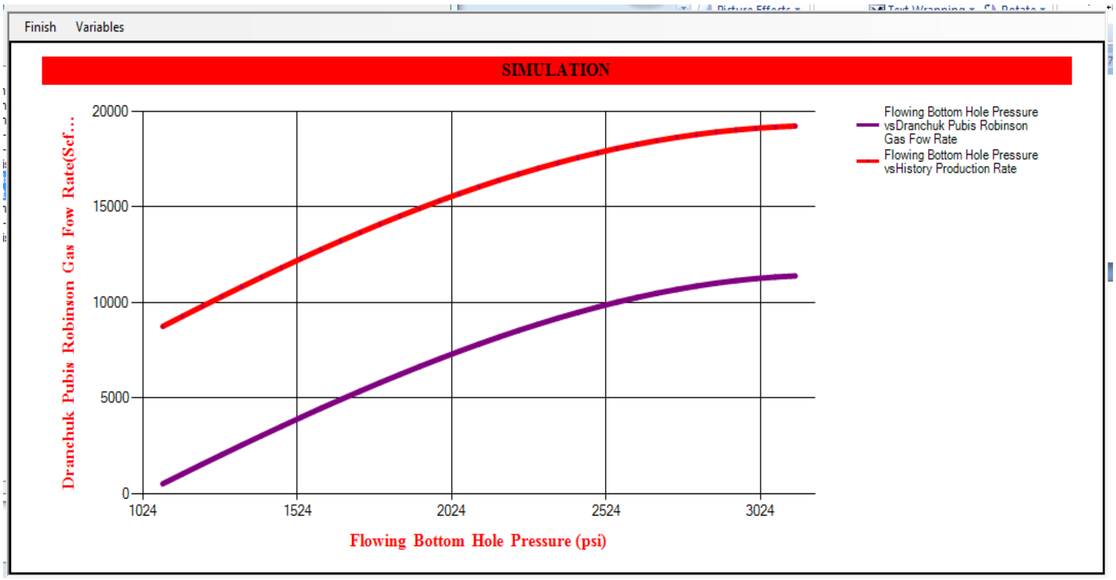


Figure 4: Model plot of BHP against Dranchuk-Purvis-Robbins correlation

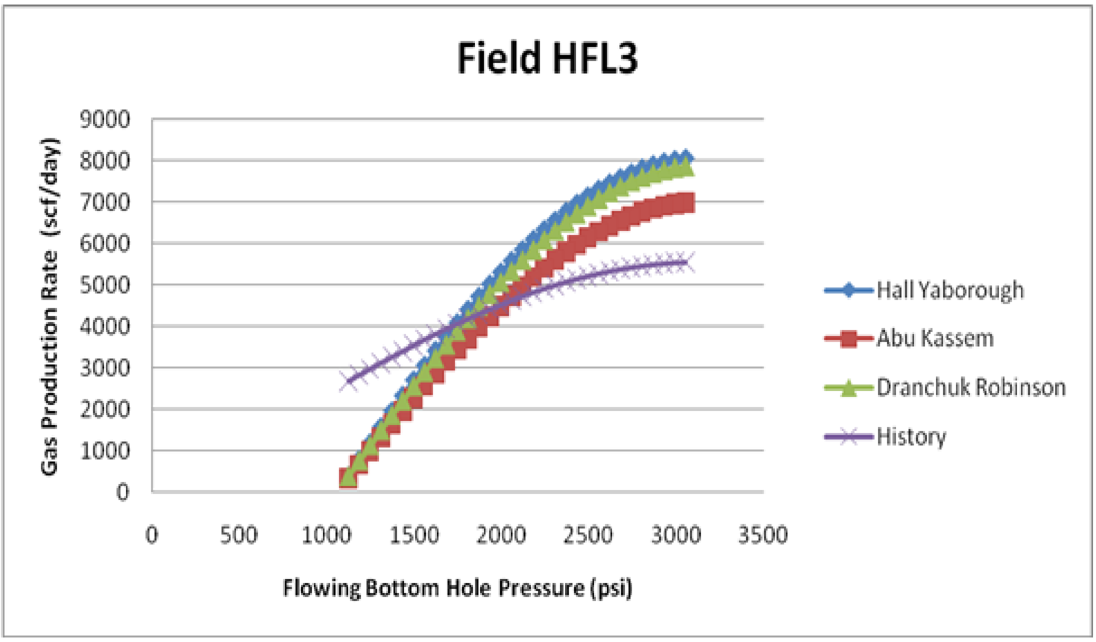
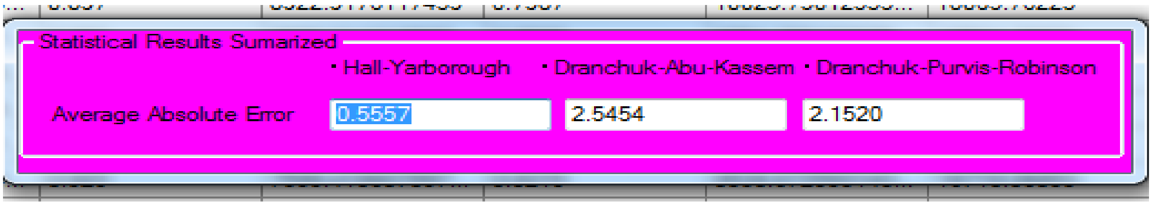


Figure 5: A plot of Gas production rate of the three correlations against BHP



Case 2: GAS FIELD 8

This is a case of a gas well that produced from 31st March, 1978 to 31 December, 1979. The initial flowing bottomhole pressure is 3020.36 and the flowing bottom hole pressure at 31st December, 1979 was 1047.88 psi. The gross thickness of the reservoir is 85 feet while the non-shale ratio of the pay zone is 0.78. The permeability of the formation is 170 md, drainage radius is 1247 feet, well bore radius is 0.396 feet, gas viscosity is 0.022, skin factor is 5, isothermal reservoir temperature is 230F and average reservoir pressure is 3082 psi. The data at a glance can be seen in Table 8.

