



Prediction of Pressure Profile During Multi-Phase Flow in Different Oil Well: A Comparative Study

Raya Satar*, Hussain Ali Baker

Department of petroleum, College of Engineering, University of Baghdad, Baghdad, Iraq

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Abstract

Multiphase flow is a very common phenomenon in oil wells. Several correlation models, either analytical or experimental, have been investigated by various studies to investigate this phenomenon. However, no single correlation model was found to produce good results in all flow conditions. 14 models available on the Prosper software were selected for the purpose of calculating the pressure gradient inside wells within a range of different flow conditions. The pressure gradient was calculated using Prosper software, then compared with the measured gradient based on the production log test (PLT) data. This study was conducted on 31 wells from five different oil fields (Kirkuk, Jambur, Bai-Hassan, Al-Ahdab, and Rumaila). It is worth noting that these wells have not been studied previously. The results indicated that the best correlation models were the Original Duns and Rose (DRO), Petroleum Experts 2 (PE2), and Hagedorn and Brown (HB), which outperformed the models of Hydro-3p and Mukherjee and Brill. The calculations also showed that the overall performance of all correlations is generally better in two-phase flow wells. Despite this, Fancher and Brown (FB), Hydro-3p, HB, and Orkiszewski (OR) models demonstrated an improved performance in three-phase flow wells as compared to the other correlation models.

Keywords: multi-phase flow models, pressure drop, prosper software.

التنبؤ بتوزيع الضغط أثناء الجريان متعدد الأطوار في آبار مختلفة المعمارية دراسة مقارنة

ريا سطار داود, حسين علي باقر*

قسم النفط, كلية الهندسة, جامعة بغداد, بغداد, العراق

الخلاصة

يعد التدفق متعدد الأطوار ظاهرة شائعة جداً في الآبار النفطية. تم اقتراح عدة علاقات من قبل باحثين مختلفين، بعضها تجريبي والآخر نماذج تحليلية. لم يتم تحديد أي علاقة حتى الآن ينتج عنها نتائج جيدة في جميع ظروف التدفق المختلفة. لذلك، تم اختيار 14 نموذجاً متوفراً في برنامج Prosper بغرض حساب تدرج الضغط داخل الآبار ضمن مجموعة من ظروف التدفق المختلفة. تم حساب تدرج الضغط باستخدام برنامج Prosper، ثم مقارنة التدرج المقاس بناءً على بيانات اختبار سجل الإنتاج (PLT). النتائج بينت أن: Duns and Rose (DRO)، و Petroleum Petroleum 2 (PE2)، و Hagedorn and Brown correlation (HB) هي الأفضل مقارنة ب Hydro-3p و Mukherjee و Brill. كما تبين من خلال الحسابات أن الأداء العام لجميع العلاقات أفضل بشكل عام في آبار التدفق ثنائية الطور. على الرغم من ذلك

*Email: reya.satar30@gmail.com

، فقد تحسن أداء Fancher و Brown (FB) و Hydro-3p HB و Orkiszewski (OR) في الآبار ،
ثلاثية التدفق مقارنة بباقي الارتباطات.

Introduction

Multi-phase flow is the simultaneous flow of more than one phase of materials. In the petroleum industry, multi-phase flow indicates the flow of gas, oil, and water. In vertical wells, the estimation of pressure drop is important for production optimization as well as cost effective design and completion of wells and surface facilities [1].

For upward vertical flow, the gas phase, due to its lower density and viscosity, tends to flow faster than the liquid phase. As a result, the multiphase flow behaviour is much complicated than single phase flow. Even though the geometry of pipeline is simple, the calculations are still complex [2]. Early correlations were observational and depended on experimental studies; the results were commonly acceptable for the conditions for which each model was developed. Thus, recent studies on the calculation of pressure drop of multi-phase flow depend on the modelling approach [3]. The principle assumption of the modelling approach is the presence of flow patterns [4]. However, none of the different multiphase flow correlations that were proposed by several investigators have been proven to provide good results for whole field conditions and parameters, such as tubing size, gas liquid ratio, water cut, etc. Thus, to avoid large errors, primarily caused by PVT characteristics of the fluid, several multiphase correlations may be used in various ranges of parameters [5].

Flow pattern is among the elements that provide most of the aid required to determine the quality of multiphase flow. However, its analysis is not as easy as that of the laminar or turbulent flow types in a single phase flow. Slug flow, bubbly flow, churn flow, annular flow, etc. are the types of flow patterns which may be found in a tubing string [6].

