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ESTIMATION OF MINIMUM REQUIRED GAS LIQUID RATIO (GLR) TO SUPPORT PLUNGER LIFT INSTALLATION IN WELLS USING A SIMPLE METHOD

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Abstract

Field testing of various artificial lift methods to determine their applicability can be costly. To alleviate these costs, it is necessary to develop a simple method to predict plunger lift applicability in advance of the installation under particular well operational conditions. In this work a simple-to-use approach has been developed to provide an accurate way to determine the applicability of plunger lift for wells. This method examines the feasibility of plunger lift for different tubing size, as a function of operating pressure and the well depth. The method is useful to obtain the minimum produced gas liquid ratio (GLR) required to support plunger lift installation in a well. If the well's measured producing GLR is greater than or equal to that given by this method, then plunger lift will likely work for the well. If the measured GLR of the well is close to the value given by the method, the well may or may not be a candidate for plunger lift. The predictive tool developed in this study can be of immense practical value for petroleum engineers to have a quick check on the applicability of plunger lift at various wells without opting for any expensive field trials. In particular, petroleum and production engineers would find the proposed method to be user-friendly with transparent calculations involving no complex expressions.

Key words: Plunger lift; artificial lift; gas liquid ratio; oil production; Vandermonde matrix; predictive tool.

1. Introduction

Plunger lift is an intermittent artificial lift method that usually uses only the energy of the reservoir to produce the liquids [12] . A plunger is a free-travelling piston that fits within the production tubing and depends on well pressure to rise and solely on gravity to return to the bottom of the well. Plunger lift operates in a cyclic process with the well alternately flowing and shut-in [6]. Many low-volume gas wells produce at suboptimum rates because of liquid loading caused by an accumulation of liquids in the wellbore that creates additional backpressure on the reservoir and reduces production, therefore plunger lift can use reservoir energy to remove these accumulated liquids from the wellbore and improve production. Lacking a thorough understanding of plunger lift systems leads to disappointing results in many applications [8,9]

One type of a typical installation of plunger lift is shown in figure 1. Plunger-lift operations are difficult to optimize owing to a lack of knowledge concerning tubing, casing, and bottom hole pressures; liquid accumulation in the tubing; and the location of the plunger [14,15].

Because expense is involved in trying out some method of lift in a well, it is desirable to be able to predict in advance if plunger lift will work or not in a well. Even though plunger lift is not too expensive, additional equipment options can increase the initial costs [9,10]. Also, downtime for installation, adjustments to see if the plunger installation will perform, and adjustments to optimize production well all add to the costs [5], therefore it worthwhile to be able to predict in advance if plunger lift will work for a candidate well or not.

In view of the above mentioned issues and the importance of plunger lift in petroleum engineering, it is necessary to develop an accurate and simple correlation to permit mathematical solution of the problem of plunger lift performance for a given well. In this wrok, the operation of the 2-in. and 2 1/2-in. expanding cycle-controlled plungers has been placed on a quantitative basis by means of simple equations obtained from correlations of field data.

This paper discusses the formulation of such a predictive tool in a systematic manner along with an example to show the simplicity of the model and usefulness of such a tool. The proposed method is exponential function which leads to well-behaved (i.e. smooth and non-oscillatory) equations enabling more accurate and non-oscillatory predictions and this is the distinct advantage of the proposed method.

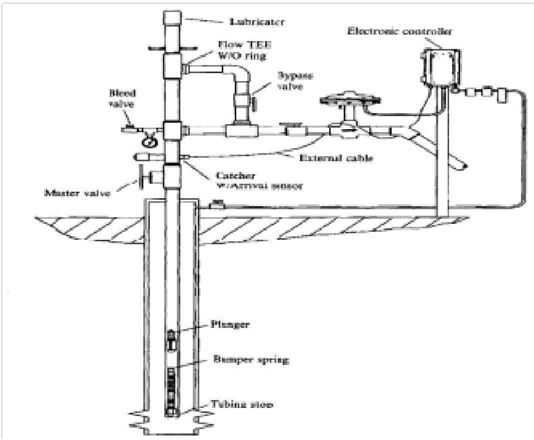

Figure 1. Installation of Plunger lift in a well

2. Methodology for the development of novel correlation

The primary purpose of the present study is to accurately correlate the minimum required gas liquid ratio to support the applicability of plunger lift as a function of net operating pressure and the depth of well. In this work, the net operating pressure is the difference in the operating casing build-up pressure and the separator or line pressure to which the well flows when opened.

