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# EFFICIENT ESTIMATION OF GAS–LIQUID RATIOS FOR PLUNGER LIFT SYSTEMS IN PETROLEUM PRODUCTION OPERATIONS

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**Abstract**

Plunger lift systems have the benefits of increasing production, as well as significantly decreasing methane emissions associated with blowdown operations. In other words, plunger lift is accounted one of the most widely accepted and economical artificial lift techniques, particularly in gas/oil wells with high gas–liquid-ratio (GLR). Hence, it is necessary to present a reliable and efficient method for predicting the applicability performance of plunger lift system. In this communication, a simple method is introduced for the calculation of the minimum required gas–liquid ratios as a function of the net operating pressure and well depth. Using this dedicated method, satisfactory results are obtained and are quantified by the following statistical error factors: average absolute relative deviations of the predicted gas-liquid ratio from existing literature-reported values: 16.33 %, and R-squared: 0.968. Finally, the method proposed in this study is compared with an intelligent method. Our results show that the method proposed in this study is more accurate and applicable than the comparative intelligent technique.

***Keywords:*** *Gas-liquid ratio; Plunger lift; Method; Net operating pressure.*

## 1. Introduction

In petroleum production, artificial lift refers to the employ of mechanical techniques such as the continuous gas-lift (CGL), intermittent gas-lift (IGL) and plunger lift systems in order to improve the flow of liquids through a producing well. To provide the adequate energy to the liquid (oil or water) flow, the gas-lift methods are widely utilized as artificial lift techniques where gas is injected in the production well [1]. The gas-lift mechanism is that high pressure gas is injected into the production well to lighten the column of fluid and allow the reservoir pressure to force the fluid to the surface, then the gas that is injected, is produced with the reservoir fluid into the surface [2]. As a result, IGL with plunger is one of the different design options available to apply for increasing the liquid flow from a producing well. Plunger lift system is accounted as one of the most widely accepted and economical artificial lift techniques, particularly in gas/oil wells with high gas–liquid-ratio (GLR). The plunger lift tool 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 production well [3]. A plunger lift tool operates in a cyclic process with the well alternately flowing and shut-in [4]. However, the installation of a plunger lift system has led to some economic and environmental benefits including lower well fewer remedial treatments, lower capital cost versus installing beam lift equipment, continuous production which improves gas production rates and increases efficiency, decreased paraffin and scale buildup, lower methane emissions, *etc.*

There are different attempts made to predict the productivity performance of oil/gas well in presence of artificial lift techniques. Brown and Jessen [5], Brill *et al.* [6], and Neely *et al.* [7] conducted some laboratory experiments on special field installations of conventional IGL, establishing empirical rules for the setting of the operational parameters. They presented useful rules, but those guidelines lack in generality. Mower *et al.* [8] studied impact of plunger geometry on the fallback using different plungers. Machado [9] proposed a mechanistic method coupling empirical correlations and physical principles to determine some variables of the IGL process. The acquired theoretical results by Liao [10] indicated good agreement with Brown and Jessen [5], Brill *et al.* [6], and Neely *et al.* [7]. Chacin [11] introduced a simple-to-use approach for the determination of the production rate, and presented a procedure to choose the appropriate IGL technique. White [12] proposed the first simple mathematical relationships for the conventional IGL and did experimental works on laboratory installations. To indicate the decreasing liquid fallback in the plunger case, White [13] performed tests with and without a plunger.

Generally, measuring flow rate is not a minor task in the plunger-lift, since an aperture meter is applied to measure the flow rate, and the measurements can have major limitations of the rangeability, *i.e.*, the range in which the measurement is reliable can be excelled in a phenomenon called overrange of the meter, leading to big errors in measurements [14]. Moreover, there are no general models/methods or thorough researches of the dynamics of all the IGL process cycles that are coherent for all designs [1]. The production engineers require an efficient method to identify the performance of the various designs under certain field conditions, and to tune the operational parameters to their optimum values. The purpose of the present study is to develop such a method to predict gas-liquid ratio and also rationalize those tasks. Hence, a reliable method is introduced to estimate the minimum required gas-liquid ratios.

