Software for Evaluating IPR Composite in Grouped Subsaturated Reservoirs

Eduardo Mascarenhas*. Oseias Alves Pessoa**

**Petroleum Engineering Department, Santa Catarina State University, Brazil (Tel: +55 11 95407-4410; e-mail: edumasc@hotmail.com).*
***Petroleum Engineering Department, Santa Catarina State University, Brazil (e-mail:oseias.pessoa@udesc.br)*

Abstract: The Inflow Performance Relationship (IPR) is widely used by the industry to predict well performance and, therefore, optimise production. This work aims to present a simple and objective approach for the initial IPR composite modeling of grouped subsaturated reservoirs within a production well. Unlike other computational implementations for the composite IPR calculation that do not consider the phase change of liquid hydrocarbons in the calculation of the IPR (Guo, 2007), the presented model will take into account the reservoir phase changes below the Bubble point (P_B), capturing the existing non-linearities and, therefore, providing more realistic results. The model presented could be used as a starting point for more comprehensive models, allowing the addition of complexities that better depict reservoirs, existing fluids and different subsurface equipment.

Keywords: IPR composite, commingled reservoirs, subsaturated reservoirs. reservoir grouping.

1. INTRODUCTION

Completion is a common terminology utilised in the Petroleum industry that describes the range of procedures and equipment necessary to bring a wellbore into safe and efficient production. Adequate completion allows the optimization of production, reduction of installation and operating costs - especially with regard to future interventions in the well - in addition to the increase of reserve recovery.

Intelligent completion improves traditional completion, as it is carried out in real time without any direct well interventions, providing monitoring, evaluation and management of the well production. Intelligent completion is implemented through the use of downhole sensors and downhole flow control valves, which are remotely controlled from the surface.

Since the first intelligent completion in the North Sea in 1997, this type of strategy has been much discussed in the Oil and Gas industry (Konopczyinski, 2008). Zhu (2006) describes the key technologies of Intelligent wells and emphasises the relevance of integrating control and monitoring systems under a single interactive model.

While completion can be implemented on a single geological formation within a well, it is also possible to develop this strategy on different formations within a well.

1. *Multilateral wells*

The implementation of multilateral wells must take into account not only technological aspects, but also the risk-return relationship obtained with the implementation. Oberkicher (2000) portrays two cases in the North Sea where multi-lateral completions were deployed. His study highlights that a case-by-case evaluation is required to ensure an adequate financial return of the project.

In technological terms, the exploration of multilateral formations within the same well has led to the development of new technologies for both the monitoring and control of completion procedures, a new research area entitled "intelligent multilateral wells".

Among the main advantages that can be mentioned through the adoption of intelligent completion in multilateral systems are: increase in total production, better understanding of target reservoirs; control and minimisation of produced water and gas; And, especially, the reduction of costs in surface equipment (Oberkicher, 2002).

2. *Modeling of Multilateral wells*

Given the scope of the subject, several researchers have presented models to predict the flow behavior of reservoirs and producer wells. The same models insert mathematical complexities by simulating the behavior of reservoirs throughout their productive life, changes in the physical state of the produced fluids and the operation of critical equipment, such as Inflow Control Valves (ICV). ICVs are commonly used in intelligent multilateral completions, as they control streamflows of formations, increase productivity and drainage in the reservoir, manage water production, and reduce production disruptions. Comprehensive field studies on the use of ICV valves in Petroleum operators demonstrate the complexity of their modeling and impacts on the Productivity Index (J) of wells (Mubarak, 2009).

3. Productivity Index (J)

The Productivity Index (J) is a parameter that allows estimating and predicting a well's productivity and production efficiency. The common practice to obtain the J value is to conduct a flow test in a well, where an initial stabilized flow (q_{oi}) is obtained for wellhead pressure (P_{wfi}).