Vandermonde matrix is a matrix with the terms of a geometric progression in each row, i.e., an $m \times n$ matrix [4]

$$V = \begin{bmatrix} 1 & \alpha_1 & \alpha_1^2 & \dots & \alpha_1^{n-1} \\ 1 & \alpha_2 & \alpha_2^2 & \dots & \alpha_2^{n-1} \\ 1 & \alpha_3 & \alpha_3^2 & \dots & \alpha_3^{n-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & \alpha_m & \alpha_m^2 & \dots & \alpha_m^{n-1} \end{bmatrix} \quad (1)$$

Or

$$V_{i,j} = \alpha_i^{j-1} \quad (2)$$

For all indices i and j. The determinant of a square Vandermonde matrix (where $m=n$) can be expressed as [4]

$$\det(V) = \prod_{1 \le i < j \le n} (\alpha_j - \alpha_i) \quad (3)$$

The Vandermonde matrix *evaluates* a polynomial at a set of points; formally, it transforms coefficients of a polynomial $a_0 + a_1 x + a_2 x^2 + \dots + a_{n-1} x^{n-1}$ to the *values* the polynomial takes at the point's α_i. The non-vanishing of the Vandermonde determinant for distinct points α_i shows that, for distinct points, the map from coefficients to values at those points is a one-to-one correspondence, and thus that the polynomial interpolation problem is solvable with unique solution; this result is called the unisolvence theorem [7]. They are thus useful in polynomial interpolation, since solving the system of linear equations $Vu = y$ for u with V an $m \times n$ Vandermonde matrix is equivalent to finding the coefficients u_j of the polynomial(s) [4].

$$P(x) = \sum_{j=0}^{n-1} u_j x^j \quad (4)$$

For degree ≤ $n-1$ which has (have) the property:

$$P(\alpha_i) = y_i \text{ for i=1,...,m.} \quad (5)$$

The Vandermonde matrix can easily be inverted in terms of Lagrange basis polynomials: each *column* is the coefficients of the Lagrange basis polynomial, with terms in increasing order going down. The resulting solution to the interpolation problem is called the Lagrange polynomial suppose that the interpolation polynomial is in the form [4,7]:

$$P(x) = a_n x^n + a_{n-1} x^{n-1} + ... + a_2 x^2 + a_1 x + a_0 \quad (6)$$

The statement that p interpolates the data points means that

$$P(x_i) = y_i \text{ for all } i \in \{0,1,..., n\}. \quad (7)$$

If we substitute equation (6) in here, we get a system of linear equations in the coefficients a_k. The system in matrix-vector form reads (Bair et al, 2006)

$$\begin{bmatrix} x_0^n & x_0^{n-1} & x_0^{n-2} & \ldots & x_0 & 1 \\ x_1^n & x_1^{n-1} & x_1^{n-2} & \ldots & x_1 & 1 \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ x_n^n & x_n^{n-1} & x_n^{n-2} & \ldots & x_n & 1 \end{bmatrix} \begin{bmatrix} a_n \\ a_{n-1} \\ \vdots \\ a_0 \end{bmatrix} = \begin{bmatrix} y_0 \\ y_1 \\ \vdots \\ y_n \end{bmatrix}. \quad (8)$$

We have to solve this system for a_k to construct the interpolant $p(x)$. The matrix on the left is commonly referred to as a Vandermonde matrix [1].

2.1. Development of correlation

The required data to develop this correlation includes minimum required gas liquid ratio to support the applicability of plunger lift as a function of net operating pressure and the depth of well. The following methodology has been applied to develop this correlation. Firstly the required gas liquid ratio to support the applicability of plunger lift data are correlated as a function of net operating pressure for several depth of well data, then, the calculated coefficients for these equations are correlated as a function of depth of well. The derived equations are applied to calculate new coefficients for equation (9) to predict required gas liquid ratio to support the applicability of plunger lift. Table 1 shows the tuned coefficients for equations (10) to (13) for predicting the required minimum gas liquid ratio to support the applicability of plunger lift. In brief, the following steps are repeated to tune the correlation's coefficients using Matlab [13].

1. Correlate required gas liquid ratio to support the applicability of plunger lift as a function of net operating pressure for a given swell depth.
2. Repeat step 1 for other well depth data.
3. Correlate corresponding polynomial coefficients, which were obtained for different depth of well dara versus depth of well data. a= f (L), b = f (L), c = f (L), d = f (L) [see equations (10)-(13)].

