International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 10 Issue 4 ǁ 2022 ǁ PP. 14-26

Optimizing oil production by regulating the factors involved by using mathematical optimization technique and programming languages

Sai Kiran Koochimanchi, Rana Aditya Singh, Upendra Singh Yadav, Rahul Nautiyal

Abstract
In this paper, we have done some mathematical simulations to form an equation comprising of many constraints that we encounter in the oil and gas industry. We have numerous equations which give us flow rate and is really important as far as planning and forecast is concerned that is pretty much the utility of the different equations and at the same time we have a way to check and balance our planning and also the scope of heterogeneity is also encompassed to an extent . We have tried to bring these equations closer to reality and also made them smarter to an extent that they comply with the actual data, the approach is very simple and is just clubbing of different equations available helped us move a bit closer to reality by including constraints which were earlier missing, we have tested this particular equation with field data available and found it to be in compliance with all the results to a very great extent. Simply we have compared our results with the VOGEL'S Equation and we found that our results are little better than the former one as we could see the same in the graphs.
Keywords: *Optimization, Particle Swarm Optimization, Constraints, VOGEL Equation*

Date of Submission: 01-04-2022 Date of acceptance: 14-04-2022

I. Introduction

We all know that our main aim in the oil fields is to maximize oil production without expanding the existing facilities and it should also be efficient when it comes to time and money. So our main focus in this project will be to maximize the oil production by optimizing the existing facilities without compromising on time and money. To break this down in simple words, we will be optimizing the constraints which were earlier being ignored and clubbing them in order to formulate an equation which brings us closer to reality and used a very simple way. We have also used MATLAB and PYTHON to make this expression well tested and robust.

Tried this equation with different field data and found it to be compliant and better in terms of accuracy and its applicability. At the end we can say that we will be considering the factors involved in a well also and that means we will be adding two layers of optimizing one for the single well and then the facility as a whole .So keeping the facility almost same with subtle changes is also one of the priority, so there will be subtle mechanical changes keeping this in mind. This mathematical expression as we will see in the methodology is a very efficient way to tackle the equations at one place and also it will help us to bring a great numbers of constraints and is a one stop solution.

Advantages of Particle Swarm Optimization (PSO)
- Can be simple to implement
- Have few parameters to adjust
- Able to run parallel computation
- Can be robust
- Have higher probability and efficiency in finding global optima
- Can converge fast
- Have short computational time
- Do not overlap and mutate

Disadvantages of PSO
- Can be difficult to define initial design parameters
- Cannot work out the problems of scattering
- Can converge prematurely and be trapped into a local minimum especially with complex problems

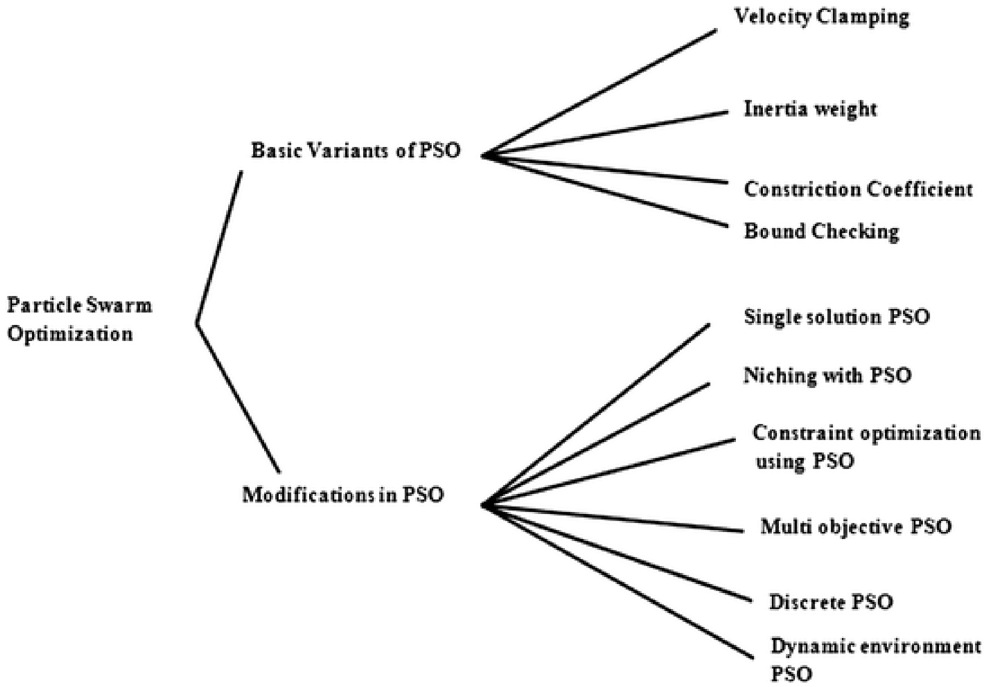

Fig 1: Flowchart of Particle Swarm Optimization

About PYTHON and MATLAB

MATLAB is an abbreviation for Matrix Laboratory. It is a programming language that is very helpful for mathematical programming and calculations. It can also be used for deep learning and other wide range of applications thus very useful in this modern era.