Table 8: Input section having imported data of case 2

Import Run Plot

Parameter	Value	Unit
Gross Thickness	85	feet
Permeability	170	mD
Drainage Raduis	1247	feet
Wellbore Raduis	0.396	feet
Average Viscosity	0.022	cp
Skin Factor	5	
Temperaure	230	deg F
Average Reservoir Pressure	3082	psi
Net to Gross Ratio	0.67	
# of Steps	50	

Date (d/m/yr)	Bottom Hole Flowing Pressure (psi)	Cum. Gas Produced (MScf)
31/03/1978	3020.36	14300
30/04/1978	2958.72	166651
12/05/1978	2897.08	302532
31/05/1978	2835.44	302532
07/06/1978	2773.8	459113
30/06/1978	2712.16	459113
23/07/1978	2650.52	670464
31/07/1978	2588.88	670464
28/08/1978	2527.24	812115
31/08/1978	2465.6	812115

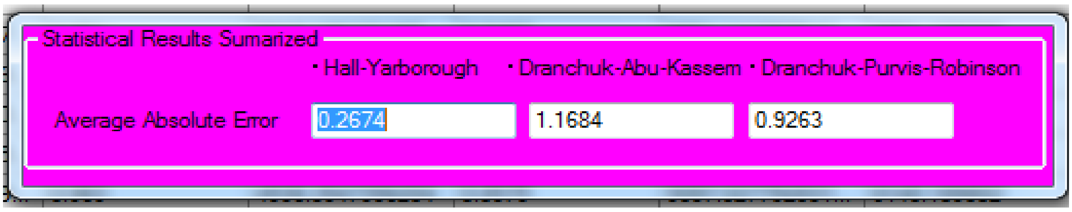
To run the production and statistical analysis, the menu item called Run is clicked. This displays the interface shown in Table 9. Here the user runs the analysis by clicking on the Run menu item. The Results in the table shows in array format the date, flowing bottom hole pressure, calculated z- factor for HALL-YARBOROUGH correlation and its corresponding gas production rate, calculated Z-factor for DRANCHUK-ABU-KASEM correlation and its corresponding gas production rate, calculated z-factor for DRANCHUK-PURVIS-ROBBINSON correlation and its corresponding gas production rate, the absolute average residual error. The plots and summarized statistical results are also displayed at the same time (Figures 6 – 9).

Table 9: Result section showing statistical analysis for case 2

Results

Back Run Plot

Date (d/m/yr)	Flowing Bottom Hole Pressure (psi)	Hall-Yarborough Z Factor	Hall-Yarborough Gas Flow Rate (scf/day)	Dranchuk-Abu-Kas Z Factor	Dranchuk-Abu-Kas Gas Flow Rate (scf/day)	Dranchuk-Purvis-R Z Factor	Dranchuk-Purvis-R Gas Flow Rate (scf/day)	History Gas Production Rate (Scf/day)	Hall-Yarborough AAE	Dranchuk-Abu-Kas AAE	Dranchuk-Purvis-R AAE
31/03/1978	3020.36	0.899027548144...	7001.289909662...	0.930	6090.443840400...	0.8279	6843.195326292...	7070.254099	0.009754131657...	0.160876659283...	0.033180226762...
30/04/1978	2958.72	0.895079538152...	6970.963910499...	0.932	6061.306816632...	0.8291	6810.457097340...	7053.658712	0.011723674886...	0.163719132752...	0.035710028149...
12/05/1978	2897.08	0.891205789702...	6925.743378620...	0.933	6018.121207382...	0.8305	6761.933940879...	7028.912544	0.014677827435...	0.167957955944...	0.039482580790...
31/05/1978	2835.44	0.887469065262...	6865.819670896...	0.935	5961.241020480...	0.8321	6698.023618517...	6996.120314	0.018624700156...	0.173601317236...	0.044505172340...
07/06/1978	2773.8	0.883876490844...	6791.394009417...	0.937	5891.024958554...	0.8338	6619.129166915...	6955.392136	0.023578559393...	0.180676059757...	0.050801693184...
30/06/1978	2712.16	0.880435405075...	6702.677942095...	0.939	5807.835741383...	0.8356	6525.658136385...	6906.843776	0.029559932224...	0.189228498110...	0.058413363318...
23/07/1978	2650.52	0.877153331335...	6599.893792301...	0.941	5712.039437762...	0.8376	6418.021840182...	6850.596898	0.036595804633...	0.199325910236...	0.067400060110...
31/07/1978	2588.88	0.874037943928...	6483.275090107...	0.943	5604.004813650...	0.8397	6296.634622079...	6786.779295	0.044719916723...	0.211058791110...	0.077842324088...
28/08/1978	2527.24	0.871097027868...	6353.066976765...	0.946	5484.102702378...	0.8419	6161.913148740...	6715.525119	0.053973164542...	0.224544010834...	0.089844169642...