Equation 9 represents the proposed governing equation in which four coefficients are used to correlate minimum required gas liquid ratio to support the applicability of plunger lift in a well as a function of net operating pressure and the depth of well, where the relevant coefficients have been reported in Table 1.

$$\ln(GLR) = a + \frac{b}{P_n} + \frac{c}{P_n^2} + \frac{d}{P_n^3} \quad (9)$$

Where:

$$a = A_1 + B_1 L + C_1 L^2 + D_1 L^3 \quad (10)$$

$$b = A_2 + B_2 L + C_2 L^2 + D_2 L^3 \quad (11)$$

$$\mathrm{c} = A_3 + B_3 L + C_3 L^2 + D_3 L^3 \quad (12)$$

$$\mathrm{d} = A_4 + B_4 L + C_4 L^2 + D_4 L^3 \quad (13)$$

These optimum tuned coefficients help to cover well depth up to 12000 ft and the net operating pressure up to 15000 psi. The optimum tuned coefficients given in Table 1 can be further retuned quickly according to proposed approach if more data become available in the future.

In this work, our efforts directed at formulating a correlation which can be expected to assist engineers for rapid calculation of minimum required gas liquid ratio to support the applicability of plunger lift in a well as a function of well depth and net operating pressure using an exponential function. The proposed novel tool developed in the present work is simple and unique expression which is non-existent in the literature. Furthermore, the selected exponential function to develop the tool leads to well-behaved (i.e. smooth and non-oscillatory) equations enabling reliable and more accurate predictions.

Table 1 Tuned coefficients used in Equations 10-13

Coefficient	Valued for 2"Plunger lift	Valued for 2.5"Plunger lift
A_1	6.1340508065759	2.8901972428
B_1	$-5.635988843297\times10^{-4}$	$1.550399631357\times10^{-3}$
C_1	$1.660794605719\times10^{-7}$	$-1.788697600954\times10^{-7}$
D_1	$-9.037508192989\times10^{-12}$	$6.8210391450598\times10^{-12}$
A_2	$-2.707056387596\times10^{3}$	$4.085389769897\times10^{3}$
B_2	1.708621693483	-1.853610034690
C_2	$-2.752949187354\times10^{-4}$	$2.425650325517\times10^{-4}$
D_2	$1.3037391566689\times10^{-8}$	$-9.326821757908\times10^{-9}$
A_3	$1.150510090267\times10^{6}$	$-1.471631721753\times10^{6}$
B_3	$-6.099678702746\times10^{2}$	$6.593881677239\times10^{2}$
C_3	$9.580947504835\times10^{-2}$	$-8.361608445292\times10^{-2}$
D_3	$-4.460605573734\times10^{-6}$	$3.192632562117\times10^{-6}$
A_4	$-1.250867973493\times10^{8}$	$1.623874342937\times10^{8}$
B_4	6.3665690829×10^{4}	$-7.151843665702\times10^{4}$
C_4	-9.813975537575	9.210337231763
D_4	$4.545726647733\times10^{-4}$	$-3.562320116296\times10^{-4}$

3. Results

Figure 2 and 2 show the proposed method results for 2-in. and 2 1/2-in. expanding cycle-controlled plungers respectively in comparison with data ([2,3]. Figures 4 and 5 show the smooth performance of predictive tool in the prediction of minimum required gas liquid ratio to support the applicability of plunger lift in a well as a function of well depth and net operating pressure for 2-in. and 2 1/2-in. expanding cycle-controlled plungers respectively. It is expected that our efforts in formulating a simple tool will pave the way for arriving at an accurate prediction of minimum required gas liquid ratio to support the applicability of plunger lift in a well as a function of well depth and net operating pressure which can be used by petroleum and production engineers for monitoring the key parameters periodically. Typical example is given below to illustrate the simplicity associated with the use of proposed method for rapid estimation of minimum required gas liquid ratio to support the applicability of plunger lift in a well as a function of well depth and net operating pressure. The tool developed in this study can be of immense practical value for experts and engineers to have a quick check on minimum required gas liquid ratio to support the applicability of plunger lift in a well at various conditions without opting for any experimental trials. In particular, petroleum engineers would find the approach to be user-friendly with transparent calculations involving no complex expressions.