Several correlations were suggested by different researchers, some of which were experimental and others were models. No correlation has yet been proved to yield good results in all different flow conditions. The main goal of this study is to suggest a proper vertical lift model to be utilized in producing wells at different flow conditions in different Iraqi oil fields.

Materials and Methods

Prosper software was used to model the flow behaviour in the wells under study. Prosper makes a model for each component that contributes to the overall performance of the producing well system, then allows to verify each model subsystem by performance matching.

The subsequent strategy that was utilized in this study consists of selection of system model and input of Pressure Volume Temperature (PVT) data, equipment data reservoir data, well test data, and flowing pressure data. Then pressure drop along the flow path is determined using the available models in the Prosper software which are illustrated in Table-1.

Table 1- Available correlations in Prosper [7].

Correlation	Category	Slip considered?	Flow regime considered?
Fancher & Brown (FB)	Empirical	No	No
Gray (GRE modified by Petroleum experts)	Empirical	Yes	No
Hagedorn & Brown (HB)	Empirical	Yes	No
Duns & Ros original and modified (DRO), (DRM)	Empirical	Yes	Yes
Orkiszewski (OR)	Empirical	Yes	Yes
Beggs & Brill (BB)	Empirical	Yes	Yes
Mukherjee & Brill (MB)	Empirical	Yes	Yes
Petroleum Experts (1,2,3) (PE 1, 2, 3)	Empirical	Yes	Yes

Petroleum Experts (4,5) (PE 4, 5)	Mechanistic	Yes	Yes
Hydro 3-Phase (Hydro-3p)	Mechanistic	Yes	Yes

This work required field data obtained from different Iraqi oil fields. The ranges of PVT data and reservoir data along with wells description are shown in Table-2.

Well K-218 (Kirkuk oil field), wells BH-102, BH-49 and BH-81 (Bai-Hassan oil field), and wells JA-31, JA-44 and JA-58 (Jambour oil field) were studied. All of these wells are located in the northern Iraqi province of Kirkuk. In addition, the study included wells R-600, R-661, Ru-020, Ru-154, Ru-233, Ru-298, Ru-416, Ru-421, Ru-427, Ru-473 and Ru-437, which belong to Rumaila oil field located in the southern Iraqi province of Basra. In addition, ten wells were studied from Al-Ahdab oil field, located in central Iraq. These wells are well AD173H, AD112H, AD151H, AD410H, AD433H, AD2171H, ADM104H, ADMA3H, ADR57 and ADRu172H.

Table 2- The ranges of PVT data

Property	Data range
PVT data	
Bubble point pressure(psig)	1603 to 4816
Solution GOR (scf/STB)	500 to 2132
Oil density (API)	21 to 39.6
Reservoir data	
Reservoir pressure (psig)	1685.7 to 5623.48
Water cut (%)	0 to 70
Productivity index (PI) ((STB/day/psi)	0.65 to 2000
Reservoir temperature (F)	130 to 220
Test data	
Liquid rate (STB)	890 to 7200
Wellhead pressure (psig)	152 to 2400
Tubing size (in)	2.44 to 3.833

Results and discussion

1-Pressure gradient calculation and flow regimes determination

The pressure for each well was calculated and matched with the measured pressures available for each well by the Prosper software. A sample of these calculations is shown in Figures-1 through 4. The actual values are shown in the figures as a blue square.

