Simulator Development for Evaluation of Inflow Performance Relationship of Solution Gas Drive Reservoir

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Abstract— *This study evaluates the analysis of Inflow Performance Relationship (IPR) of a solution gas drive oil reservoir system (i.e. Saturated Reservoir, case; $P_r \leq P_b$) using an ad-hoc (simulator Ronald Obia Simulator (ROS)) designed for the purpose of this research work. The computer program (ROS) was developed in the cause of this study to analyze a 6-Test point Inflow performance Relationship problem to give solutions with higher degree of accuracy and precision instead of solving the system manually. IPR describes the behavior of the well's flowing pressure and production rate, which is an important tool in understanding the reservoir/well behavior and quantifying the production rate. The newly developed simulator is very easy and simple in terms of application. Fast and accurate results were produced after being compared to calculations and results from the manual solution method. From the results obtained, a plot of wellbore flowing pressure (P_{wf}) vs the simulated wellbore flowrate (Q_o) was carried out. The IPR plots obtained revealed that the plot was initially a straight line and then later deviated to a curve line. The straight line indicates a single phase system, whereas the curved line indicates a two-phase system (oil and gas). The point of deviation from the straight line indicates the bubble point pressure. Furthermore, it reveals that the point of deviation which is the bubble point pressure is 2000 psig. Finally, the application of the developed IPR simulator (ROS) was validated with PROSPER and proven to be very accurate and efficient in calculations involving Inflow Performance Relationship and also plotting of the corresponding IPR curves. Hence, the newly developed IPR simulator should be introduced to higher institutions and oil and gas firms to assist them on proffering solutions to problems involving IPR calculations and beyond.*

Index Terms—Bubble Point Pressure, Graphic User Interface (GUI), Inflow Performance Relationship (IPR), Productivity Index, Saturated Reservoir, Simulator, Wellbore Flowing Pressure.

1 Introduction

It is generally assumed that fluid inflow rate is proportional to the difference between wellbore pressure and reservoir pressure. This assumption leads to a linear relationship that is derived from Darcy's law for steady state flow of an incompressible, single phase fluid and is called productivity index (PI). However, this assumption is valid only above the bubble point pressure.

Vogel (1968), presented an empirical inflow performance relationship for solution gas drive reservoirs, based on computer simulation results and a wide range of rock and fluid properties. His famous dimensionless IPR was developed for flow of saturated oil from a solution-gas drive reservoir into well ignoring skin effects. After Vogel, several empirical relationships have been developed to predict the performance of oil wells in saturated reservoirs. However, these IPRs are empirical and have been developed for homogenous, solution-gas drive reservoirs and may not be applicable to other cases.

There are two major correlations to model the behavior of IPR and can be categorized as empirically-derived and analytically-derived correlations. The empirically-derived are those derived from field or simulation data. The analytically-derived are those from the basic principal of mass balance that describes multiphase flow within the reservoir. The limitations of empirically-derived correlations is in terms of issues in the ranges of data used in its generation and they are not functions of reservoir rock and fluid data that vary per reservoir. For the analytical approach, its limitation is in terms of difficulty in obtaining their data for its application.

One simple method of predicting a well's inflow performance is the calculation of a productivity index (PI). The PI is a ratio of fluid production rate (Q) in barrels per day (BPD) to the difference between the static bottomhole pressure (BHP_s) and the flowing bottomhole pressure (BHP_f).

The use of PROSPER (Production and Systems Performance Analysis Software) allows for efficient modelling of the well component of production systems; Ozdogan and Gutman (2008). PROSPER enables the creation of well models which form the link between subsurface and surface production system components.

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2 Design Methodolgy

2.1 Programming Tool

An ad-hoc computer simulator (ROS) is developed for the purpose of this project to solve Inflow Performance Relationship problems considering a solution gas drive oil reservoir system (case: Saturated reservoir i.e. $P_r < P_b$).
This simulator is developed using Java source codes written in Java programming language with the aid of a java virtual machine incorporated inside a Compiler called NetBeans Integrated Development Environment.
A 6-Test Point wellbore flowing pressure data gotten from a Niger Delta well is used for the analyses of the project work.