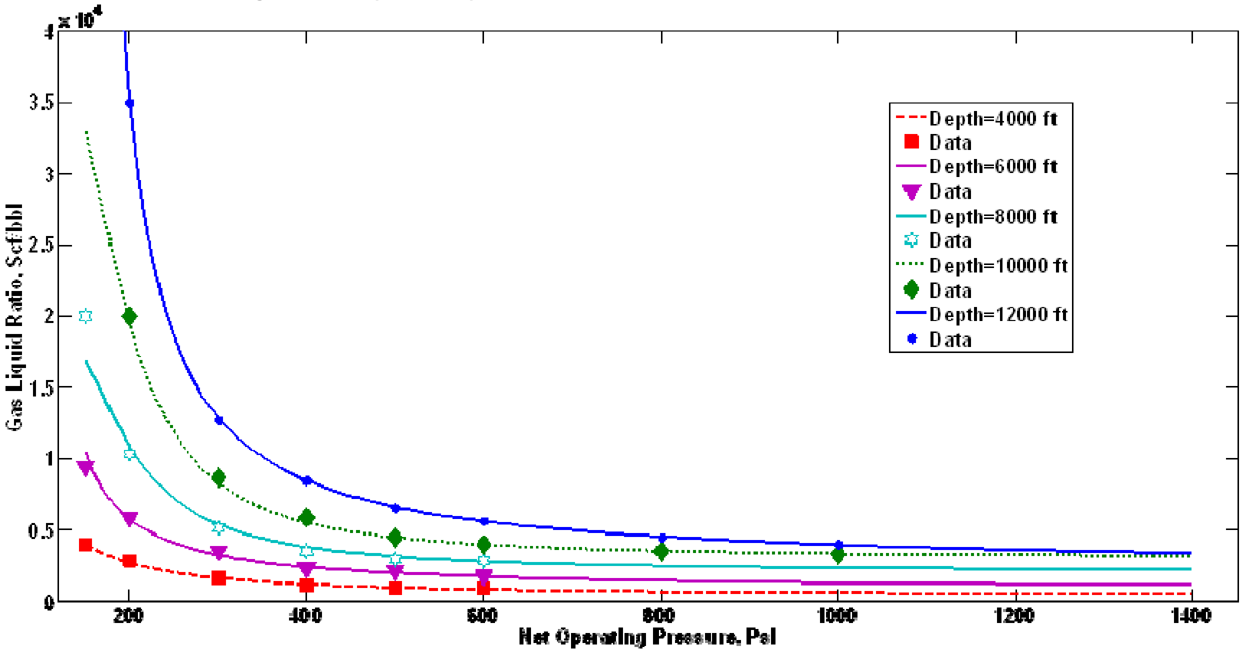

Figure 2. The results of predictive tool for the estimation of minimum gas liquid ration for 2” plunger lift in comparison with Beeson *et al.* [3] data.