## 2. Gas–Liquid Ratio Data

In this study, about 60 samples were gathered from literature [15] and applied to develop an efficient model for predicting the minimum gas-oil ratio. The required data [15] to develop this model includes the minimum gas–liquid ratio (GLR, SCF/BBL) as a function of net operating pressure ($P_n$, psi) and the depth of well (d, ft) in 2-in and 2.5-in expanding cycle controlled plungers. Regarding the databank collected in this study, gas–liquid ratio ranges from 900 to 39000 SCF/BBL, the well depth ranges 4000 to 12000 ft, and net operating pressure is 100-1000 psi. Here, it should be mentioned that the fundamental step in developing reliable predictive models is the selection of an efficient and representative dataset [16-19]. The ranges and averages of parameters applied for developing the method as well as the reported values of gas–liquid ratio are summarized in Table 1.

Table 1 Ranges of data used for developing the model; data from [15]

| Parameter | Min. | Avg. | Max. | Type |
|---|---|---|---|---|
| Well Depth, ft | 4000 | 8135.59 | 12000 | Input |
| Net Operating Pressure, psi | 100 | 413.89 | 1000 | Input |
| Gas Liquid Ratio, Scf/bbl×$10^4$ | 0.09 | 0.68 | 3.90 | Output |

## 3. Development of the new method

As mentioned earlier, the main objective of the present study is to introduce an accurate, reliable and applicable method for estimating the gas–liquid ratio during petroleum production implementing plunger lift. To this end, well depth and net operating pressure are considered as predictor variables for the calculation of gas–liquid ratio. Furthermore, average absolute relative deviation (AARD) as a reliable statistical error parameter is considered to estimate the accuracy, and to find the best model with lowest deviation from actual data of gas–liquid ratio. For minimizing the deviation in field condition, the form of method presented in this study is as follows:

$$GLR = \left( \frac{-8.5224}{0.066487\, P_n + 1.7726} - \frac{(1.3961\, P_n - d)}{2.883\, w + 3026.4} - \frac{P_n - d}{(P_n)^{\frac{1}{3}} (8.9581\, P_n - 0.10452\, w)} \right) \times 10^4 \quad (1)$$

$d$= Well depth, ft ;$P_n$= Net operating pressure, psi; $GLR$= Gas–liquid ratio, SCF/BBL.

Having developed the method for the estimation of gas–liquid ratio in plunger lift system, some important statistical error factors including average percent relative error (APRE), standard deviation of error (SD), root mean square error (RMSE) and R-squared ($R^2$) have been employed to evaluate the performance of the newly developed method in terms of accuracy. Relevant formulas of the abovementioned error factors are defined as follows:

**1. APRE**

$$E_r\,\% = \frac{1}{n}\sum_{i=1}^{n} E_i\,\% \quad (2)$$

where $E_i$% stands for the relative deviation of calculated GLR data by the method presented in this study from its actual value, as follows:

$$E_i\,\% = \left[ \frac{GLR_{\exp} - GLR_{\text{rep./pred}}}{GLR_{\exp}} \right] \times 100 \Rightarrow i = 1,2,3,...,n \quad (3)$$

**2. AARD:**

$$AARD\% = \frac{1}{n}\sum_{i=1}^{n} | E_i\,\% | \quad (4)$$

**3. RMSE:**

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(GLR_{i\,\exp} - GLR_{i\,\text{rep./pred}}\right)^2} \quad (5)$$

**4. SD:**

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{GLR_{i\,\exp} - GLR_{\text{i rep./pred}}}{GLR_{i\,\exp}}\right)^2} \quad (6)$$

**5. $R^2$:**

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(GLR_{i\,\exp} - GLR_{\text{i rep./pred}}\right)^2}{\sum_{i=1}^{n}\left(GLR_{\text{i rep./pred}} - \overline{GLR}\right)^2} \quad (7)$$

where $\overline{GLR}$ is the mean of the actual GLR data values presented in the above formula.

## 4. Results and Discussion

To compare the results obtained by the newly proposed method (Eq. (1)), an intelligent technique called least square support vector machine (LSSVM) algorithm [20-21] was applied in this study. As a result, the LSSVM approach has only two adjustable parameters (γ and $\sigma^2$) which should be tuned by using an optimization approach. To this end, the coupled simulated annealing approach (CSA) was used with the LSSVM algorithm. Consequently, the LSSVM tuning parameters have been optimized using CSA tuning method. As a consequence, the optimized values of the LSSVM model proposed in this study for the estimation of minimum required gas–liquid ratios are 0.866642104 and 35392.53828 for $\sigma^2$ and γ, respectively.

Table 2 lists the results obtained by both Eq. (1) and LSSVM model for the estimation of gas–liquid ratios in plunger lift system. As it is clear in the table, the results obtained from Eq. (1) are in better agreement with the actual data of gas–liquid ratio than the results of LSSVM model. The AARD for Eq. (1) and LSSVM model are reported 16.3 and 17.3, respectively.