PYTHON is a general purpose coding language, so it can be used for multiple purposes i.e. from solving a simple equation to creating a software. It has a very simplified syntax and thus can be used to write complex codes very easily and execute them.

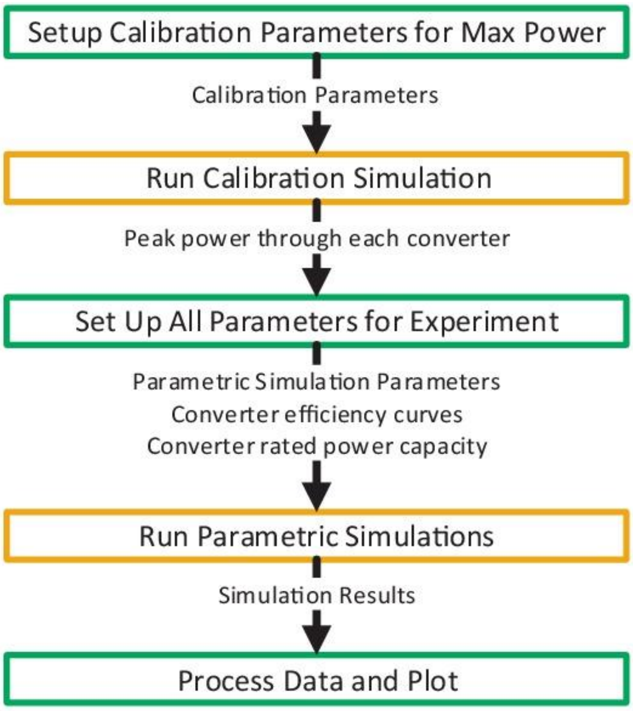

Fig 2: Block diagram of Python Functioning

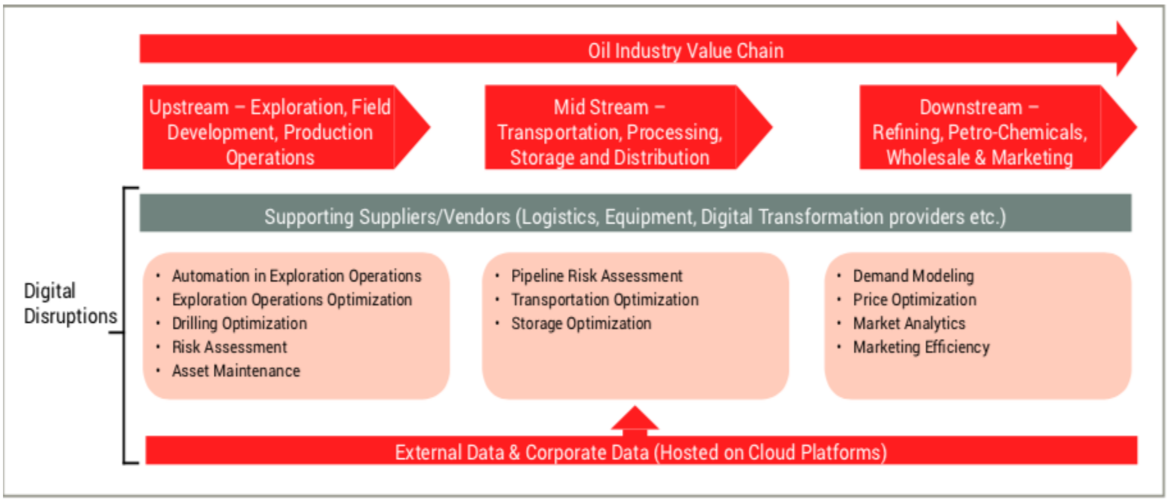

Fig 3: Flow Chain of Oil Industry with Digital Disruptions

Advantage of PYTHON/MATLAB
- Reduction in human error.
- Helping in repetitive jobs.
- Faster decisions.
- 24*7.

Disadvantages of PYTHON/MATLAB
- PYTHON is comparatively slower than other languages.
- Making human lazy.
- Lacking out of box thinking.

II. Objective/Purpose

When we started our journey to formulate a mathematical expression which can have the following attributes:

- Have maximum coverage for constraints.
- Have accurate output and should comply with the existing equation.
- Give us a way to relatively compare the importance of different constraints involved.
- Give us a comprehensive approach toward planning for the field.
- If we are having a producing field we can relatively prioritize the constraints and changes
- Can be done in the most economical way.
- Safety as a parameter can be seen through the lense of mathematics and the changes.
- We will never breach those boundaries and always keep us safe.