For the calculation of J, there are some assumptions that must be made: flow is radial around the well; a single-phase liquid is flowing; permeability distribution in the formation is homogeneous; And, the formation is fully saturated with the given liquid. From these considerations and using a simplified version of Darcy's equation (Tacaks, 2005), it is possible to obtain the Productivity Index:

$$J = \frac{q_{oi}}{\left(\bar{P}_R - P_{wfi}\right)} \quad \text{(I)}$$

This equation indicates that the liquid inflow into a wellbore is directly proportional pressure drawdown.

Thus, given a reservoir, there are two options for increasing *J* of a well.

The first possibility would be to perform a hydraulic fracture in such a way as to increase the flow near the well and thus create a negative Skin effect. This practice is widely used in non-conventional shale reservoirs, given the very low permeability characteristics of these formations, being extensively studied by several authors in light of the current relevance of shale gas in the global energy industry (King 2002; US MIT 2011; Erbach 2014 US Energy 2017, US EPA 2017).

The second possibility would be to increase the drawdown factor ($\overline{P_R} - P_{wf}$) by reducing wellhead pressure (P_{wf}). Since J is held constant, a reduction of the wellhead pressure increases the drawdown in the same proportion as the increase in the production flow q_o. This reduction in wellhead pressure can be achieved by optimizing the pressure drop between the wellhead and the surface separation facility *or* through the implementation of artificial lift techniques.

The complexity of the total J evaluation increases when there is the need to evaluate J not only in one single formation, but for several formations along a drilled well.

It is also worth noting that many of the published works for the modeling of the Productivity Index and evaluation of recoverable reserves of multilayer reservoirs have focused on gas reservoirs (Kuppe, 2000; Cox, 2003).

This work aims to present a simplified approach for the initial modeling of IPR composite of subsaturated reservoir groups in a well in production. Unlike other computational implementations for the composite IPR calculation that do not consider the phase change of liquid hydrocarbons in the calculation of the IPR (Guo, 2007), the suggested model will take into account the phase changes of the reservoir below the Bubble point (P_B), presenting more realistic results.

This model can be used as a starting point for more detailed models, with the addition of complexities that improve the characterisation of reservoirs, existing fluids and different subsurface equipments. Thus, the broader model can be compared in the future with more sophisticated models proposed by other researchers that take into account cross-flow [1] between the lateral formations and the respective pressure variations (Guo, 2006) or well geometry oriented models (Salas, 1996). Particularly, there is a major interest in implementing the methodology presented in this article for the economic evaluation of multi-layer reservoirs (commingled reservoirs).

The work is organized as follows: in section 2, the mathematical model and the relevant considerations for the analysis of the problem are presented. In section 3, the software is described. In Section 4, results are provided for a specific dataset. Finally, in section 5, conclusions are drawn, with suggestions for future work.

2. MODELING FOR MULTI-LAYER WELLS

2.1 Initial Assumptions

The following characteristics will be assumed for the modeling of this work:

1. The pseudo-permanent regime prevails in all reservoirs;

2. Fluids in all reservoirs have similar properties;

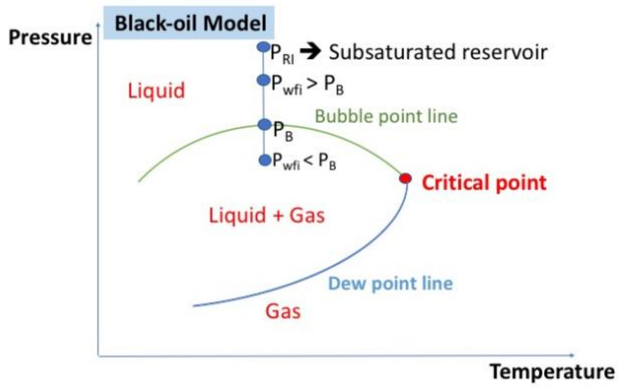
3. The pressure losses between the layers of reservoirs are negligible;

4. At $t = 0$, the reservoirs are subsaturated (Figure 1);

5. The relevant characteristics of the layers are known: Formation pressure (P_R, psi), Bubble Pressure (P_B, psi), Wellhead Test Pressure (P_{wfi}, psi) and Test Flow (q_{oi}, STB / d).