Table 2 Accuracy results of the developed models for prediction of minimum gas-liquid ratio

| Performance | AARD, % | APRE, % | SD | RMSE | $R^2$ |
|---|---|---|---|---|---|
| Eq. (1) | 16.3 | 0.13 | 0.21 | 0.14 | 0.97 |
| LSSVM approach | 17.3 | -3.3 | 0.24 | 0.12 | 0.97 |

This indicates that Eq. (1) is more appropriate for the estimation of gas–liquid ratios in plunger lift system. Figs. 1 and 2 illustrate the scatter diagram (left view) and relative error distribution diagram (right view) for the newly developed equation and the LSSVM model, respectively. As clear from the figures, the predicted data by Eq. (1) are more matched with the actual gas–liquid ratio data. Moreover, the distribution of relative error around zero line for Eq. (1) is less than the LSSVM model. Additionally, the error analysis conducted in this study clearly indicates that the LSSVM model underestimates the actual gas–liquid ratio data with respect to the APRE= –3.3%. Furthermore, the method developed in this study is more applicable than the LSSVM model, because the LSSVM approach is a complex mathe-matical algorithm while the proposed method is a simple equation. Therefore, it can be concluded that Eq. (1) is a promising choice for application in petroleum engineering calculations related to production optimization, and artificial lift systems.

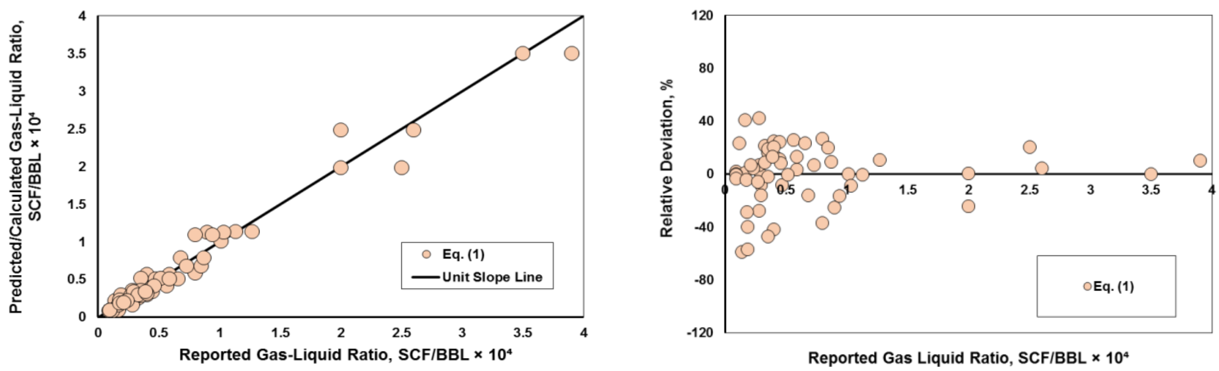


Figure 1 The results obtained by Eq. (1); left view: scatter diagram; right view: relative error distribution plot

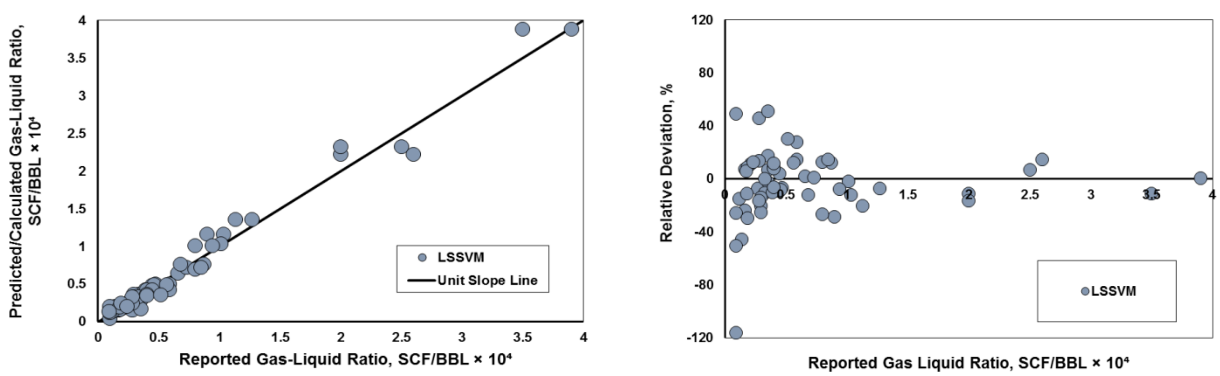


Figure 2 The results obtained by the LSSVM model; left view: scatter diagram; right view: relative error distribution plot