2.2 IPR Correlations

Many IPR correlations addressed the curvature of the inflow performance curves in case of solution gas drive oil reservoirs in which P_b is the initial reservoir pressure. Based on the literature survey, the most known IPR correlations can be subdivided into empirically and analytically derived correlations. Some of the most known empirical correlations are Vogel (1968), Fetkovich (1994), Kilns and Majcher (1992), Wiggins (2005), and Sukarno and Wisnogroho (1995). Some of the most known analytical correlations are Wiggins (1993) and Archer & Del Castillo (2003).

2.3 IPR Models

For the purpose of this work, three major models are used for the development of the IPR simulator and computation. The three models used are as follows:

Vogel Model

$$Q_o = Q_{omax}[1-0.2(P_{wf}/P_r) - 0.8(P_{wf}/P_r)^2] \quad (1)$$

Wiggins Model

$$Q_o = Q_{omax}[1-0.52(P_{wf}/P_r) - 0.48(P_{wf}/P_r)^2] \quad (2)$$

Fetkovich Model

$$Q_o = c\,(P_r^2 - P_{wf}^2)^n \quad (3)$$

Where;

Q_o = oil flowrate , STB/day
$(Q_o)_{max}$ = maximum oil flow rate at zero wellbore pressure, i.e., the AOF
P_r= current average reservoir pressure, psig
P_{wf} = wellbore pressure, psig
c= performance coefficient
n= reservoir exponent value
AOF= Absolute Open Flow

Assumptions for IPR models

i. Saturated Reservoir
ii. Fluid is slightly compressible
iii. Stabilized wellbore flowing pressure
iv. Homogenous reservoir
v. Reservoir exponent value does not change across the reservoir
vi. Constant density
vii. The reservoir system is isotropic
viii. No skin effect

2.4 Wellbore and Reservoir Data

A 6-test point wellbore flowing pressure data, a stabilized wellbore pressure, average reservoir pressure and a stabilized wellbore flowrate data obtained from a Niger Delta oil well, are being used for this project.

Also, the reservoir performance coefficient (C) and exponents (n) which are factors that accounts for reservoir data are used as well.

2.5 Simulator Design Steps

Step 1: Problem Definition

This is the most important step in the simulator development which is defining the problem to be solved.

Step 2: Project Planning

There are constraints involve in the simulator development which are:
Time and Resources. It took so much time to carry out this project. Especially the writing of the source code that gave birth to the simulator. Gathering the required resources was also of primary importance. This involved downloading several Production and Reservoir Engineering books, getting a high speed Laptop, acquiring the latest Microsoft excel Application Package, downloading the latest NetBeans Integrated Development Environment, JFreeChart software Library and other Java Programming language modules.

Step 3: Model Definition

Here, the three required mathematical model was identified. That is the Vogel, Wiggins and Fetkovich model.

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Step 4: Model Formulation
Understanding how the actual system behaves and determining the basic requirements. Creating a flowchart and Pseudocode of how the system operates.

Step 5: Input Data Collection and Analysis
In this step, all the required input data are itemized and then calculated manually using the three different IPR models to solve for Wellbore Flowrates and production of Inflow Performance Curves.

Step 6: Model Transformation
In this step, the three different mathematical models are transformed into programming language. That is; the Vogel, Wiggins and Fetkovich model are transformed to programming codes using the NetBeans Integrated Development Environment.

Step 7: Verification and Validation
At this stage, the already developed simulator is tested for runtime and compile time errors. That is; the simulator is tested if it will actually run as desired. A simulator can be verified but not valid. Hence, the developed simulator (ROS) was validated using numerical values and then the results produced was compared to those gotten from manual solution method and PROSPER.

2.6 Simulator Pseudocode

As a result of the complex nature of the java source code used for developing the ROS simulator, a Pseudocode for the program is presented for better understanding of the simulator design.