[1] Cross-flow happens when there is a flow of fluids from one layer to another layer.

Figure 1: P x T curve for Multi-layer reservoirs



2.2 Influx Performance Relationship (IPR)

The Influx Performance Ratio (IPR) characterises the ability of the formation to produce fluids, being dependent on a number of variables, such as: type of reservoir; Existing mechanism of production and reservoir pressure; Permeability and eventual damages or stimuli to formation; The properties of the fluids; And, the laminar or turbulent characteristics of the flow lines within the reservoir, etc.

Given a subsaturated reservoir (Figure 1), the IPR is calculated from the wellhead pressure collected during the formation flow test (P_{wfi}). The calculation will depend on the value of P_{wfi} in relation to the bubble pressure (P_B) of the formation:

Case 1: $P_{wfi} \geq P_B$

In this particular case, the following calculation steps must be carried out:

1. The Productivity index J is calculated using the well data flow test and equation (I);
2. Given J obtained from 1, one can calculate the flow rate at the bubble point pressure, $q_B = J \times (\bar{P}_R - P_B)$;
3. Considering Vogel's method for sub-saturated reservoirs, the IPR is obtained (Beggs, 1991):

$$q_o = q_B + \frac{J \times P_B}{1{,}8} \times \left[1 - 0{,}2 \times \left(\frac{P_{wf}}{P_B}\right) - 0{,}8 \times \left(\frac{P_{wf}}{P_B}\right)^2\right] \text{ (II);}$$

Case 2: $P_{wfi} < P_B$

In this particular case, the following calculation steps are implemented:

1. Since q_b is not known, J is calculated through the formula (Beggs, 1991):

$$J = \frac{q_{oi}}{\bar{P}_R - P_B + \frac{P_B}{1{,}8} \times \left[1 - 0{,}2 \times \left(\frac{P_{wfi}}{P_B}\right) - 0{,}8 \times \left(\frac{P_{wfi}}{P_B}\right)^2\right]} \text{ (III);}$$

2. Afterwards, the flow rate is calculated:

   $q_B = J \times (\bar{P}_R - P_B)$;
3. Similarly to the previous case, the IPR is obtained through the formula (II).

3. SOFTWARE DESCRIPTION

The software allows the evaluation of up to five subsaturated multilayer reservoirs in a vertical well, but it could be easily scaled to N sub-saturated multilayer reservoirs.

The software is designed exclusively for subsaturated reservoirs, having a trigger that alerts the user when the reservoir is non-subsaturated. In this case, the data for the reservoir in question has to be reviewed by the user or, excluded from the IPR group.

The decision point for the adequate implementation of the algorithm happens during the evaluation of P_{wfi}, which could be greater or lower than P_B. This categorisation will define if the calculation of J happens through formula (I) or formula (III).

For the purpose of calculating the IPR of each formation, we assume P_{wf} varying between the highest Pressure from the dataset formations (P_R) to the value zero.

The software will visually alert about cross-flow points in the formations. *Cross-flow* will always occur when the P_{wf} is greater than the P_R of the formation under analysis.

Composite IPR can be configured for multiple producing groups of formations. The end user may *or* may not take into account the P_{wf} data when cross-flow occurs.

It must be emphasised that the piece of software was implemented in Excel, as there is a major interest in evaluating the best production (i.e., economics) strategy for multi-layer wells.

4. RESULT DISCUSSION

In order to evaluate the software implementation, a dataset with five subsaturated reservoirs is used. In this dataset, all P_{wfi} are greater than P_B. However, as discussed in the previous section, it should be noted that the software was developed having the possibility to insert datasets with P_{wfi} lower than P_B. In such cases, where there are simultaneously formations with P_B higher and lower than P_{wfi}, the graphic analysis must be done manually.

It is worth noting that in the current analysis cross-flow data is avoided through the visual alert of the software.