To indicate smooth performance of the developed equation and also a further comparison between literature-reported gas–liquid ratio data [15] and the obtained values by the newly proposed method, the trend plot of the minimum gas-oil ratio versus net operating pressure is sketched. Figs. 3 and 4 illustrate the trend plot of the minimum gas-oil ratio values versus net operating pressure for 2 and 2.5 inches plunger lift, respectively. These figures show satisfactory agreement for the newly developed method in comparison with the literature-reported gas–liquid ratio data.

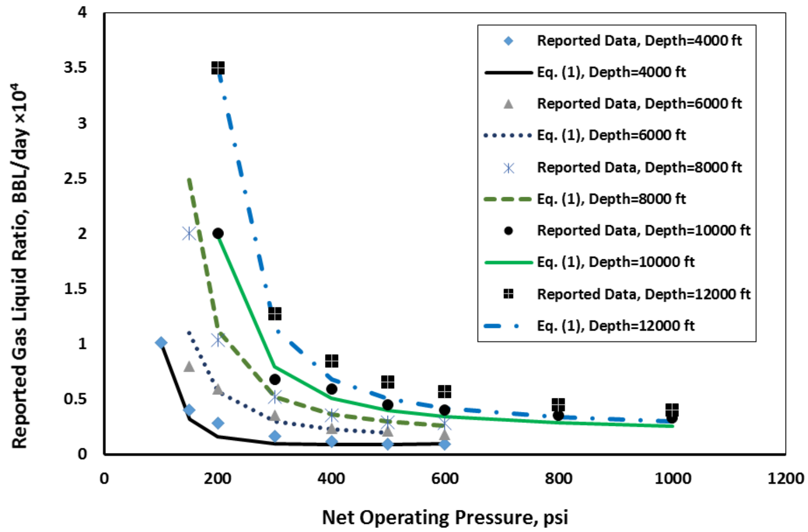


Figure 3 The performance of proposed equation (Eq. (1)) for the determination of gas-liquid ratio in comparison with the data for 2 inch plunger lift.

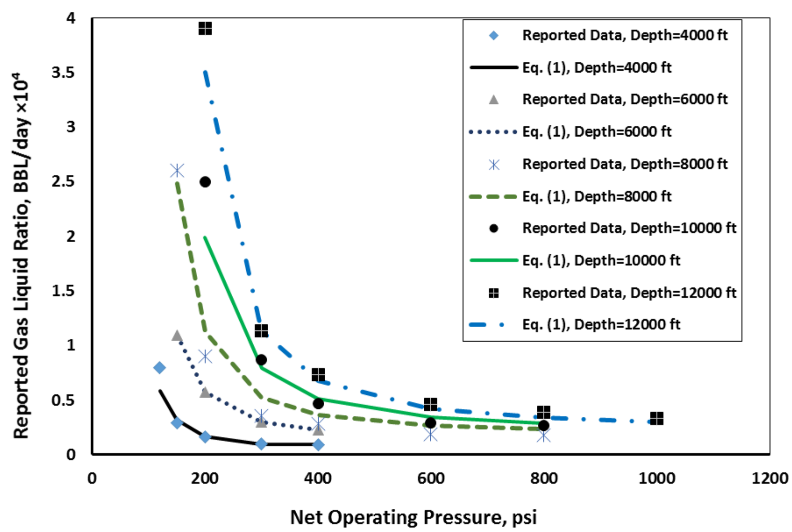


Fig. 1 The performance of the proposed equation (Eq. (1)) for the determination of gas-liquid ratio in comparison with the data for 2.5 inch plunger lift

## 5. Conclusion

In this study, a reliable method was introduced for the estimation of gas–liquid ratio in plunger lift as a function of net operating pressure and well depth. Furthermore, least square support vector machine technique (LSSVM) as a well-known intelligent technique has been applied in order to compare the performance prediction of equation presented in this study. The results illustrate that the equation proposed in this investigation is more accurate than the intelligent technique, and gives better results and can be advantageously used for prediction of the minimum gas-liquid. Furthermore, the method introduced can easily be utilized in any production simulation software and can provide good accuracy and performance for the minimum gas-liquid estimation.

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