Program Start:

- *Importation of the required packages and modules;*
- *Creating the front panel to handle the Graphic User Interface (GUI);*
- *Creating the Text fields for all the required input data;*
- *Creating uneditable text fields to hold the output data;*
- *Adding all the created components to the GUI panel;*

```
addGB( write, x=6,y=0);
addGB( new JLabel("Stab Pwf"), x=0,y=2);
addGB( stpwf, x=1,y=2);
```

- *Creating the buttons to handle the computational task*
- *Formatting the keyboard input texts to numbers;*
- *Using the IF and TRY statements to check for errors and exceptions;*

```
try {
if(p1str.length() != 0 &&
p2str.length() != 0 &&
}
```

- *Using the CATCH statement to address the errors;*

```
} catch (Exception e){
e.printStackTrace();
}
```

- *Converting all the mathematical models to computer language.*

```
public double Pindex() {
double b;
b=sqo1/(spr1-spw1);
return b;
}
public double compvq1() {
double c;
c=compvmax()*(1-(0.2*(p1/spr1))-
(0.8*(Math.pow((p1/spr1), 2))));
return c;
}
```

- Assigning the computed results to the output GUI textfield.

Program End

2.7 Steps to Calculate Percentage Error

1. Subtract the accepted value from the experimental value.
2. Take the absolute value of step 1.
3. Divide that answer by the accepted value.
4. Multiply that answer by 100 and add the % symbol to express answer in percentage.

That is: percentage error (%)
= (ROS – Manual Method)/ Manual Method

and
error (%)= (ROS – PROSPER)/ PROSPER

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Table 1. Input Parameters

SIMULATOR INPUT PARAMETERS							
Stabilized Wellbore flowrate, Q_o (STB/day)	**Reservoir Exponent Value (n)**	**Average Reservoir Pressure, P_r (Psig)**	**Stabilized wellbore flowing pressure, P_{wf} (Psig)**	**Wellbore flowing pressure, P_{wf} (Psig)**	**VOGEL**	**WIGGINS**	**FETKOVICH**
				$P_{wf}(1)$	2500	2500	2500
				$P_{wf}(2)$	2200	2200	2200
				$P_{wf}(3)$	1500	1500	1500
				$P_{wf}(4)$	1000	1000	1000
				$P_{wf}(5)$	500	500	500
350	0.85	2500	2000	$P_{wf}(6)$	0	0	0