31/08/1978	2465.6	0.868338431904...	6209.526573207...	0.949	5352.705401702...	0.8442	6014.275732250...	6636.975073	0.064404114086...	0.239929077899...	0.103536879330...
20/09/1978	2403.96	0.865770014564...	6052.923302567...	0.951	5210.186101468...	0.8467	5854.141687042...	6551.276596	0.076069646294...	0.257397810445...	0.119084051296...
30/09/1978	2342.32	0.863399583118...	5883.539156126...	0.954	5056.918344638...	0.8492	5681.930724312...	6458.584001	0.089035746037...	0.277177830614...	0.136688269246...
31/10/1978	2280.68	0.861234825612...	5701.668891660...	0.957	4893.275523531...	0.8519	5498.062385989...	6359.05859	0.103378462241...	0.299550487075...	0.156599933497...
30/11/1978	2219.04	0.859283236369...	5507.620153035...	0.960	4719.6304122577	0.8546	5302.955519390...	6252.868717	0.119185064918...	0.324864061550...	0.179129014779...
13/12/1978	2157.4	0.857552035670...	5301.713500159...	0.963	4536.3547356204	0.8575	5097.027792831...	6140.189802	0.136555437027...	0.353551509935...	0.204660843842...
31/12/1978	2095.76	0.856048084667...	5084.282338968...	0.967	4343.818774102...	0.8604	4880.695251800...	6021.204295	0.155603748042...	0.386154581516...	0.233677577549...
11/01/1979	2034.12	0.854777796954...	4855.672742309...	0.970	4142.391004069...	0.8634	4654.371914685...	5896.10158	0.176460466899...	0.423357083917...	0.266787804686...
31/01/1979	1972.48	0.853747048570...	4616.243154113...	0.974	3932.4377718998	0.8665	4418.469406628...	5765.077808	0.199274787287...	0.466031541349...	0.304768071801...
19/02/1979	1910.84	0.852961088551...	4366.363971406...	0.977	3714.323000452...	0.8697	4173.396629721...	5628.335673	0.224217561800...	0.515305931205...	0.348622278773...
28/02/1979	1849.2	0.852424452414...	4106.417001273...	0.981	3488.407926093...	0.8729	3919.559467520...	5486.084112	0.251484862893...	0.572661290832...	0.399668548840...
31/03/1979	1787.56	0.852140881135...	3836.794792903...	0.985	3255.050864342...	0.8763	3657.360521733...	5338.537942	0.281302327605...	0.640078193702...	0.459669592394...
30/04/1979	1725.92	0.852113248270...	3557.899848133...	0.988	3014.607002167...	0.8797	3387.198878839...	5185.917425	0.313930485861...	0.720263179005...	0.531034229314...
31/05/1979	1664.28	0.852343497776...	3270.143717406...	0.992	2767.428214931...	0.8831	3109.469904417...	5028.447774	0.349671337084...	0.817011096030...	0.617139875467...
30/06/1979	1602.64	0.852832594903...	2973.945991503...	0.996	2513.862906048...	0.8866	2824.565062975...	4866.358604	0.388876522774...	0.935809065916...	0.722870068665...
31/07/1979	1541	0.853580492145...	2669.733202728...	1.000	2254.255867461...	0.8902	2532.8717611922	4699.883327	0.431957557884...	1.084893465218...	0.855555184044...
31/08/1979	1479.36	0.854586111783...	2357.9376520905	1.004	1988.9481591629	0.8939	2234.773212542...	4529.258512	0.479398747975...	1.277212953557...	1.026719528666...
30/09/1979	1417.72	0.855847345918...	2038.996181415...	1.008	1718.277006090...	0.8975	1930.648321449...	4354.723215	0.531773644214...	1.534354588674...	1.2555755839207
31/10/1979	1356.08	0.857361074272...	1713.348910965...	1.013	1442.575710832...	0.9013	1620.871585204...	1930.64832144995	0.589766213079...	1.895181341706...	1.576711394118...
15/11/1979	1294.44	0.859123199319...	1381.437964016...	1.017	1162.173580728...	0.9051	1305.813012054...	3994.885658	0.654198372048...	2.4374259785666	2.059309120924...