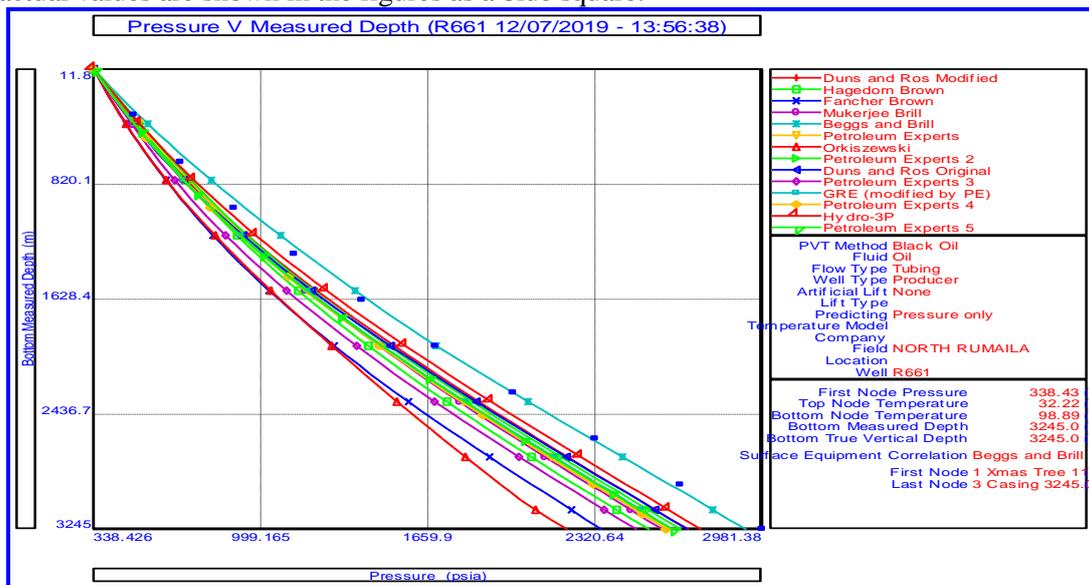


Figure 1- Pressure gradient calculations for well R-661

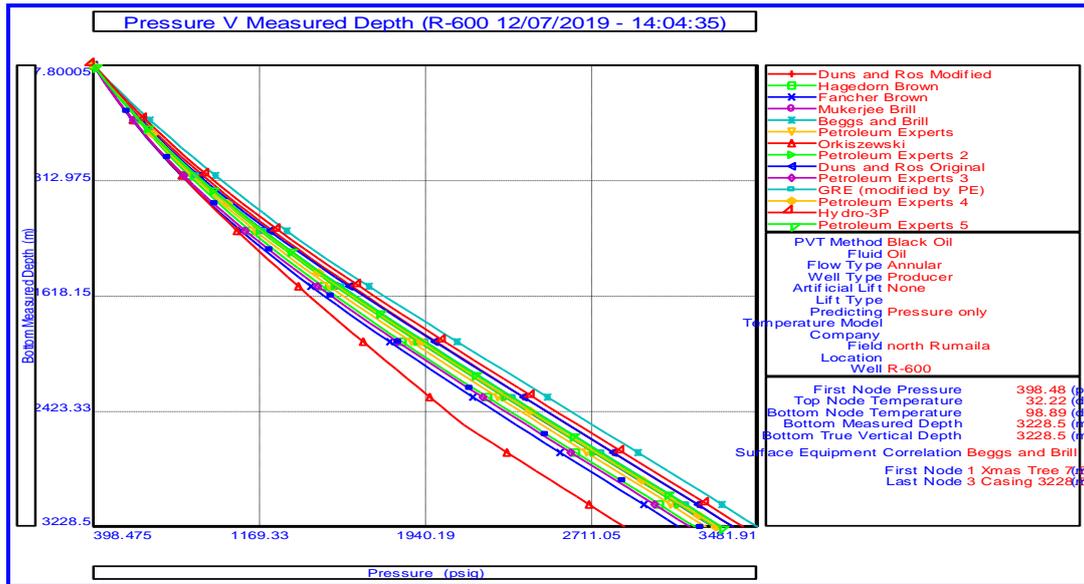


Figure 2- Pressure gradient calculations for well R-600

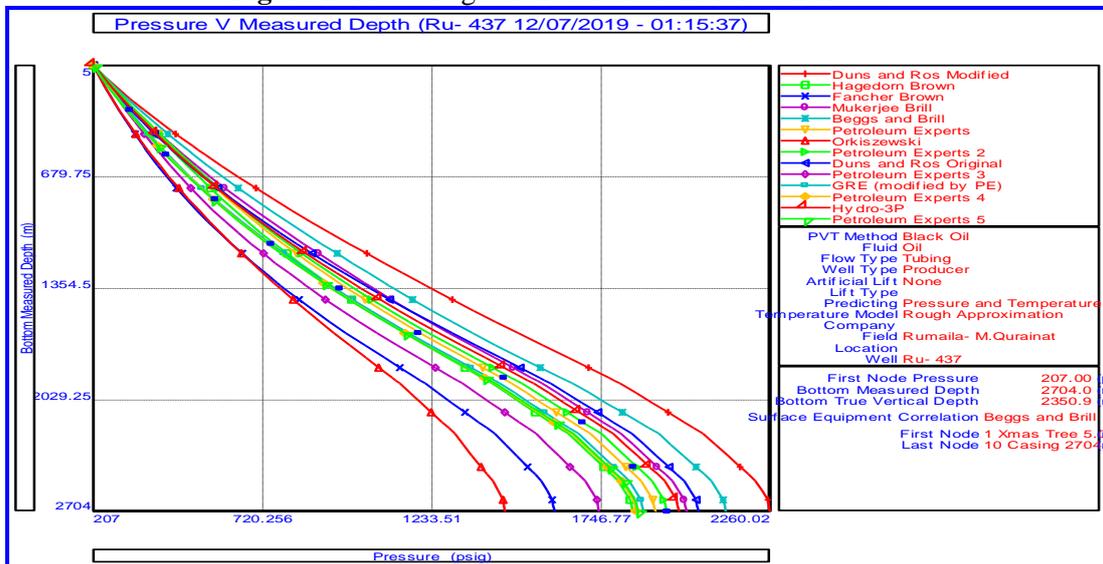


Figure 3- Pressure gradient calculations for well Ru-437

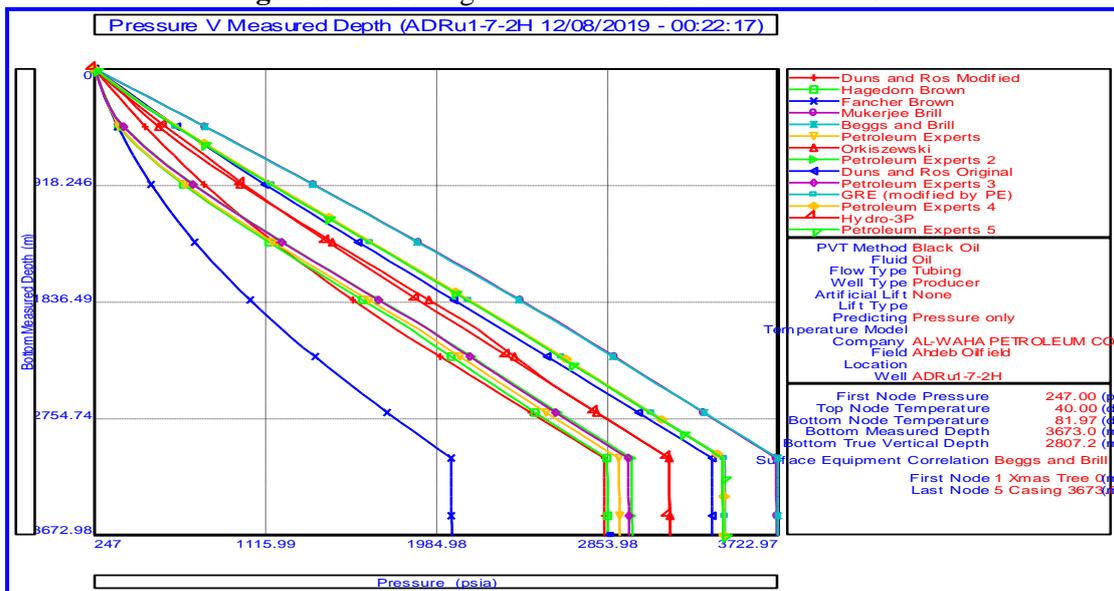


Figure 4- Pressure gradient calculations for well ADRU172H

Well R661 is a vertical well with a two-phase nature of flow (only oil and gas flow). It was observed that the pressure values calculated using all correlations were under the predicted values along the path of flow. Beggs and Brill correlation (BB) predicted that the pressure for 960 m from the bottom hole of the well over than the measured value while the rest of flow path pressure prediction by this correlation were under prediction. The most efficient correlation model for this well was BB which resulted in good match for most of flow paths. FB and OR correlations did not show as high efficiency as the other correlations. In this well, pressure values of the reservoir and the bottom hole were above those of bubble point. Therefore, we expect liquid flowing in the first 320 m from the bottom hole, whereas after this depth the pressure of flowing become lower than that of the bubble point, depending on production test data. Depending on BB, as the best correlation model, the predicted flow regimes was represented by liquid flow from the bottom hole up to 3176 m. The pressure at this depth was equal to 2850 psig, which is below the bubble point pressure. Therefore, the transition flow began at this depth up to 3041 m. At this point, the flow regime changed from a transition to a distributed flow, and the flowing pressure at which the flow regime changed was equal to 2786 psig. Then, the flow pressure was reduced to 1782 psig at 1980 m, where the intermittent flow began and continues to the wellhead.