III. Methodology

The main part of any research work depends upon its execution of its methodology. So here what we are going to do is forming an mathematical equation which is different from the existing equation and also the constraints that are in the latter one are limited to an extent, but the equation which we have proposed is constituting of all the major constraints which are encountered every now and then in the oil and gas industry. Also it will be helpful in forming the IPR curve which tells you about the nature of the fluid present in the reservoir. Here we have compared the field data with the Vogel's Equation of IPR and we found that the equation which we have proposed has yielded better results than the former one. The main aim in the oil and gas industry is that how can we optimize the oil production without much expansion of existing facilities and expenditure. So we have proposed an optimization problem which gives us better idea about the values which

are very much nearer to the values given by existing equation and also this method will give us the best value out of produced results which is even better than the existing one.
Now the following equations have been merged to form the required equation:

$$q = \frac{k * h * (Pi - Pwf)}{(162.6 * \mu o * Bo * (\log(t) + \log(k)/((phi) * \mu o * Ct * rw^2) - 3.23 + 0.87 * s))}$$

$$q = \frac{0.246 * 10^-4 * (\rho w - \rho o) * (\frac{\rho o - \rho g}{\rho w - \rho g})^2 + (\rho o - \rho g) * (1 - ((\rho o - \rho g)/(\rho w - \rho g)))^2}{\ln(\frac{re}{rw})}$$

$$q = \frac{Pwh * S^n * 1000}{C * R^m}$$

Now on combining all the three equations we will get the transformed Transient flow equation:

$$q = \frac{k * h * (Pi - Pwf) * \ln(re/rw) * C * R^m * 1.45 * 2\sigma * 10^-5 * \cos\Theta}{\left(162.6 * \mu o * Bo * \left(\log(t) + \frac{\log(k)}{(phi) * \mu o * Ct * rw^2} - 3.23 + 0.87 * s\right)\right) * [0.246 * 10^-4 * (\rho w - \rho o) * ((\rho o - \rho g)/(\rho w - \rho g))^2 + (\rho o - \rho g) * \left(1 - \left(\frac{\rho o - \rho g}{\rho w - \rho g}\right)\right)^2] * Pwh * S^n * r * \cos\Psi * 1000}$$

Now Vogel's equation for fluid flow is:

$$q = \frac{k * h * (Pr - Pb)}{141.2 * \mu o * Bo * [\ln\left(\frac{re}{rw}\right) - \left(\frac{3}{4}\right) + s]} \quad (1)$$

$$\mathbf{q} = \frac{\mathbf{1.45 * 10^-5 * C * R^m * 2\sigma * \cos\Theta * \ln(\frac{re}{rw})}}{\mathbf{[0.246 * 10^-4 * (\rho w - \rho o) * ((\rho o - \rho g)/(\rho w - \rho g))^2 + (\rho o - \rho g) * \left(1 - \left(\frac{\rho o - \rho g}{\rho w - \rho g}\right)\right)^2] * Pwh * S^n * r * \cos\Psi * 1000}} \quad (2)$$

$P_c = (2*\sigma*\cos\Theta)/r$ (3)

Now adding equation(1) and equation(2)we get:

$$q = \frac{k * h * (Pr - Pb)}{141.2 * \mu o * Bo * [\ln\left(\frac{re}{rw}\right) - \left(\frac{3}{4}\right) + s]} + \frac{1.45 * 10^-5 * C * R^m * 2\sigma * \cos\Theta * \ln(\frac{re}{rw})}{[0.246 * 10^-4 * (\rho w - \rho o) * ((\rho o - \rho g)/(\rho w - \rho g))^2 + (\rho o - \rho g) * \left(1 - \left(\frac{\rho o - \rho g}{\rho w - \rho g}\right)\right)^2] * Pwh * S^n * r * \cos\Psi * 1000}$$

Now based on these equations we compared our results by putting the field data in the existing equation and the new equation.
We can see from the above equations that the number of constraints in the Vogel's IPR is restricted but the new equation for IPR have multiple constraints including all the major factors affecting oil inflow performance.

Here is the list of constraints that has been included in the New IPR Equation:

- Viscosity
- Oil formation volume factor
- Reservoir pressure

- Bubble point pressure
- Flowing bottom hole pressure
- Effective radius
- Wellbore radius
- Density of oil
- Density of water
- Density of gas
- Gas-Liquid ratio
- Wellhead pressure
- Radius of capillary
- Surface tension
- Angle between phase, Angle of Dip
- Choke size
- Effective horizontal permeability
- Thickness
- Skin factor
- C, m, n are constants taken from Gilbert correlations

Now after this we have formulated a coding on PYTHON to check the different values of flow rate at different points of all the constraints and then compared with the existing equation of Vogel's. By doing this we matched the flow rate given by the certain programming with the Vogel's equation and it was found that our equation is yielding better results than the former one. We got the optimum values for five different values by varying the limits of constraints through this optimization and then we simply processed that data with both the equations and the plot has been shown below in the results.