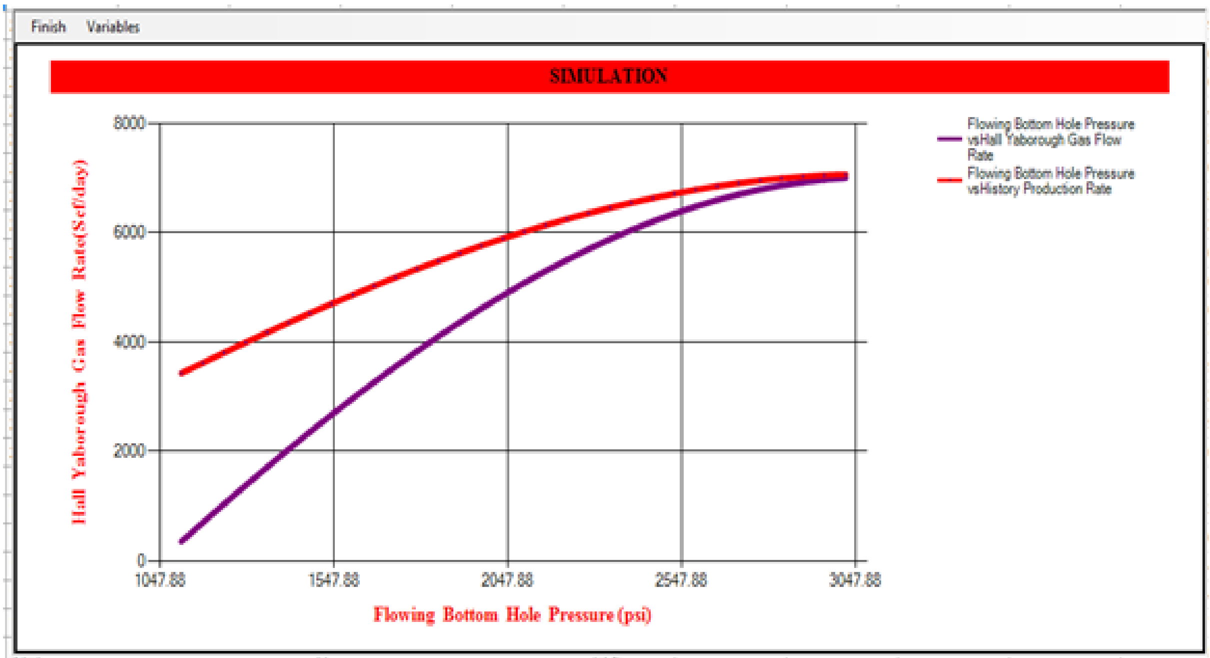


Figure 6: Model plot of Bhp vs Hall- Yarborough correlation case 2

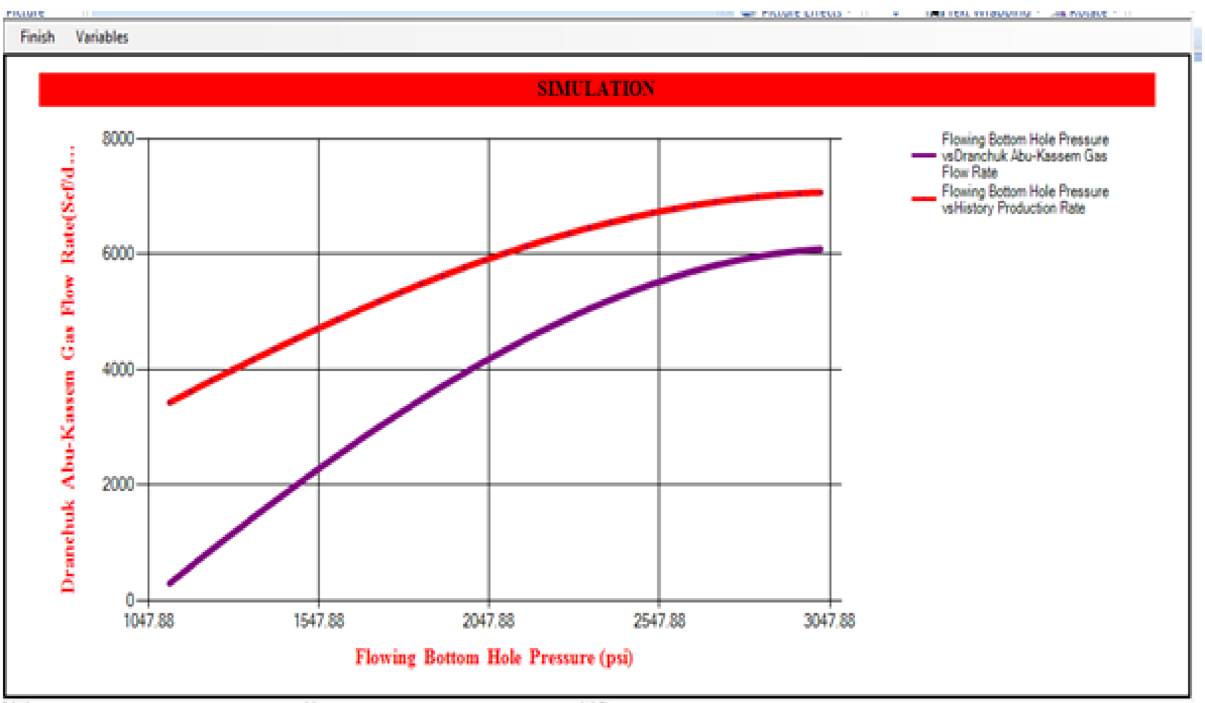


Figure 7: Model plot of Bhp vs Dranchuk- Abu -Kaseem correlation case 2

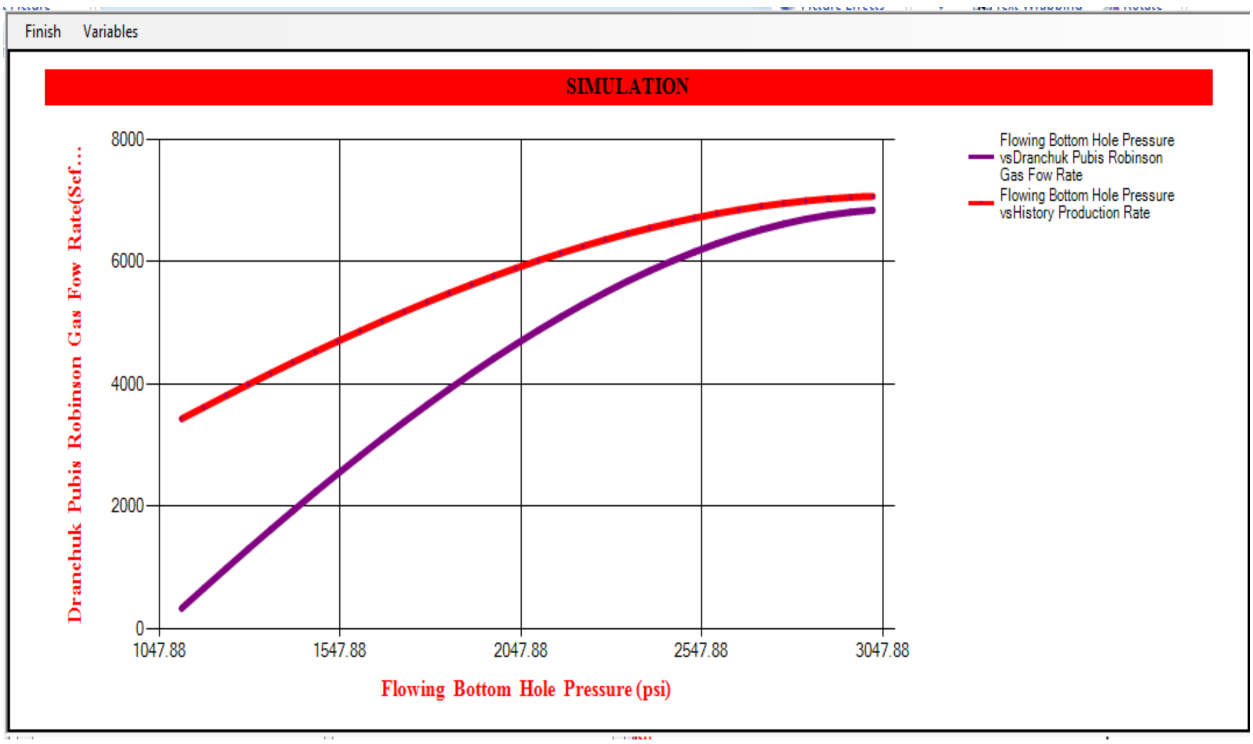


Figure 8: Plot of Bhp Vs Dranchuk-Pur-Robbinson correlation case 2

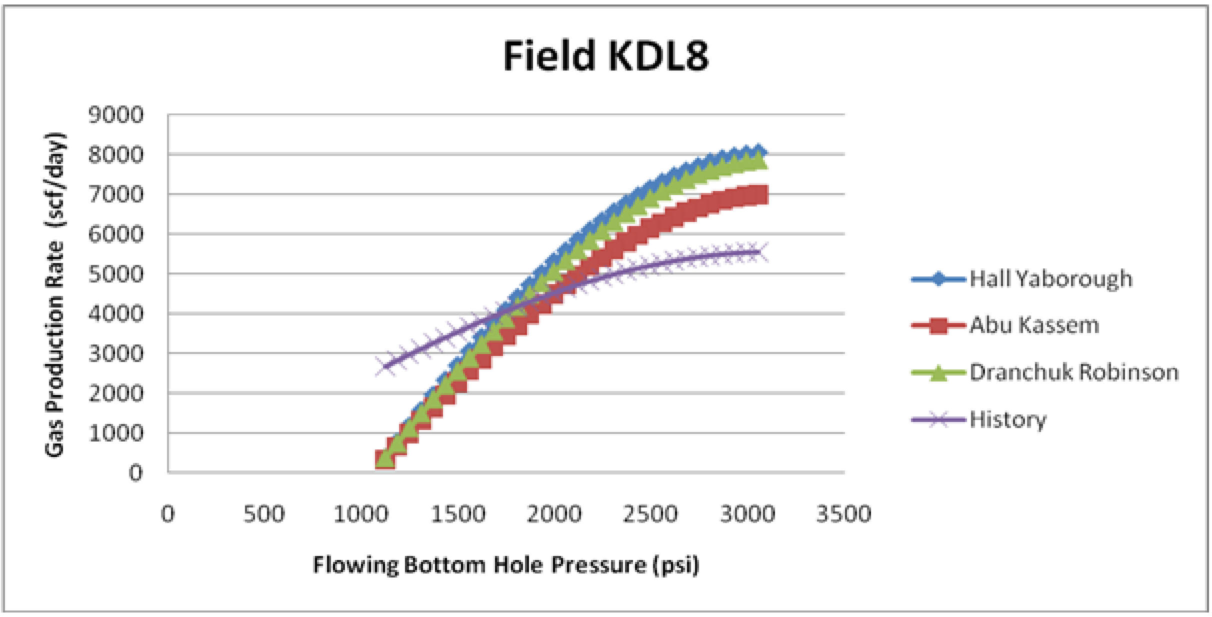


Figure 9: Excel plot of Bhp vs rate of three correlations case 2

Case 3: GAS FIELD 11

This is a case of a gas well that produced from 31st March, 1978 to 31 December 1979. The initial flowing bottom hole pressure is 3054.66 and the flowing bottom hole pressure at 31st December 1979 was 1059.78 psi. The gross thickness of the reservoir is 80 feet while the non-shale ratio of the pay zone is 0.78. The permeability of the formation is 170 md, drainage radius is 1359 feet, well bore radius is 0.425 feet, gas viscosity is 0.022, skin factor is 5, isothermal reservoir temperature is 212F and average reservoir pressure is 3117 psi. The data at a glance can be seen in Table 10.