Well R600 is a three-phase vertical flow well. Most of the correlations showed predicted pressure values higher than the measured values for the entire flow path. Pressure values calculated by FB, OR, and PE3 were below the predicted values and, again, for the entire flow path. It was observed that the predicted pressure by HB was below the measured value for 960 m from the bottom of the well, but the value of the remaining of the flow path was over the predicted one. The same observation applies to PE1. In addition, in this well, PE3 was the most efficient correlation model for most of the flow path. The flow regimes predicted by this correlation were liquid from bottom hole to 2850 m, whereas the pressure at this depth was equal to 2765 psig, and the bubbles of gas began to be released from oil. Bubble flow continued to 2177 m, where slug flow began at 2051 psig and continued to the wellhead. The least accurate correlation model was BB.

Well 437 is a two-phase deviated well with 84° inclination at the bottom hole. FB, GRE, OR, PE3, PE4 and PE5 models showed predicted pressure values that are lower than the measured value for the entire flow path. While BB, DRM, DRO, and MB correlations showed calculated pressure values that were higher than the predicted values. HB, PE, and PE2 showed predicted pressure values lower than the measured values at the beginning of the runoff. After that, the calculated were greater than the measured pressure values. The most accurate correlation model was GRE, while DRM was the least accurate. The flow regime predicted based on the most accurate correlation models was the slug flow from the bottom to the head of the well, as a result of the fact that the measured flowing pressure at the bottom hole was lower than the bubble pressure. In addition, the predicted pressure was lower than the measured pressure and, therefore, the flow regime began and ended with slug flow.

Well ADRU172H is a horizontal three-phase flow well with 42% water cut. All correlations showed expected pressure values higher than the measured value, except HB (the most accurate correlation model to calculate the pressure in this well), DRM, and FB, where the calculated pressure was lower than the measured value. The least accurate correlation model was BB. To determine the flow regime, HB correlation model cannot be adopted because the flow regimes was not considered in this correlation. Instead, the flow regimes predicted by DRM should be discussed because it is the second-best correlation model to calculate the pressure in this well. As a result of the fact that the pressure in the bottom of the well is greater than the pressure of the bubble, we expect liquids to flow alone at the beginning of the flow path. This was expected by using DRM model from the bottom to 3032 m, where the bubble flow began. The pressure causing flow regime change was equal to 2804 psig. Bubble\slug flow began when the pressure of flow was equal to 2616 psig at 2780 m. Then, this flow regime was ended at 2048 m where the plug flow began. The pressure causing this change was equal to 1778 psig. At 758 m, plug flow was changed to heading flow at a flowing pressure of 701 psig, and continued to the wellhead.

As shown in the previous figures, there is a convergence between the results of correlation in most wells. The slight difference between the correlations is due to the convergence of the liquid holdup estimation. On the other hand, a similar flow map is used by PE1, PE2, PE3 and DRM correlation models.

2- Pressure gradient validation

The average percentage error values for each correlation to predict the bottom hole pressure are shown in Figure-5. Each of the absolute average error values as well as the average error values for 14 flow correlation models are shown. This figure shows that the original models of DRO, HB, GRE, which were modified by petroleum experts, as well as PE2 and FB models, were the best fit multi-phase flow correlations in the range of data used in this study, while BB, Hydro-3phase and MB correlation had the highest percentage error.