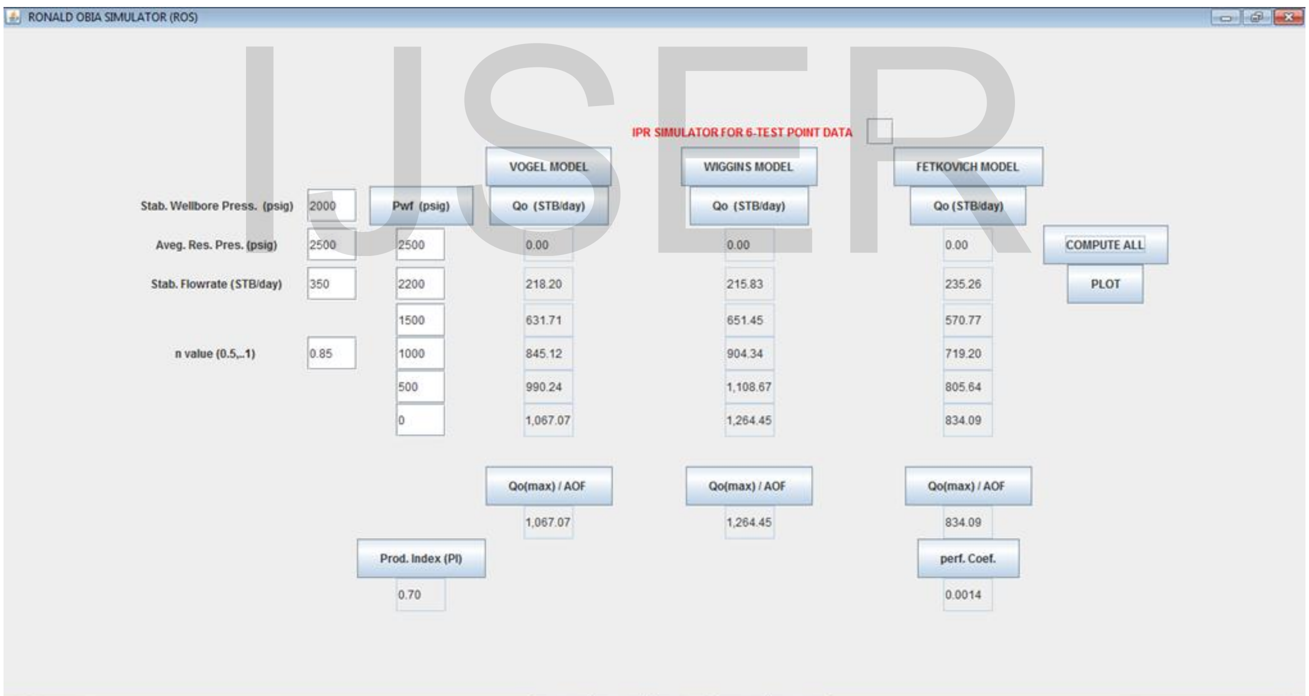

Fig.1. GUI of ROS Simulator

International Journal of Scientific & Engineering Research, Volume 10, Issue 3, March-2019
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3.0 Results and Discussion

Table 2 shows the combined results obtained from the ROS simulator.

Table 2. Combined Results from the ROS Simulator

VOGEL		WIGGINS		FETKOVICH	
P_{wf} (psig)	Q_o (STB/d)	P_{wf} (psig)	Q_o (STB/d)	P_{wf} (psig)	Q_o (STB/d)
2500	0.0	2500	0.0	2500	0.0
2200	218.195	2200	215.827	2200	235.261
1500	631.707	1500	651.445	1500	570.774
1000	845.122	1000	904.335	1000	719.198
500	990.244	500	1108.671	500	805.641
0	1067.073	0	1264.451	0	834.086

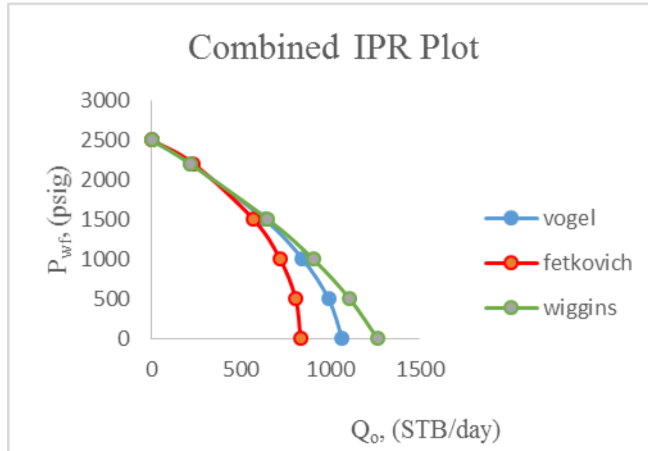

Fig.2. Combined IPR Plot of P_{wf} versus Q_o

3.1 Models Comparison

For the purpose of analyses, the three different IPR curves were plotted together and then the plot reveals that the wellbore flowing pressure (P_{wf}) is inversely proportional to the calculated flowrate (Q_o). When wellbore flowing pressure (P_{wf}) equals the average reservoir pressure (P_r =2500 psig), the flow rate is equal to zero due to the absence of any pressure drawdown. The IPR plot was initially a straight line but later deviated from the straight as a result of pressure drop below bubble point pressure Evinger and Muskat (1949). The point of deviation indicates that the reservoir condition has moved from single phase to two-phase reservoir system. The point of deviation from straight line is observed to be at 2000 psig. Since the deviation occurs at 2000 psig, this means that the bubble point pressure is 2000 psig. The Maximum rate of flow in the wellbore occurs when P_{wf} is zero. This maximum flowrate is called "Absolute Open Flow" and referred to as AOF. That is; $AOF_{(v)}$ =1076.073 STB/day, $AOF_{(w)}$ =1264.451 STB/day, $AOF_{(f)}$ =834.086 STB/day. The maximum flow rate from the Fetkovich plot is observed to differ a little far from that of Vogel and Wiggins as a result its model accounting for more of reservoir parameters.