To run the production and statistical analysis, the menu item called Run is clicked. This displays the interface shown in Table 11 below. Here the user runs the analysis by clicking on the Run menu item. The Results in the table shows in array format the date, flowing bottom hole pressure, calculated z-factor for HALL-YABOURGH correlation and its corresponding gas production rate, calculated z-factor for DRANCHUK-ABU-KASEM correlation and its corresponding gas production rate, calculated z-factor for DRANCHUK- PURVIS-ROBINSON correlation and its corresponding gas production rate, the absolute average residual error in that order. The plots and summarized statistical results are also displayed in Figures 11 - 14 at the same time.

Table 10: Input section having imported data of case 3

Import Run Plot

Parameter	Value	Unit
Gross Thickness	80	feet
Permeability	170	mD
Drainage Raduis	1490	feet
Wellbore Raduis	0.425	feet
Average Viscosity	0.022	cp
Skin Factor	5	
Temperaure	212	deg F
Average Reservoir Pressure	3117	psi
Net to Gross Ratio	0.78	
# of Steps	50	

Date (d/m/yr)	Bottom Hole Flowing Pressure (psi)	Cum. Gas Produced (MScf)
31/03/1978	3054.66	14300
30/04/1978	2992.32	166651
12/05/1978	2929.98	302532
31/05/1978	2867.64	302532
07/06/1978	2805.3	459113
30/06/1978	2742.96	459113
23/07/1978	2680.62	670464
31/07/1978	2618.28	670464
28/08/1978	2555.94	812115
31/08/1978	2493.6	812115