Data Interpretation

We have taken the data from random fields of random basins based on which we performed MATLAB programming. Here we are mentioning data from five random fields.
Ref: Well Data has been taken from Buoyen Guo, OPEC Oil Production Data Source

Table 1 : Data for Well 1

k=8.2	Θ=30	ρ_0=47.5
h=53	P_{wh}=100	ρ_w=63.76
P_r= 5651	S=32.015	ρ_g=5.1
P_b=3000	R=1700	μ_0=1.7
r_e=2980	C=10	B_o=1.1
r_w=0.328	m=0.546	Ψ=30
σ=25	n=1.89	
r=10^{-4}	s=0	

Table 2: Data for Well 2

k=8.1	Θ=45	ρ_0=47.5
h=53	P_{wh}=300	ρ_w=63.76
P_r= 9654	S=32.015	ρ_g=5.1

P_b=3765	R=1650	μ_0=1.8
r_e=2980	C=10	B_o=1.2
r_w=0.328	m=0.546	Ψ=45
σ=100	n=1.89	
r=10^{-3}	s=0	

Table 3: Data for Well 3

k=8.1	Θ=60	ρ_0=47.5
h=53	P_{wh}=800	ρ_w=63.76
P_r= 9357	S=32.015	ρ_g=5.1
P_b=3480	R=1650	μ_0=1.9
r_e=2980	C=10	B_o=1.1
r_w=0.328	m=0.546	Ψ=60
σ=70	n=1.89	
r=10^{-4}	s=0	

Table 4: Data for Well 4

k=8.1	Θ=30	ρ_0=47.5
h=53	P_{wh}=200	ρ_w=63.76
P_r= 9200	S=32.015	ρ_g=5.1
P_b=3300	R=1650	μ_0=1.7
r_e=2980	C=10	B_o=1.4
r_w=0.328	m=0.546	Ψ=30
σ=50	n=1.89	
r=10^{-4}	s=0	

Table 5: Data for Well 5

k=8.2	Θ=45	ρ_0=47.5
h=52	P_{wh}=300	ρ_w=63.76
P_r= 5700	S=32.015	ρ_g=5.1
P_b=3500	R=1650	μ_0=1.9
r_e=2980	C=10	B_o=1.4
r_w=0.328	m=0.546	Ψ=45
σ=50	n=1.89	
r=10^{-4}	s=0	

Now based on these above mentioned well data we have calculated flow rate with both the equations i.e Vogel's IPR and New IPR equation and based plotted the curves and clearly showing that the results from our values are better than former one.

IV. Results& Discussion

Well 1

Vogel's equation		Developed equation	
q(STB/day)	P_{wf}(psi)	q(STB/day)	P_{wf}(psi)
849.6597	0	849.6771	0
845.7237	565	845.7411	565
826.0497	1130	826.0671	1130
806.3755	1695	806.3929	1695
781.4552	2260	781.4726	2260
751.2306	2826	751.248	2826
740.881	3000	740.8984	3000
0	5651	0	5651

PLOTS/GRAPHS

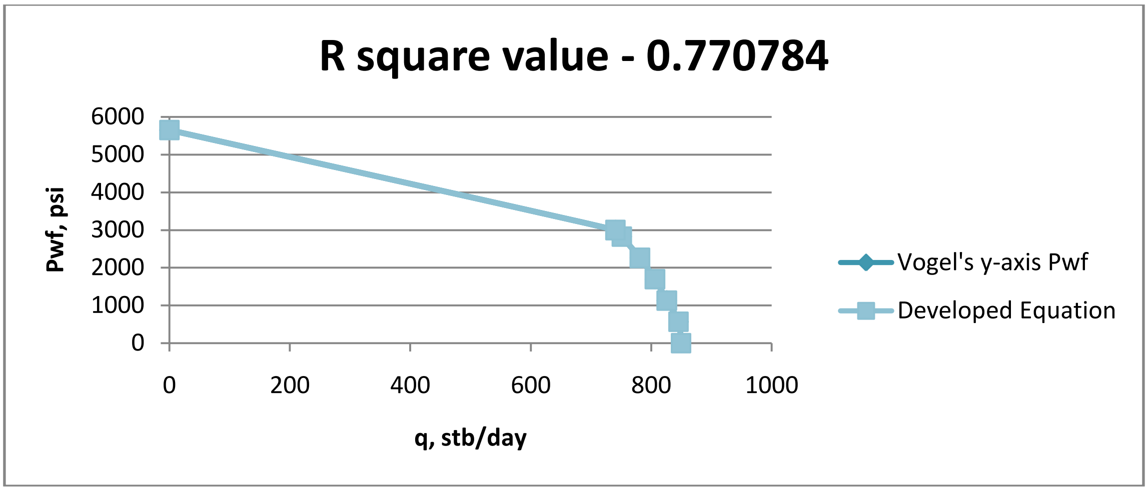

Fig 4: Plot of Well data 1

Well 2

Vogel's equation		Developed equation	
q(STB/day)	P_{wf}(psi)	q(STB/day)	P_{wf}(psi)
1343.0378	0	1343.0402	0
1338.6359	500	1338.6383	500
1332.7232	1000	1332.7256	1000
1325.2996	1500	1325.302	1500
1316.3652	2000	1316.3674	2000
1305.9199	2500	1305.9223	2500
1293.9638	3000	1293.9662	3000
1282.4968	3500	1280.4992	3500
1272.7467	3765	1272.7491	3765
0	9654	0	9654