Table 3. Percentage Error Result from Manual Method and ROS Method

Maximum Flowrate Results From The Manual Solution Method and That of The ROS Simulated Results			
Models	**Manual Method AOF (STB/day)**	**ROS AOF (STB/day)**	**% Error**
Vogel	1067.1	1067.073	0.0025%
Wiggins	1264.45	1264.451	0.000079%
Fetkovich	833.82	834.086	0.032%

Table 4. Percentage Error Result from PROSPER Method and ROS Method

Maximum Flowrate Results of The ROS Simulator and That of PROSPER			
Models	**PROSPER Method AOF (STB/day)**	**ROS AOF (STB/day)**	**% Error**
Vogel	1068.3	1067.073	0.1%
Fetkovich	832.4	834.086	0.2%

4 Conclusion

In this work, the most commonly used IPR models (Vogel, Wiggins and Fetkovich) was reviewed and also an IPR simulator was developed for the computations of this models.

Based on the results from this work, the following

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conclusions were drawn:

The developed simulator produced accurate results of flowrates and also inflow performance relationship of the wellbore of a solution gas drive reservoir.

The IPR calculations; if done manually, is a tedious task but the introduction of the simulator makes it very easy to compute and analyze. However the simulator was able to eliminate the stress involve in analyzing inflow performance relationship using more number of test-points.

From the combined IPR plot in figure 2, it reveals that the plot of pressure against flowrate gives a straight line for a single phase oil reservoir system. Whereas for two-phase system (oil and gas), the IPR plot is a curved line.

The pressure and flowrate varies inversely proportional to each other.

Comparing maximum flowrate results from the manual solution method with that of the ROS simulated results, Vogel's model gave a percentage error of 0.0025%, Wiggin's model gave a percentage error of 0.000079% and Fetkovich model gave a percentage error of 0.03%.

Comparing maximum flowrate results from the ROS solution method with that of PROSPER simulated results, Vogel's model gave a percentage error of 0.1% and Fetkovich model gave a percentage error of 0.2%.

From the percentage error results, it however proves the ROS simulator to be accurately validated.