Table 11: Result section showing statistical analysis for case 3

Results

Back Run Plot

Date (d/m/yr)	Flowing Bottom Hole Pressure (psi)	Hall-Yarborough Z Factor	Hall-Yarborough Gas Flow Rate (scf/day)	Dranchuk-Abu-Kas Z Factor	Dranchuk-Abu-Kas Gas Flow Rate (scf/day)	Dranchuk-Purvis-R Z Factor	Dranchuk-Purvis-R Gas Flow Rate (scf/day)	History Gas Production Rate (Scf/day)	Hall-Yarborough AAE	Dranchuk-Abu-Kas AAE	Dranchuk-Purvis-R AAE
31/03/1978	3054.66	0.898147587593...	8066.843416273...	0.911	7001.152018346...	0.8109	7866.462941962...	5553.439871	0.452584993023...	0.206781990100...	0.294035971189...
30/04/1978	2992.32	0.893686764494...	8032.193864235...	0.913	6967.231798101...	0.8125	7828.350334945...	5540.486599	0.449727153150...	0.204779350026...	0.292253621523...
12/05/1978	2929.98	0.889283756162...	7980.495177815...	0.915	6916.978312383...	0.8142	7771.885744250...	5521.159736	0.445438197663...	0.201796003015...	0.2895984426837
31/05/1978	2867.64	0.885019397674...	7911.945516440...	0.917	6850.820342513...	0.8161	7697.550946644...	5495.533361	0.439704755973...	0.197828422547...	0.286067296066...
07/06/1978	2805.3	0.880901920485...	7826.754670298...	0.919	6769.193421837...	0.8182	7605.835305435...	5463.685901	0.432504505587...	0.192860129631...	0.281645515372...
30/06/1978	2742.96	0.876939914788...	7725.1447419508	0.922	6672.538701497...	0.8205	7497.234496064...	5425.700388	0.423805995450...	0.186861158739...	0.276306431278...
23/07/1978	2680.62	0.873142307807...	7607.350832644...	0.925	6561.301833357...	0.8229	7372.249250963...	5381.664709	0.413568336935...	0.179787053593...	0.270010477698...
31/07/1978	2618.28	0.869518334620...	7473.621724150...	0.927	6435.9318859972	0.8255	7231.384141569...	5331.671868	0.401740750214...	0.171577331388...	0.262703824935...
28/08/1978	2555.94	0.866077500596...	7324.220545286...	0.931	6296.880307227...	0.8282	7075.146412614...	5275.820234	0.388261961255...	0.162153324092...	0.254316458441...
31/08/1978	2493.6	0.862829534534...	7159.425410518...	0.934	6144.599943911...	0.8310	6904.044880799...	5214.213775	0.373059433206...	0.151415255249...	0.244759577171...
20/09/1978	2431.26	0.859784331621...	6979.530016331...	0.937	5979.544127131...	0.8340	6718.588906889	5146.962286	0.356048408459...	0.139238347176...	0.233922128987...
30/09/1978	2368.92	0.856951885454...	6784.844179365...	0.941	5802.165828126...	0.8371	6519.2874473327	5074.181587	0.337130739812...	0.125467672364...	0.221666228404...
31/10/1978	2306.58	0.854342208571...	6575.694298847...	0.944	5612.916888004...	0.8403	6306.6481887686	4995.993699	0.316193473215...	0.109911335106...	0.207821088245...
30/11/1978	2244.24	0.851965241230...	6352.423724646...	0.948	5412.247322106...	0.8436	6081.176766412...	4912.526979	0.293107142576...	0.092331394588...	0.192174941183...
13/12/1978	2181.9	0.849830748619...	6115.393011555...	0.952	5200.604698105...	0.8471	5843.376065287...	4823.916214	0.267723720782...	0.072431670156...	0.174464186438...
31/12/1978	2119.56	0.847948207175...	5864.980040246	0.956	4978.433585464...	0.8506	5593.745601645...	4730.302671	0.239874157779...	0.049841161924...	0.154358634112...
11/01/1979	2057.22	0.846326681357...	5601.579986003...	0.960	4746.175072807...	0.8542	5332.780980682...	4631.834081	0.209365423727...	0.024091187125...	0.131441156541...
31/01/1979	1994.88	0.844974692883...	5325.605117854...	0.964	4504.266348940...	0.8579	5060.973425776...	4528.664564	0.175976944768...	0.005416690126...	0.105179145787...
19/02/1979	1932.54	0.843900085204...	5037.484413306...	0.968	4253.1403427825	0.8617	4778.809373912...	4420.954489	0.139456292943...	0.039456526870...	0.074883691085...
28/02/1979	1870.2	0.843109886688...	4737.662977516...	0.973	3993.225417191...	0.8656	4486.7701316758	4308.870252	0.099513956197...	0.079045083067...	0.039649876070...
31/03/1979	1807.86	0.842610176597...	4426.601260421...	0.977	3724.945111631...	0.8695	4185.331586102...	4192.583985	0.055816955905...	0.125542487031...	0.001732813457...
30/04/1979	1745.52	0.842405958424...	4104.774070977...	0.981	3448.717928685...	0.8735	3874.963964815...	4072.273191	0.007981016609...	0.180807846628...	0.050918983499...
31/05/1979	1683.18	0.842501045359...	3772.669393971...	0.986	3164.957159665...	0.8776	3556.131640073...	3948.120295	0.044439097068...	0.247448257851...	0.110228949488...
30/06/1979	1620.84	0.842897962625...	3430.787021632...	0.991	2874.070744807...	0.8817	3229.292971694...	3820.312139	0.101961594549...	0.329233856160...	0.183018131983...
31/07/1979	1558.5	0.843597871058...	3079.637019008...	0.995	2576.461163947...	0.8859	2894.900184211...	3689.039403	0.165192701247...	0.431824183737...	0.274323523525...
31/08/1979	1496.16	0.844600515625...	2719.738048399...	1.000	2272.525353861...	0.8901	2553.399274001...	3554.495982	0.234845654018...	0.564117194979...	0.392064303531...
30/09/1979	1433.82	0.845904201620...	2351.615583651...	1.005	1962.654648886...	0.8944	2205.229942569...	3416.878318	0.311764902114...	0.740947303152...	0.549443099806...
31/10/1979	1371.48	0.847505800078...	1975.8000493117	1.010	1647.234741796...	0.8987	1850.825552580...	3276.384702	0.396957247387...	0.989021126659...	0.770228802726...
15/11/1979	1309.14	0.849400782652...	1592.824922367...	1.015	1326.645662219...	0.9031	1490.613103617...	3133.214569	0.491632351602...	1.361756916882...	1.101963656025...