PLOTS/GRAPHS

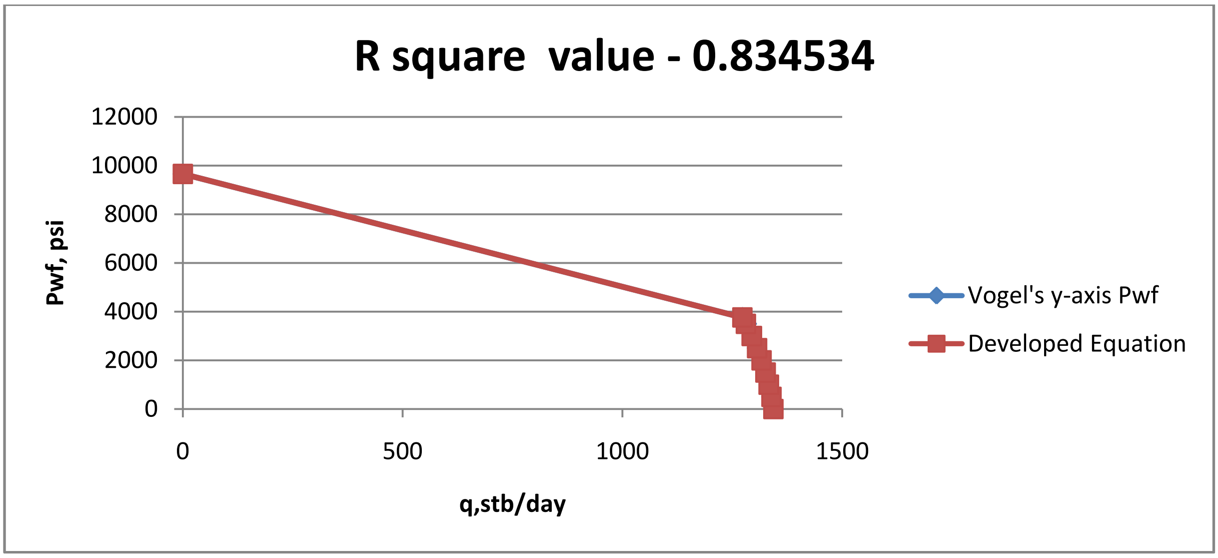

Fig 5: Plot of Well data 2

Well 3

Vogel's equation		Developed equation	
q(STB/day)	P_{wf}(psi)	q(STB/day)	P_{wf}(psi)
1358.3066	0	1358.3066	0
1353.9454	500	1353.9454	500
1348.0483	1000	1348.0483	1000
1340.6152	1500	1340.6152	1500
1332.8442	2000	1332.8442	2000
1322.8735	2500	1322.8735	2500
1309.0998	3000	1309.0998	3000
1296.0953	3480	1296.0953	3480
0	9357	0	9357

PLOTS/GRAPH

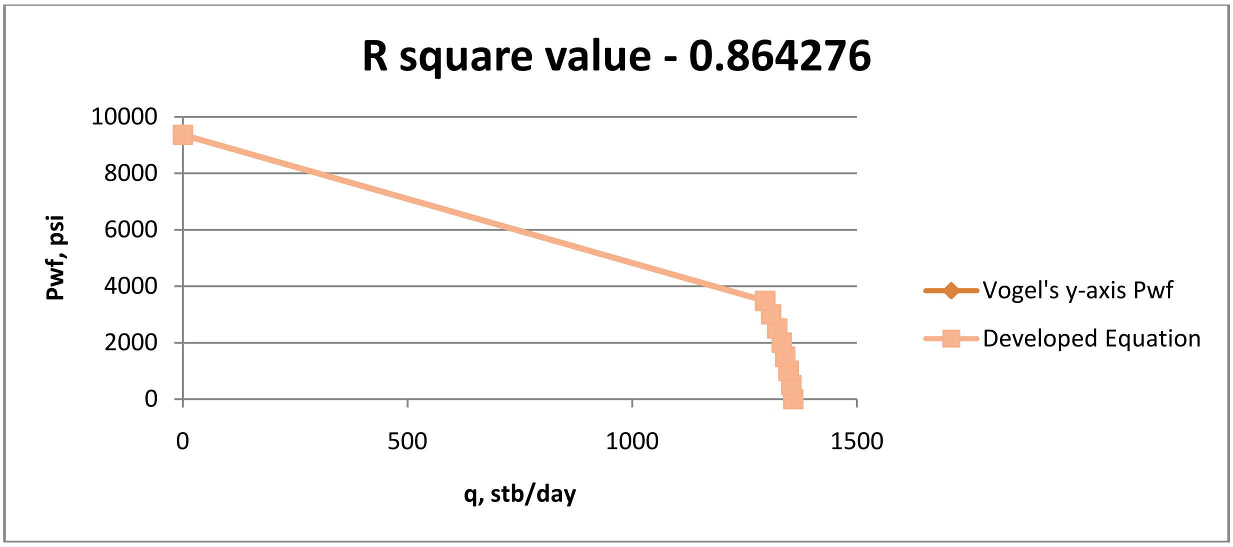

Fig 6: Plot of Well data 3

Well 4

Vogel's equation		Developed equation	
q(STB/day)	P_{wf}(psi)	q(STB/day)	P_{wf}(psi)
1181.0343	0	1181.0519	0
1177.3298	500	1177.3474	500
1172.3024	1000	1172.32	1000
1165.9519	1500	1165.9695	1500
1158.2784	2000	1158.296	2000
1149.2819	2500	1149.2995	2500
1138.9624	3000	1138.98	3000
1132.1356	3300	1132.1532	3300
0	9200	0	9200