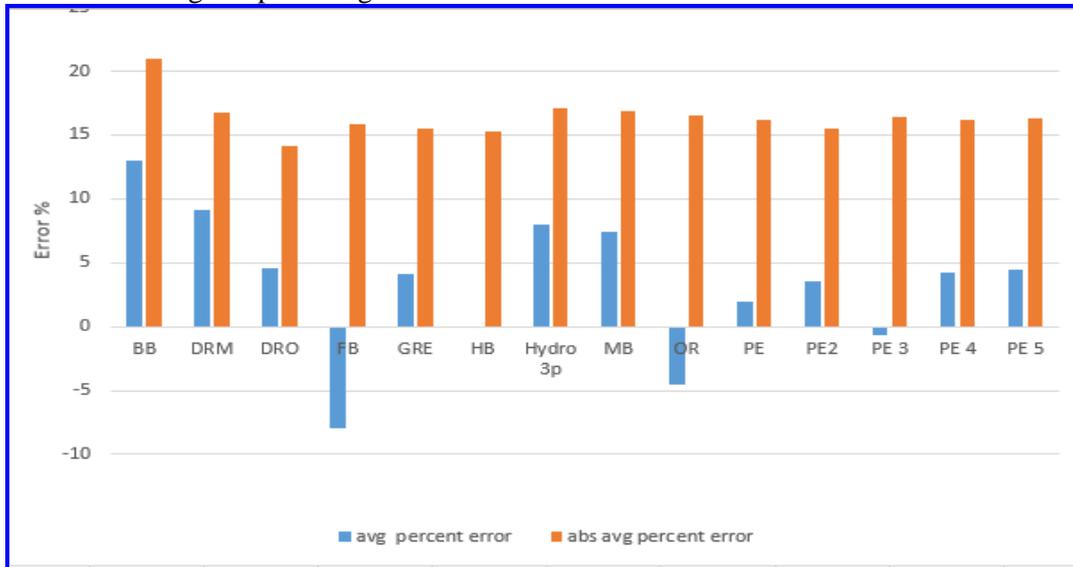


Figure 5-Average percentage error for each correlation

BB is mainly a correlation for pipelines that was developed depending on gas-water data in horizontal and slanted pipes [7]. In spite of that, it provided very good results in some wells. As shown in Figure-5, FB provided a negative percentage error as a result of the lowest pressure drop calculated by this correlation for all tests. FB should always predict pressures lower than the measured values, as stated by petroleum experts [8]. Nevertheless, the results showed that the drop of the predicted pressure value shown by the use of FB may be too high or too low compared to the measured values. However, as compared to the other correlations, FB always predicts low pressure. The same observations about FB correlation model were made by Fevang *et al.* [7].

3- Comparison of the performance of correlations in two and three phase flow wells

It was found through our study that the performance of all correlations becomes more efficient in the two-phase flow wells, while their efficiency is clearly reduced in three-phase flow wells, as shown in Figure-6. Despite this, some correlation models performed better overall in the three phase flowing wells as compared to the other relationships. This applies to FB, Hydrp-3p, HB, and OR.

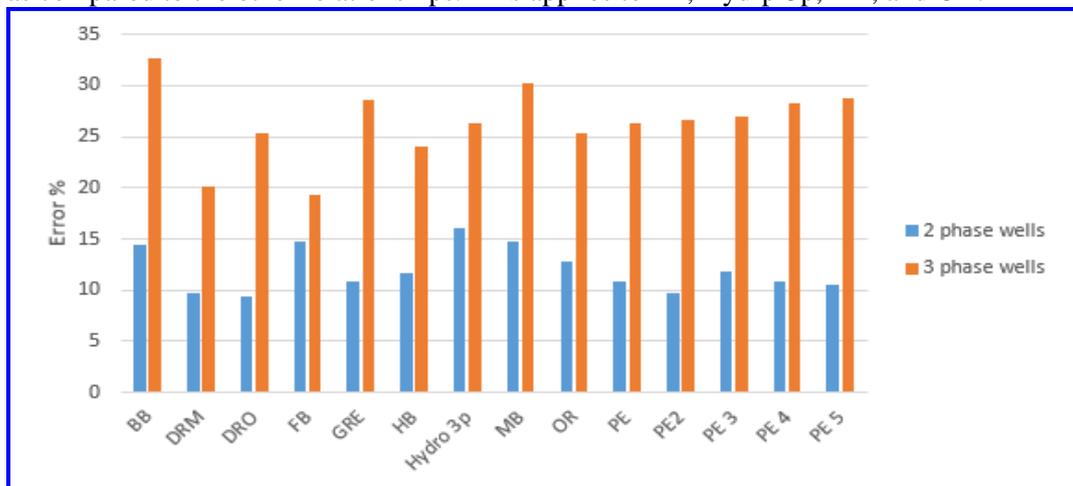


Figure 6- Average of absolute error for two and three-phases flow wells

It was observed that the correlation models with highest percentage of increase in error, i.e., those most affected by the three-phase flow, were PE2, PE5, and DRO, while FB model was the least affected.

Conclusion

- 1- The most accurate correlation model to calculate pressure within the data used in this study is DRO, while the least accurate one is BB relationship.
- 2- All the correlation models provided better results when used in two-phase flow wells than in three-phase wells.
- 3- In three-phase flow wells, FB and DRM correlations were used to calculate pressure gradient and performed better than BB and MB correlations.
- 4- In two-phase flow wells, DRO and DRM were used to calculate pressure gradient and performed better than Hydro-3p and MB correlations.
- 5- FB, Hydro-3p, HB and OR correlation models showed better performance in the multi-phase flow wells compared to the other correlations.
- 6- BB correlation models could be used for calculating pressure gradient.
- 7- In general, all correlation models tend to over-predict the flowing pressure when applied in three-phase flow wells. As the water cut increases, this over prediction also increases.

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