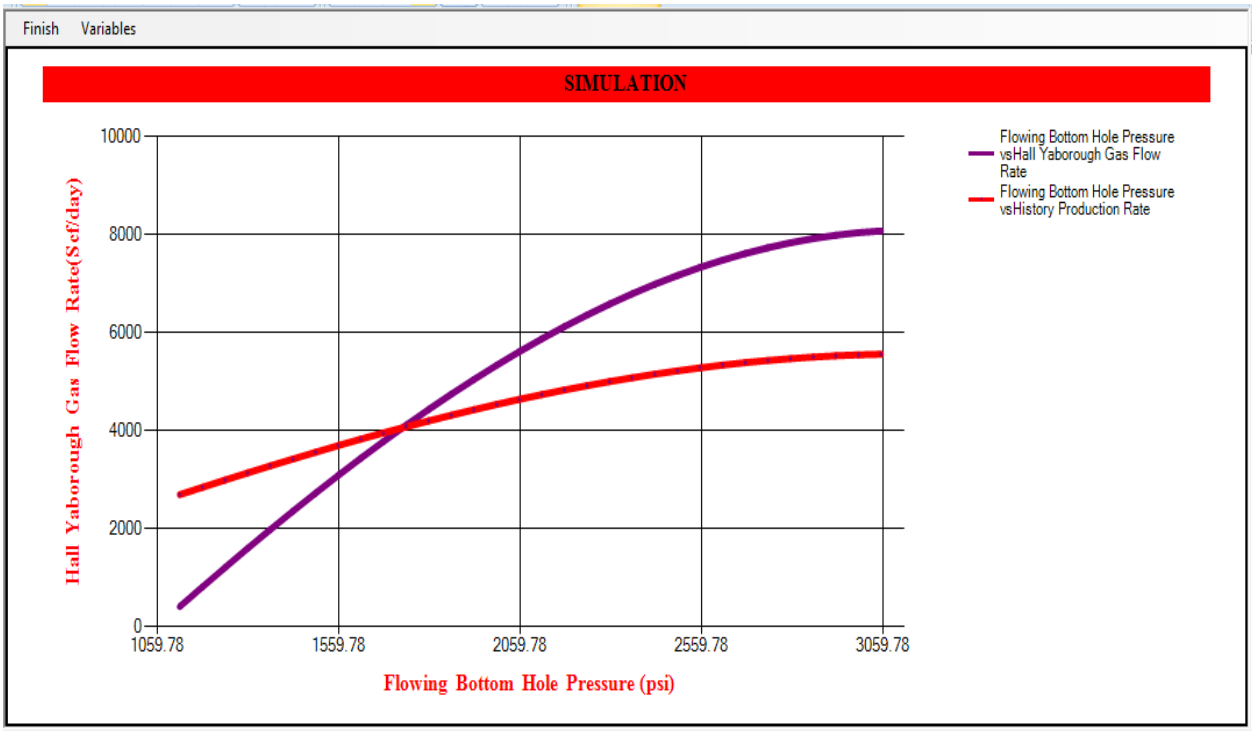


Figure 11: Model plot of Bhp vs Hall –Yarborough correlation (Rate) case 3

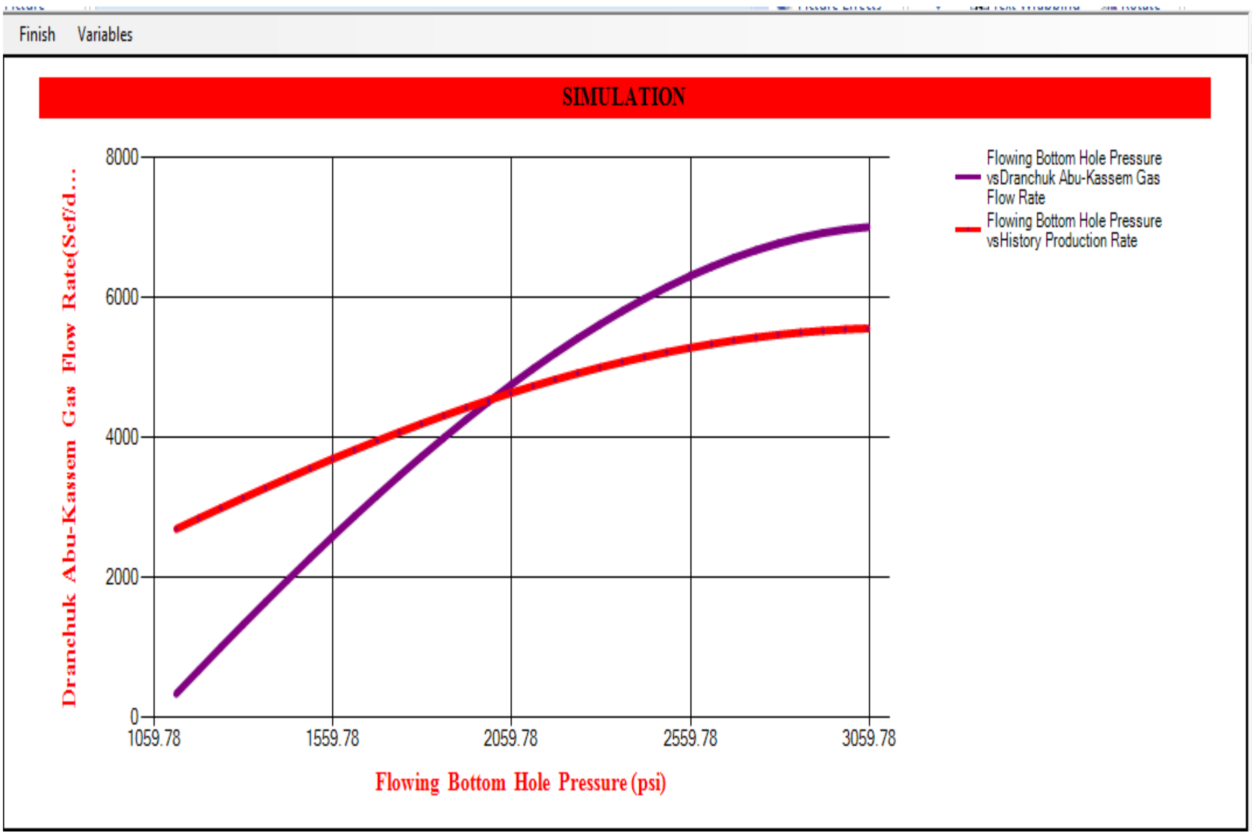


Figure 12: Model plot of bhp vs Dranchuk-Abu-Kaseem correlation (Rate) case 3

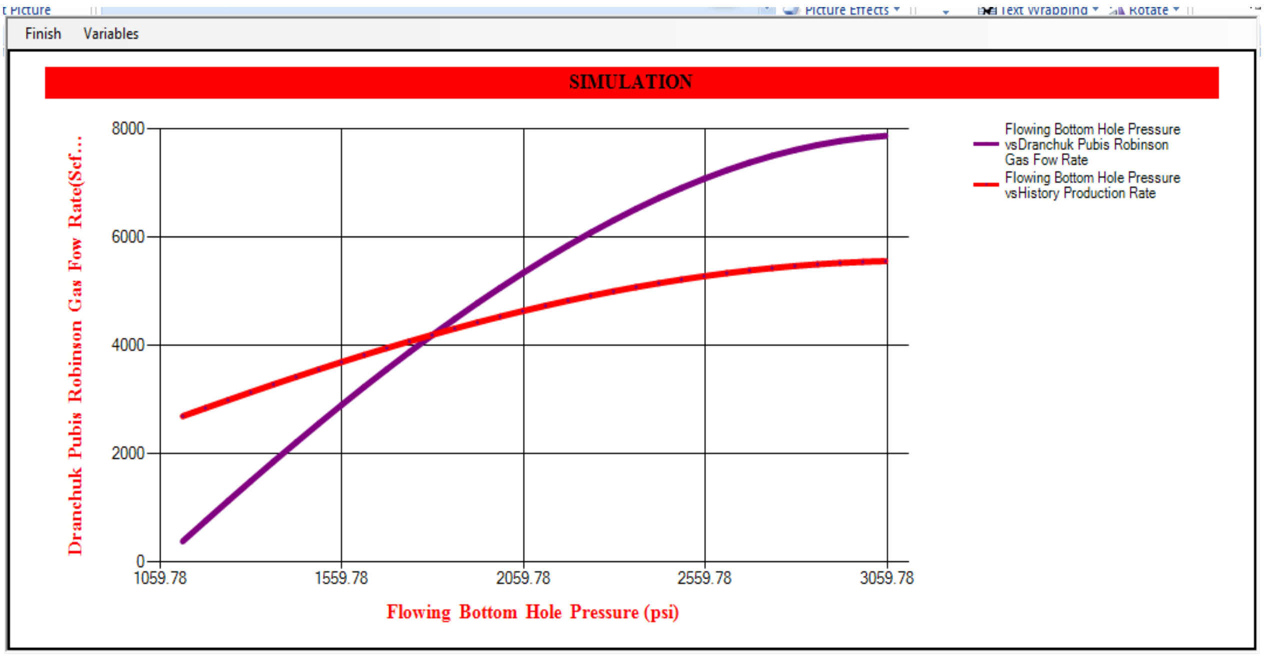


Figure 13: Model plot of bhp vs Dranchuk –Pur-Robbinson correlation (Rate) case 3

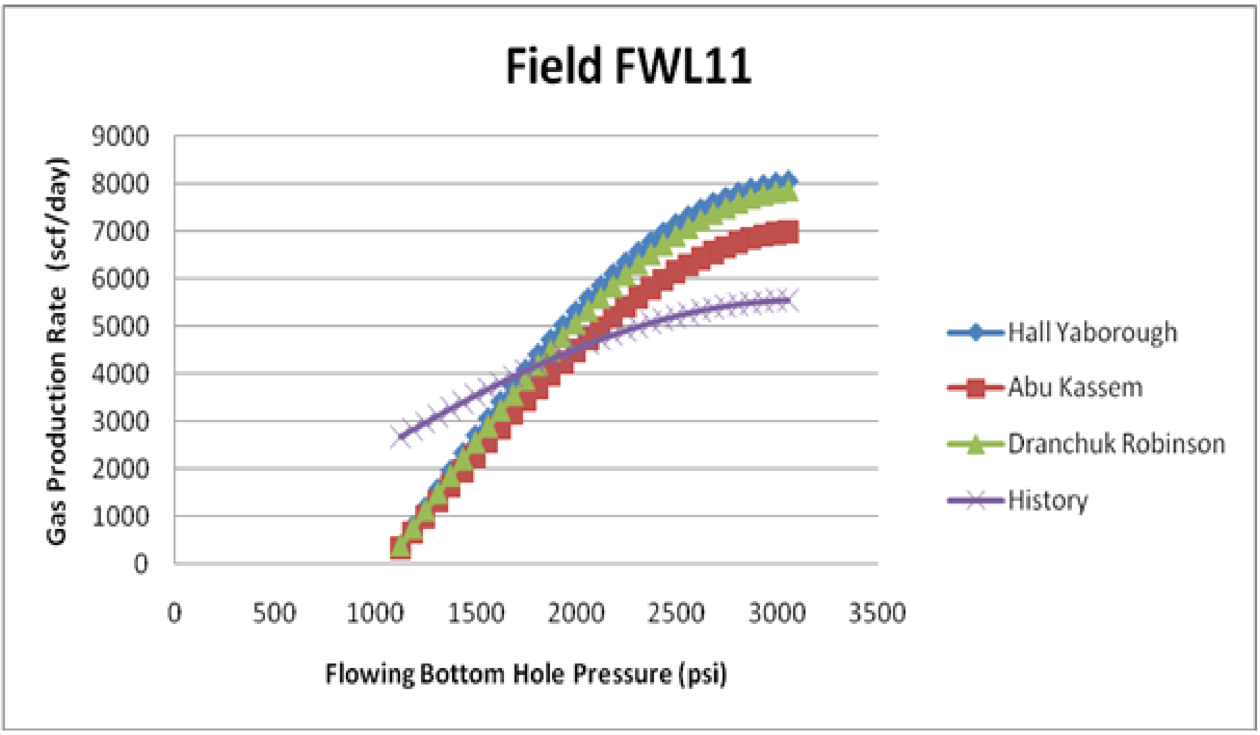
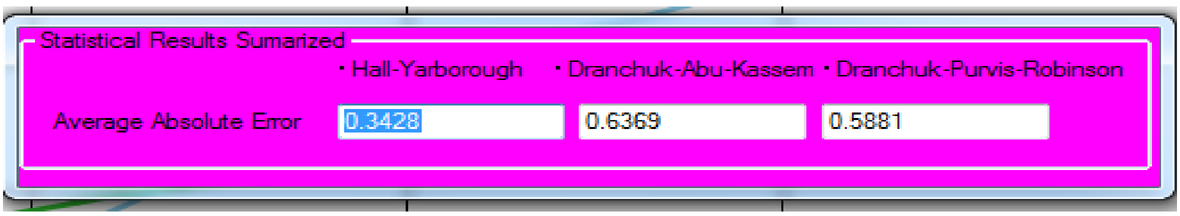


Figure 14: Excel plot of bhp vs gas rate of the three correlations case 3



CONCLUSION

Production data from about four gas fields were used for the study just to prove a point beyond all reasonable doubt. Since chart is not used as input parameter to develop computer model, z-factor mathematical models were used in the study. A computer application was developed to run the matching and ranking. To build a good comparative chart analysis, the results were moved to Microsoft Excel sheet and made plots as expressed in chapter four. Based on the study analysis performed using the Niger-Delta, the Hall and Yarborough is ranked first, followed by Dranchuk-purvis-Robbinson, while Dranchuk-Abu-Kaseem is recorded the last in the ranking model.

Based on this study, it is recommended that the Hall and Yarborough gas deviation model is the best model for Niger Delta. Consequently, this model should be used to model any gas or gas related system to avoid error in results and apparently reduce modelling time.

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