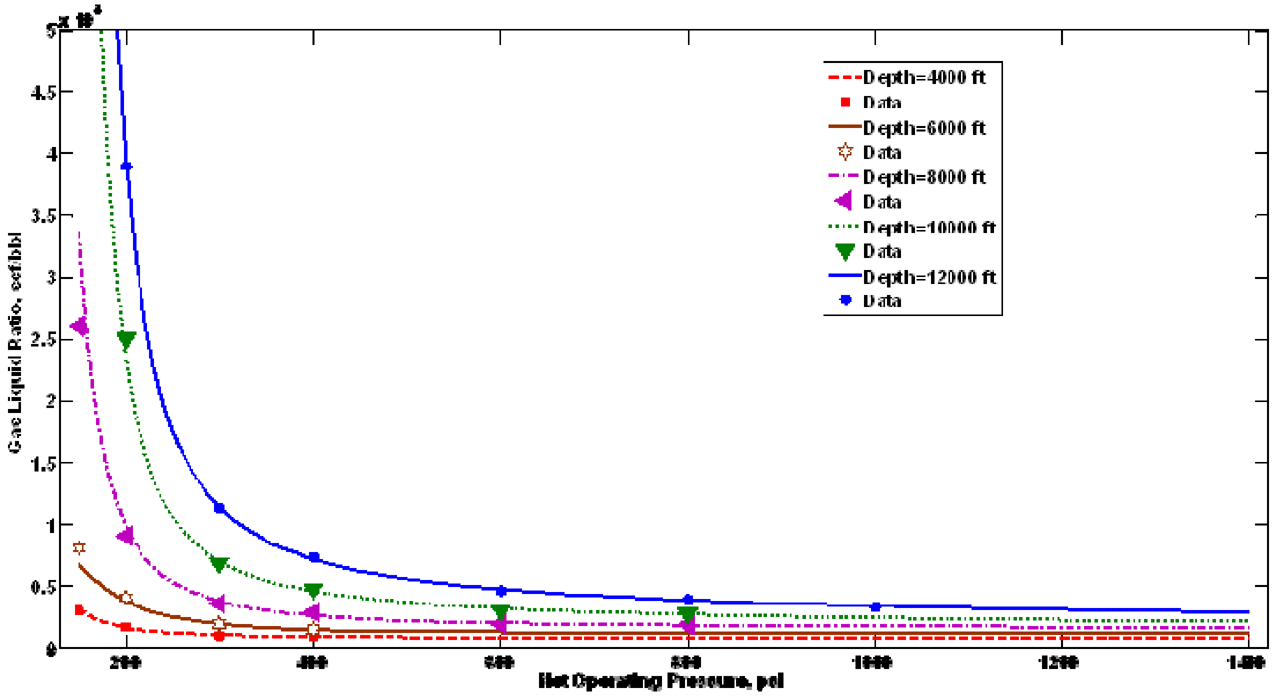

Figure 3. The results of predictive tool for the estimation of minimum gas liquid ration for 2.5” plunger lift in comparison with Beeson *et al.* [3] data.

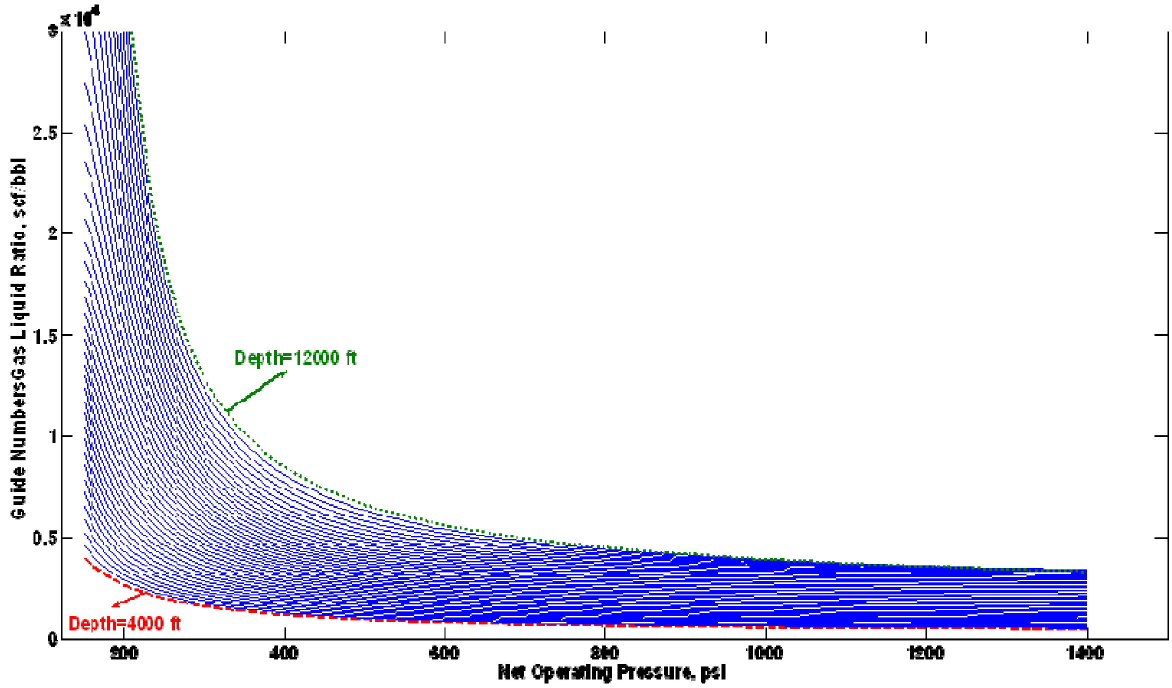

Figure 4. The performance of predictive tool for the estimation of minimum gas liquid ration for 2” plunger lift.