PLOTS/GRAPHS

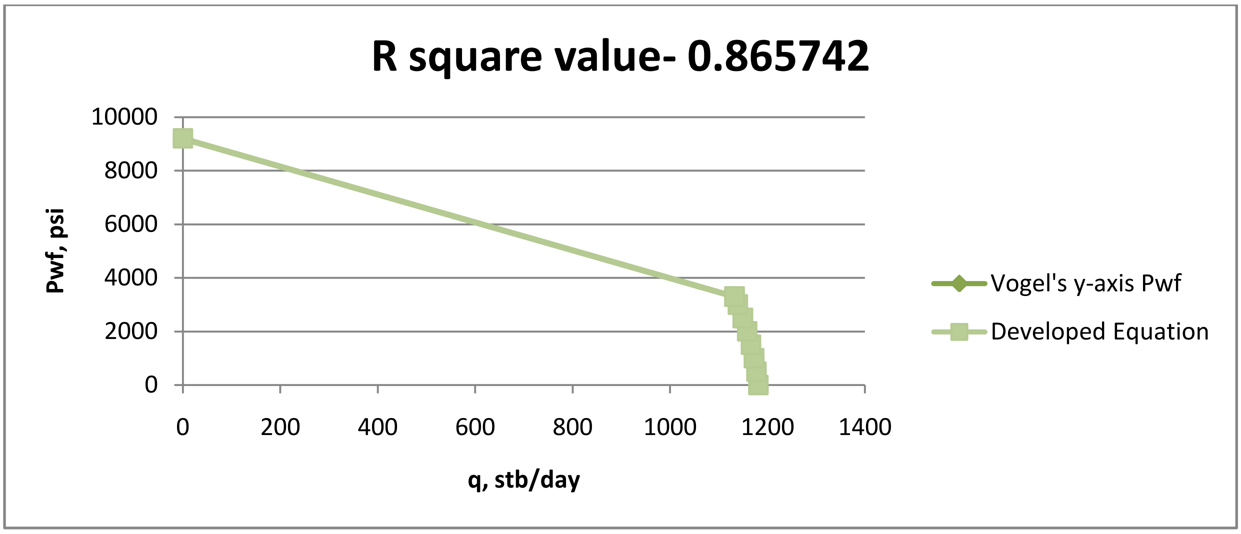

Fig 7: Plot of Well data 4

Well 5

Vogel's equation		Developed equation	
q(STB/day)	P_{wf}(psi)	q(STB/day)	P_{wf}(psi)
562.4597	0	562.4717	0
556.2062	500	556.2182	500
546.7073	1000	546.7163	1000
533.9539	1500	533.9659	1500
517.9549	2000	517.9669	2000
498.7074	2500	498.7194	2500
476.2114	3000	476.2234	3000
450.4669	3500	450.4789	3500
0	5700	0	5700