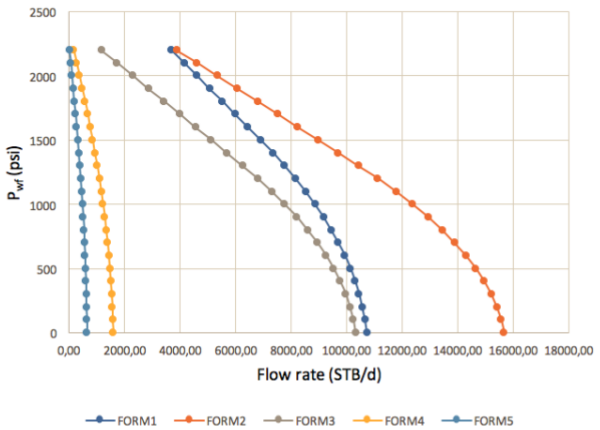
Table 1: Dataset of Formations within a Well

P_{wfi}>P_{bubble}	F1	F2	F3	F4	F5
Formation Pressure (psi)	3008	2735	2407	2357	2235
Bubble Pressure (psi)	1500	1300	1300	1800	1700
q_{oi} Test Rate (STB/d)	3200	3500	3510	227	173
P_{wfi} Test Pressure (psi)	2309	2253	1785	2135	1839

Firstly, a plot with all IPRs of the individual formations is presented. The curves show the production potential for each formation as a function of different drawdowns, which are related not only to the formation itself, but also to decisions of the production engineer regarding the design of the production system (i.e., the Tubing Performance Relationship, TPR, and the Choke Performance Relationship, CPR).

These curves are more adequate than those presented by GUO (2007), as the curves presented by GUO do not take into account liquid phase changes in the calculation. This omission results in linear plots, very different from the ones presented in Figure 2 and 3.

Figure 2: Individualised IPR in Multi-layer formations



For the composite IPR calculation, 3 groups of formations were randomly segmented:

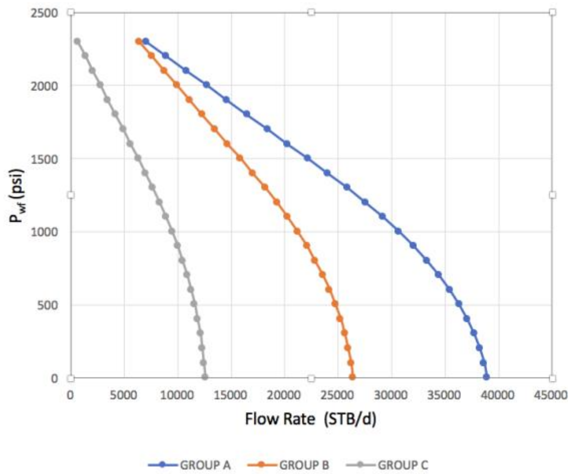
Group A: F1 + F2 + F3 + F4 + F5

Group B: F1 + F 2

Group C: F3 + F4 + F5

In the chart below, the IPR Composite is presented respecting the formation groups:

Figure 3: IPR Composite



Finally, it is must be emphasised that the great advantage of selecting group of reservoirs is the possibility of adopting a production strategy that evaluates *both* the technical complexity of multi-lateral completion *and* the increased financial return from simultaneous production regions (ie, engineering-financial evaluation of the project, as observed by Oberkicher in 2000).

5. CONCLUSIONS

This work presents an initial framework methodology for the modeling of IPR composite in grouped subsaturated reservoirs within a producing well. The analysis model could be used as a starting point for more detailed models, with the addition of complexities that improve the characterisation of reservoirs, existing fluids and different subsurface equipments.

As discussed, results are more realistic than previous methodologies, as the study takes into account phase change behaviour in reservoirs.

Finally, future work will develop functionalities to improve the user interface and the evaluation of data in real-time. For example, it will be possible to use the software considering N formation layers and there will be graphical automation of the software, allowing automatic data evaluation for cross-flow reservoirs, without user intervention. Further input complexities – reservoir characterisation, various fluids and different subsurface equipment – will be also added to the software.