5.0 Appendices

Appendix A

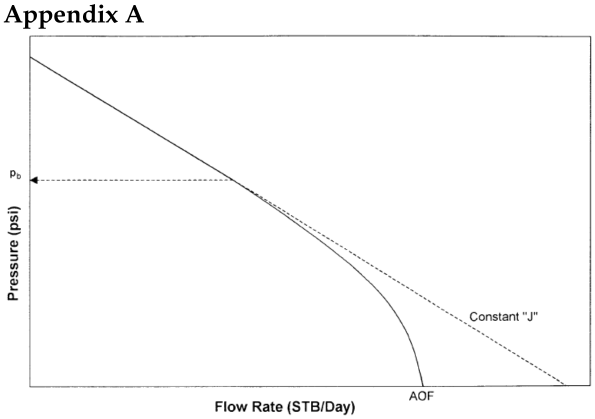
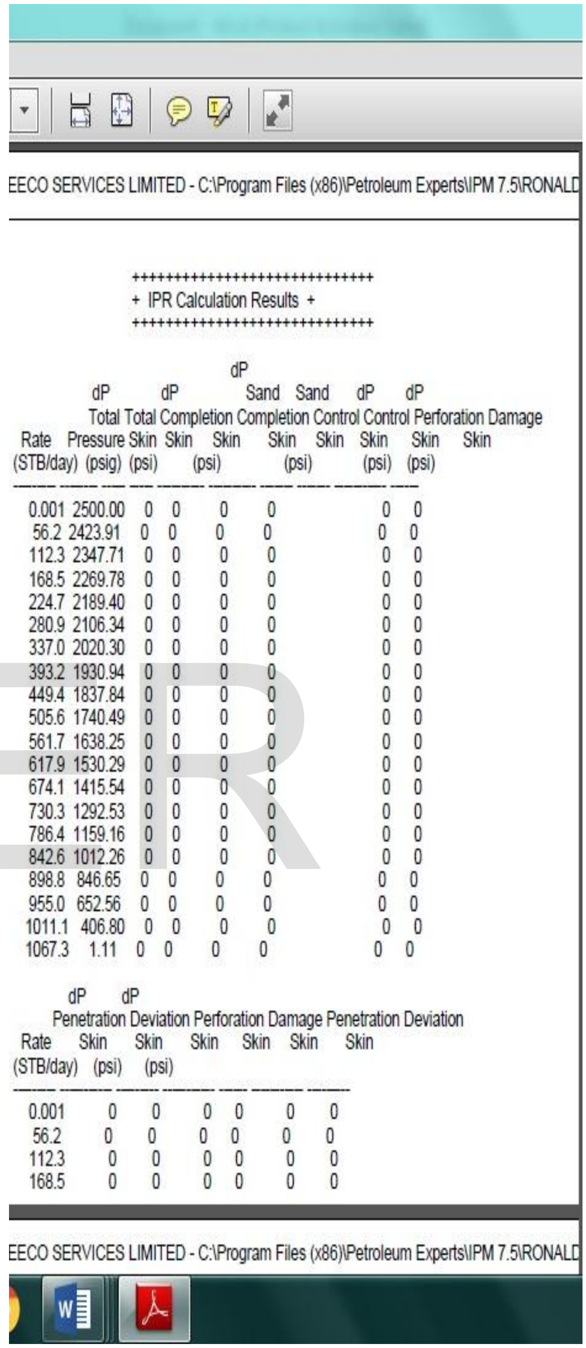


Fig. A. The Inflow Performance Curve below Bubble-Point Pressure (Ahmed, 2005)

Appendix B



+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (STB/day)	Pressure (psig)	dP Total Skin (psi)	Total Skin	dP Completion Skin (psi)	Completion Skin	dP Sand Control Skin (psi)	Sand Control Skin	dP Perforation Skin (psi)	Perforation Skin	Damage Skin
0.001	2500.00	0	0	0	0			0	0	
56.2	2423.91	0	0	0	0			0	0	
112.3	2347.71	0	0	0	0			0	0	
168.5	2269.78	0	0	0	0			0	0	
224.7	2189.40	0	0	0	0			0	0	
280.9	2106.34	0	0	0	0			0	0	
337.0	2020.30	0	0	0	0			0	0	
393.2	1930.94	0	0	0	0			0	0	
449.4	1837.84	0	0	0	0			0	0	
505.6	1740.49	0	0	0	0			0	0	
561.7	1638.25	0	0	0	0			0	0	
617.9	1530.29	0	0	0	0			0	0	
674.1	1415.54	0	0	0	0			0	0	
730.3	1292.53	0	0	0	0			0	0	
786.4	1159.16	0	0	0	0			0	0	
842.6	1012.26	0	0	0	0			0	0	
898.8	846.65	0	0	0	0			0	0	
955.0	652.56	0	0	0	0			0	0	
1011.1	406.80	0	0	0	0			0	0	
1067.3	1.11	0	0	0	0			0	0	

Rate (STB/day)	dP Penetration Skin (psi)	dP Deviation Skin (psi)	Perforation Skin	Damage Skin	Penetration Skin	Deviation Skin
0.001	0	0	0	0	0	0
56.2	0	0	0	0	0	0
112.3	0	0	0	0	0	0
168.5	0	0	0	0	0	0