PLOTS/GRAPHS

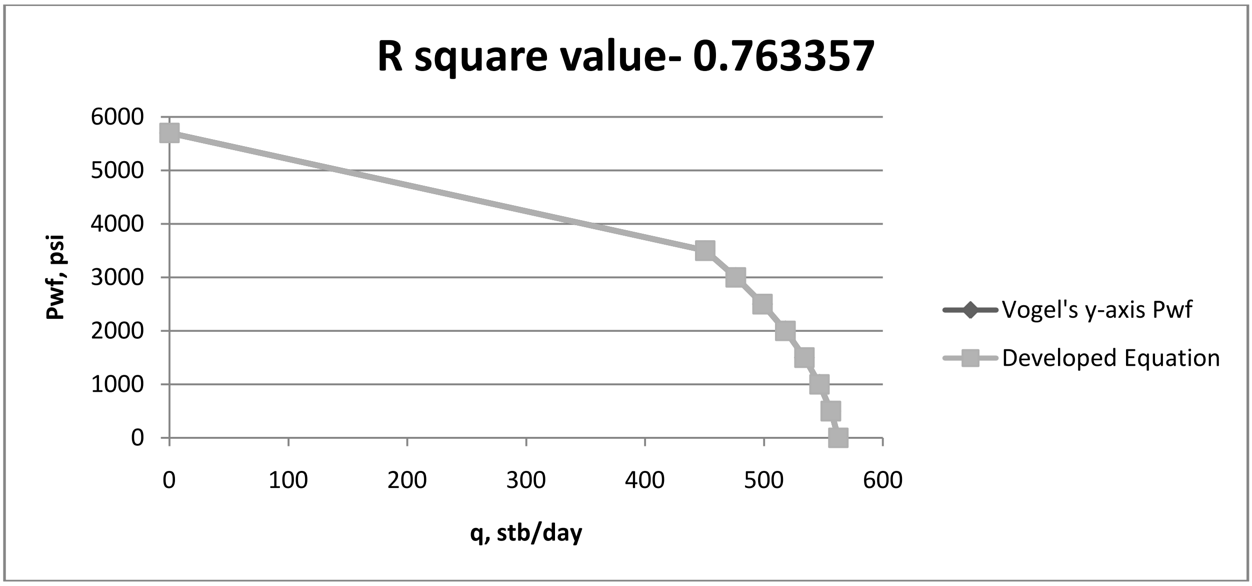

Fig 8: Plot of Well data 5

V. Discussion

We formulated the equation as shown in methodology and based on that equation we simulated the values on MATLAB and also we formulated a coding on PYTHON to check for the different values of flow rate at different points close to our data and by putting the optimization condition we got the results closer to our calculated flow rate. This optimization gave usa vast idea of various data that can be used to find out any given equation at different values of constraints and also it will give the results closer to the calculated value as well.

Now as we are looking at the results and the respective well data plots, the existing Vogel's plot and the New plot has been shown by different colors for each well. As we are getting close results so it is very difficult to show it separately on the graph.

We tried to maximize the use of our equation to address different problems in production, and the compliance of our equation with the existing Vogel's equation boosted our confidence and we tried our equation with different wells and found it to be closer with the real data, which tells us that we the proposed equation is bringing more constraints at one place and is bringing the existing equation closer to reality. Along with that we also tried to make assessment and the impact of different constraints in a single equation and also it gives us a scope to optimize the constraints which was quite hectic when we have to handle them in different equations and here it is a one stop solution to all of those problems and also we tried our bit to optimize the production values to some extent, with a scope for optimization and improvements.

Under the able guidance of our Mentor has been a constant source of motivation and how attention to detail is important and how it can improve our work and it acceptance. We adjusted our scope of work to certain extent and to ultimately completing it to the best of our capability, this experience we had have changed our perspective and the horizons of our ideas have become limitless.
The team which we have made during our journey and how important discussion are , listening to what others have to say and also prioritizing our tasks as per requirements , these subtle changes can make a great difference in the quality of our work is immense.

VI. Conclusion

The optimization of oil production is a very hectic and required task as far as the future of the oil industry is concerned. As of now, there are hundreds of methods have been proposed so as to get the maximum cumulative oil production rate. But to do this without expanding the facilities available throughout the production system is matter which every researcher is looking for. So far there are several optimization problems that have been taken into the considerations and applied to get the desired results by taking some constraints. But what we are trying in our project is to include as many constraints as we could in the IPR (Inflow Performance Relationship) so as to get the results nearer to the existing Vogel's Pseudo Steady State Equation. Here we have analyzed the data from random fields and then tried to simulate those in MATLAB with the help of Optimization and we found our data is even improved from what the existing Vogel's Equation is yielding and also we have performed the coding on PYTHON by taking nearer values to our data to see the values of different flow rates and to pick the best out of those.

Scope of Work

The method which we are proposing can be used in the oil industry as it is very intelligent optimization technique. The constraints which we are using while maximizing oil production of any random field are being optimized in this project and the graphs will be drawn on the basis of optimized data which in other words would be the best data for oil production optimization as compared to Vogel's IPR curve.

The use of AI here also can be applicable in the industry because we want to reduce the work of manpower so that he can monitor the emergency situation while working from his control room. Here also we can use a superstructure model to minimize the hectic well connections so that it will give a simple understanding of different well connections that are created already.

Certain more optimization techniques can be developed which could provide better results than the previous best as it is one of those areas where we can work on an ample number of equations that we have not even think of.

Abbreviations

k=Effective Permeability, md
ϴ=Angle between phases, degree
ρ_0=Desity of oil, lb/ft^{3}s= Skin factor
h=Reservoir Thickness, ft
P_{wh}=Wellhead Pressure, psia
ρ_w=Density of water, lb/ft^3
P_r=Reservoir Pressure, psia
S=Choke Size, inch
ρ_g=Density of Gas, lb/ft^3
P_b=Bubble point pressure, psia
R=Gas Liquid Ratio, scf/bbl
μ_0=Viscosity, cp
r_e=Effective radius, ft
B_o=Oil Formation Volume Factor
σ=Surface Tension, dyne/cm
Ψ=Angle of Dip, degree
r=Capillary Radius, cm
r_w=Wellbore Radius, ft
q= Flow rate, stb/day
m, n, C= constants
P_c= Capillary pressure, psi

References

1. B. L. Wang, Q.Feng, and H. Y. Jiang, "Application of water flooding characteristic curve in the development of low－ permeability oil reservoir," Special Oil & Gas Reservoirs, vol. 26, no. 6, pp. 82–87, 2019.

2. H. Q. Tan, Q. Fu, and L. X. Li, "Application of streamline numerical simulation method to study of remaining oil distribution in high water-cut stake oilfield," Journal of Chengdu University of Technology (Science & Technology Edition), vol. 44, no. 1, pp. 30–35, 2017.