REFERENCES

Beggs, H. D. (1991) *Production Optimization Using Nodal Analysis*. Oil & Gas Consultants International Inc., Tulsa, Oklahoma, USA.

Cox, S. A. et al. (2003) Reserve Analysis for Multilayered Tight Gas Reservoirs. Article presented at *SPE Eastern Regional/AAPG Eastern Section Joint Meeting*, Pittsburgh, Pennsylvania, USA.

Erbach, G (2014). Unconventional gas and oil in North America – The Impact of shale gas and tight oil on the US and Canadian economies and on global energy flows. *European Parliamentary Research Service*, Article available at: http://www.europarl.europa.eu/RegData/bibliotheque/briefing/2014/140815/LDM_BRI(2014)140815_REV1_EN.pdf , Access on: 15 March 2018.

Guo, B. et al. (2006) A Rigorous Composite-IPR Model for Multilateral Wells. SPE Annual Technical Conference & Exhibition, San Antonio, Texas, USA.

Guo, B. et al. *(2007) Petroleum Production Engineering – A Computer-Assisted Approach***.**, 1st. Edition, pp. 312, Elsevier Science & Technology Books.

King, G. E. (2012) Hydraulic Fracturing 101: What Every Representative, Environmentalist, Regulator, Reporter, Investor, University Researcher, Neighbor and Engineer Should Know About Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells. SPE 152596, article published at SPE Hydraulic Fracturing Technology Conference, Woodlands, Texas, USA.

Konopczynski, M. R. e Ajayi, A. A. (2008). Reservoir Surveillance, Production Optimisation and Smart Workflows for Smart Fields - a Guide for Developing and Implementing Reservoir Management Philosophies and Operating Guidelines in Next Generation Fields. Article published at Intelligent Energy Conference and Exhibition, Amsterdam, Holland.

Kuppe, F. et al. (2000) Material Balance for Multi-layered, Commingled, Tight Gas Reservoirs. Article published at SPE/CERI Gas Technology Symposium, Calgary, Alberta, Canada.

Mubarak, S. et al. (2009) Lessons Learned from 100 Intelligent Wells Equipped with Multiple Downhole Valves. Article presented at Saudi Arabia Section Technical Symposium, Alkhobar, Saudi Arabia.

Oberkicher, J. P. (2000) The Economic Viability of Multilateral Wells. Article published at IADC/SPE Drilling Conference, Louisiana, USA.

Oberkicher, J. P. et al. (2002) Intelligent Multilaterals: The Next Step in the Evolution of Well Construction. Article published at OTC 14253, offshore Technology Conference, Houston, Texas, USA.

Salas, J.R. et al. (1996) Multilateral Well Performance Prediction. Article published at Western Regional Meeting, Anchorage, Alaska, USA.

U.S. Energy. (2017) What is Shale gas? Available at: https://energy.gov/sites/prod/files/2013/04/f0/what_is_shale_gas.pdf , Access on: 15 March 2018

U.S. EIA. (2017) EIA Expects Natural Gas to Be the Largest Source of U.S. Electricity Generation this Summer, Available at: https://www.eia.gov/todayinenergy/detail.php?id=30832 , Access on 15 March 2018.

U.S. MIT. (2011) Future of Natural Gas – An Interdisciplinary MIT Study. Available at: http://energy.mit.edu/research/future-natural-gas/ , Access on 15 March 2018.

Takacs, G. (2005) *Gas Lift Manual*. PennWell Corporation. Tulsa, Oklahoma, USA.

Zarea, M. and Ding, Z. (2011) An Integrated Performance Model for Multilateral Wells Equipped with Inflow Control Valves. Article presented at SPE Europe/EAGE Annual Conference and Exhibition, Vienna, Austria.

Zhu, D. and Furui, K. (2006) Optimizing Oil and Gas Production by Intelligent Technology. Article presented at 2006 SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA.