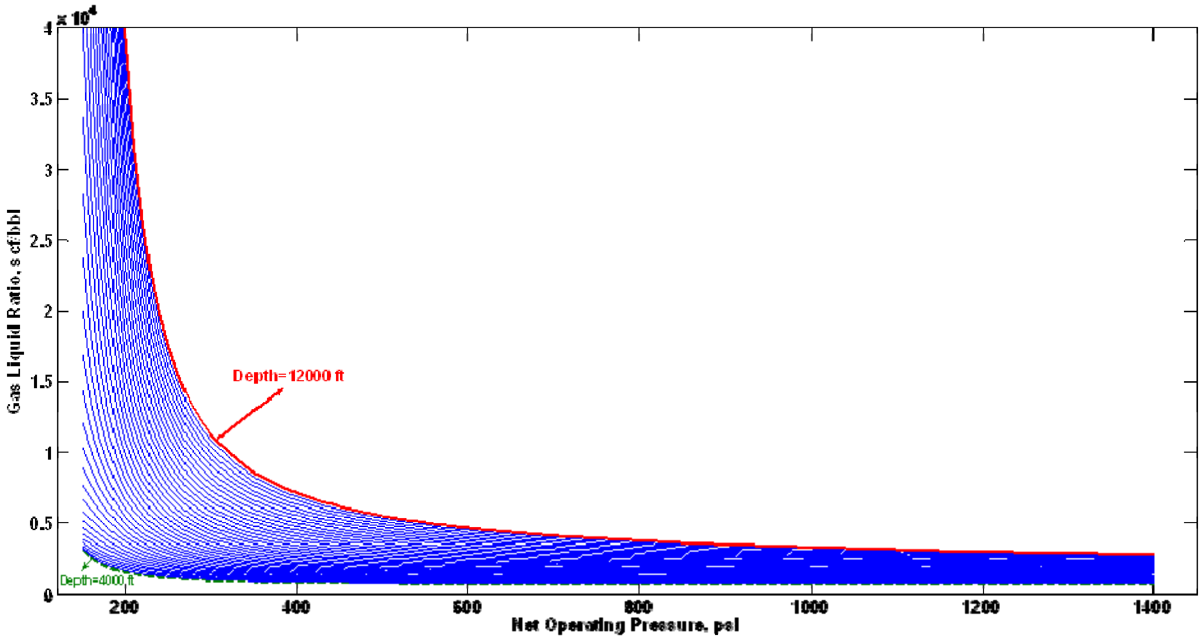

Figure 5. The performance of predictive tool for the estimation of minimum gas liquid ration for 2.5” plunger lift

3.1 Example

A well is equipped with 2 3/8-inch tubing (a 2-inch plunger approximately). Is this well a good candidate for plunger lift?

Operational data:

Casing build-up pressure 350 psi
Line or separator pressure 110 psi
Well GLR 8500 scf/bbl
Well depth 8000 ft

Use the predictive tool to determine whether plunger lift will work for this well.

Solution:

Net operating pressure = (Casing build-up operating pressure -Line pressure)=350-110= 240 psi. Calculations using new predictive tool show that at a depth of 8000 ft, the well is required the following minimum gas liquid ratio:

a= 7.627141 (from equation 10)

b= 1.8186843×10^{1} (from equation 11)

c= 1.18743477×10^{5} (from equation 12)

d= -1.11145×10^{7} (from equation 13)

GLR= 7788 scf/bbl (from equation 9)

In this example, the well must produce a GLR of approximately 7788 scf/bbl to maintain plunger lift. The example well has a measured GLR of 8500 scf/bbl and is therefore a likely plunger lift candidate. Note that pressure, gas rate, and depth are accounted for in this predictive tool.

4. Conclusions

In this work, simple-to-use equations, which are easier than existing approaches less complicated with fewer computations and suitable for engineers is presented here for the estimation of minimum required gas liquid ratio to support the applicability of plunger lift in a well as a function of well depth and net operating pressure. Unlike complex mathematical approaches the proposed correlation is simple-to-use and would be of immense help for engineers especially those dealing with petroleum production and operations. Additionally, the level of mathematical formulations associated with the estimation of minimum required gas liquid ratio to support the applicability of plunger lift can be easily handled by an engineer or practitioner without any in-depth mathematical abilities. Example shown for the benefit of engineers clearly demonstrates the simplicity and usefulness of the proposed tool. The proposed method has clear numerical background, wherein the relevant coefficients can be retuned quickly if more data become available in the future.

Nomenclatures

A	tuned coefficient
B	tuned coefficient
C	tuned coefficient
D	tuned coefficient
m	matrix row index for $m \times n$ matrix
n	matrix column index for $m \times n$ matrix
P	Polynomial
Pn	Net operating pressure, psi
U	coefficient of polynomial
GLR	Gas liquid ratio, scf/bbl
I	index
J	index
L	Well depth, ft
V	Vandermonde matrix
X	data point
Y	data point
ɑ	Matrix element

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