3. J. X. Zhang, C. Y. Lin, and S. Z. Chen, "Study on numerical simulation of low saturation oil reservoirs based on J function and water-cut rising laws of horizontal well," Journal of Xi'an Shiyou University(Natural Science Edition), vol. 33, no. 2, pp. 58–64, 2018.

4. P. Zhou, X. F. Chen, and P. Yue, "Establishment of a new type of water drive characteristic curve," Petroleum Geology and Recovery Efficiency, vol. 19, no. 4, pp. 99–102, 2012.

5. C. Liu, J. Q. Zhang, and W. Z. Li, “A new dynamic calculation method of volume sweep coefficient of water drive reservoir based on approximate theoretical water drive curve,” Petroleum Geology and Recovery Efficiency, vol. 27, no. 5, pp. 112–118, 2020.

6. C. S. Zhao, Y. W. Yuan, and J. M. Xu, “Numerical simulation of horizontal wells at late high water cut stage,” Special Oil & Gas Reservoirs, vol. 18, no. 2, pp. 59–61, 2011.

7. F. Liu, Z. Du, and X. Chen, “Combining water flooding typecurves and Weibull prediction model for reservoir production performance analysis,” Journal of Petroleum Science and Engineering, vol. 112, pp. 220–226, 2013.

8. H. E. Dou, H. J. Zhang, and S. B. Shen, “Correct understanding and application of water flooding characteristic curve,” Petroleum Exploration and Development, vol. 46, no. 4, pp. 755–762, 2019.

9. H. H. Ling, Z. Q. Meng, and H. F. Shi, “Improvement of characterization method based on type A water drive curve,” Lithologic Reservoirs, vol. 30, no. 6, pp. 125–130, 2018.

10. H. Zhao, Z. J. Kang, and X. S. Zhang, “A physics-based datadriven numerical model for reservoir history matching and prediction with a field application,” SPE Journal, vol. 21, no. 6, pp. 2175–2194, 2016.

11. J. G. Hu, “A new growth curve for forecasting production of oil-gas field,” Xinjing Petroleum Geology, vol. 27, no. 5, pp. 569–571, 2006.

12. J. Q. Wang, C. F. Shi, and S. H. Ji, “New water drive characteristic curves at ultra-high water cut stage,” Petroleum Exploration and Development, vol. 44, no. 6, pp. 955–960, 2017.

13. K. Li, S. Y. Hu, and J. Q. Zhang, “A new type water flooding characteristic curve and its application,” Reservoir Evaluation And Development, vol. 9, no. 2, pp. 13–16, 2019.

14. L. F. Li, S. T. Teng, and X. B. Feng, “A new water－flooding characteristic curve based on the whole water－flooding process,” Special Oil & Gas Reservoirs, vol. 26, no. 3, pp. 85–88, 2019.

15. P. Liu, Z. B. Mu, and W. H. Wang, “A new combined solution model to predict water cut in water flooding hydrocarbon reservoirs,” International Journal of Hydrogen Energy, vol. 44, no. 6, pp. 955–960, 2017.

16. P. Zhou, “An Improved growth curve for predicting development indexes in water flooding oilfield,” Xinjing Petroleum Geology, vol. 41, no. 2, pp. 243–247, 2020.

17. P. Zhou, X. F. Chen, and P. Yue, “A combined solution model based on rayleigh model and water drive curves,” Xinjing Petroleum Geology, vol. 33, no. 2, pp. 205–207, 2012.

18. Q. T. Yu, “Classification and optimization of increase curves,” Fault-Block Oil& Gas Field, vol. 7, no. 1, pp. 34–41, 2000.

19. Q. T. Yu, “Three increase curves for description and prediction of oilfield development indexes,” China Offshore Oil and Gas (Geology), vol. 9, no. 2, pp. 141–148, 1995.

20. Q. Xu, Y. H. Chen, and Y. P. Hou, “Research on numerical simulation processing mode based on reservoir time varying physical properties and seepage in extra high water cut stage,” Drilling and Production Technology, vol. 38, no. 5, pp. 41–43, 2015.

21. Q. Y. Xu, X. G. Liu, and Z. M. Yang, “Non-linear seepage numerical simulation for super-low permeability reservoirs with artificial fractures,” Petroleum Science and Technology, vol. 31, no. 1, pp. 23–31, 2013.

22. W. J. Gao, R. Yin, and J. Yang, “Establishment and theoretical basis of the new water flooding characteristic curve,” Acta Petrolei Sinica, vol. 41, no. 3, pp. 342–347, 2020.

23. Y. Q. Huang, Z. J. Zhou, and Z. J. Liu, “Research on precision improvement of numerical simulation in extra high water cut stage, three block of Pu reservoir,” Petroleum Geology and Recovery Efficiency, vol. 21, no. 5, pp. 65–68, 2014.

24. Y. S. Wang, C. F. Shi, and J. Q. Wang, “New equations for characterizing water flooding in ultra-high water-cut oilfields,” Oil ＆ Gas Geology, vol. 41, no. 6, pp. 1282–1287, 2020.