EECO SERVICES LIMITED - C:\Program Files (x86)\Petroleum Experts\IPM 7.5\RONALD

Fig. B1. Vogel Simulated Result from PROSPER

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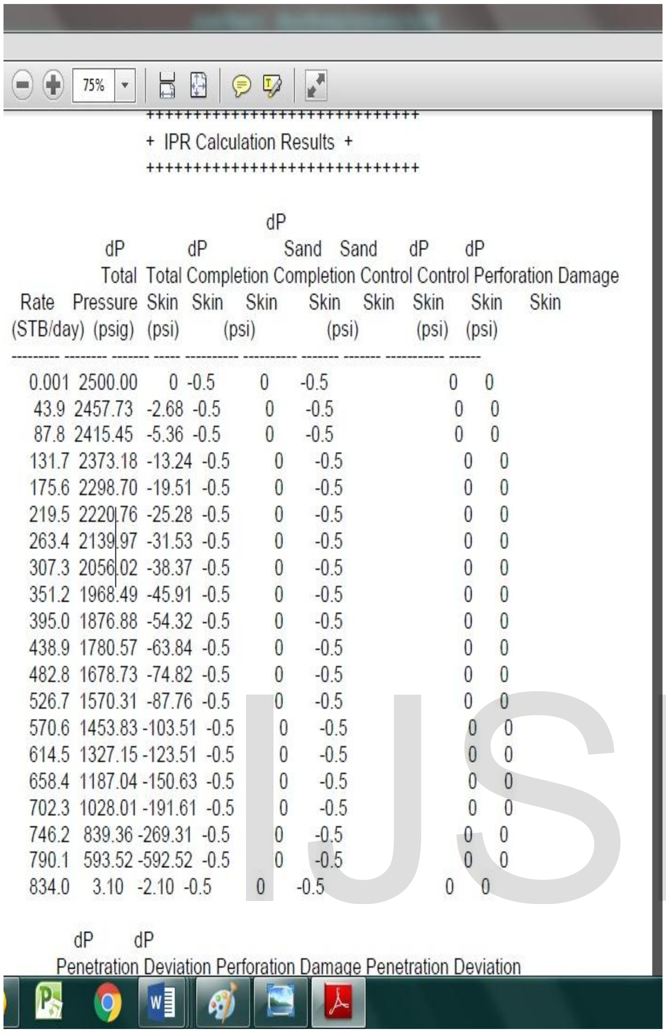

+++++++++++++++++++++++++++++
+ IPR Calculation Results +
+++++++++++++++++++++++++++++

Rate (STB/day)	Pressure (psig)	dP Total Skin (psi)	Total Skin	dP Completion Skin (psi)	Completion Skin	dP Sand Control Skin (psi)	Sand Control Skin	dP Perforation Skin (psi)	Perforation Damage Skin
0.001	2500.00	0	-0.5	0	-0.5			0	0
43.9	2457.73	-2.68	-0.5	0	-0.5			0	0
87.8	2415.45	-5.36	-0.5	0	-0.5			0	0
131.7	2373.18	-13.24	-0.5	0	-0.5			0	0
175.6	2298.70	-19.51	-0.5	0	-0.5			0	0
219.5	2220.76	-25.28	-0.5	0	-0.5			0	0
263.4	2139.97	-31.53	-0.5	0	-0.5			0	0
307.3	2056.02	-38.37	-0.5	0	-0.5			0	0
351.2	1968.49	-45.91	-0.5	0	-0.5			0	0
395.0	1876.88	-54.32	-0.5	0	-0.5			0	0
438.9	1780.57	-63.84	-0.5	0	-0.5			0	0
482.8	1678.73	-74.82	-0.5	0	-0.5			0	0
526.7	1570.31	-87.76	-0.5	0	-0.5			0	0
570.6	1453.83	-103.51	-0.5	0	-0.5			0	0
614.5	1327.15	-123.51	-0.5	0	-0.5			0	0
658.4	1187.04	-150.63	-0.5	0	-0.5			0	0
702.3	1028.01	-191.61	-0.5	0	-0.5			0	0
746.2	839.36	-269.31	-0.5	0	-0.5			0	0
790.1	593.52	-592.52	-0.5	0	-0.5			0	0
834.0	3.10	-2.10	-0.5	0	-0.5			0	0

dP dP
Penetration Deviation Perforation Damage Penetration Deviation

Fig.B2. Fetkovich Simulated Result from PROSPER

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