METHOD COMPARISON FOR GAS LIFT ALLOCATION AIMED AT MULTIPLE GAS LIFT WELLS

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ABSTRAK

Gas angkat yang berterusan adalah penting untuk membolehkan setiap telaga yang memerlukan gas angkat mengeluarkan minyak. Walaubagaimanapun, jumlah gas yang tersedia adalah sangat terhad. Oleh itu, jurutera harus menggunakan sumber gas yang terhad untuk di agihkan ke setiap telaga. Salah satu cara ialah dengan setiap telaga diagihkan jumlah gas yang sama tetapi cara ini tidak optimum terutama untuk telaga yang mempunyai prestasi gas angkat yang berbeza. Thesis ini telah dijalankan untuk membandingkan kaedah yang bebeza didalam model lengkungan untuk membahagikan gas kepada beberapa telaga supaya jumlah pengeluaran minyak didalam sesebuah lapangan telaga minyak dapat ditingkatkan. Didalam model lengkungan, tiga kaedah telah dikaji iaitu Binari Integer Linear Optimum, Umum Pengurangan Kecerunan Optimum dan Pengoptimunan Evolusi Peruntukan. Perisian GAP telah digunakan untuk membina model and mengira agihan optimum serta dijadikan sebagai kayu ukur untuk thesis ini. Keputusan kajian menunjukkan pengagihan optimum adalah lebih baik dibandingkan dengan pengagihan sama rata. Tambahan pula, persamaan lengkungan telah dikira dan telah dimodelkan dengan baik untuk disamakan degan lengkungan prestasi gas angkat. Persamaan Alarcon ada yang terbaik untuk mewakii lengkungan prestasi gas angkat jika dibandingkan dengan persamaan Hamedi, Haiquan dan Viera. Umum Pengurangan Kecerunan Optimum adalah pengiraan yang terpantas jika dibandingkan dengan model lengkungan yang lain. Binari Integer Linear telah mengagihkan gas dengan lebih baik jika di bandingkan dengan kaedah optimum lain iaitu Umum Pengurangan Kecerunan Optimum adan Pengoptimunan Evolusi Peruntukan.

ABSTRACT

Continuous gas lift source is essential which allows each of gas lift wells to produce. However, the problem is the amount of total gas lift availability for a field is typically limited. Therefore engineers have to use the total available gas to allocate to all or selected gas lift wells in the field. One of the approaches is to apply the same amount of gas lift injected for each well in a field, but this method is not optimum especially for wells that have different gas lift performance. This study has been executed to compare different methods in the curve based model for gas lift allocation aimed multiple wells to maximize the total production rate in a field. In the curve based model, three methods of optimization have studied which are Binary Integer Linear Optimization, General Reduced Gradient (GRG) Optimization, and Evolutionary Optimization. General Allocation Program (GAP) software has been used to model and compute the optimum allocation and has used as a benchmark in this thesis. Result confirmed that optimize allocation can deliver more production compare to the average amount of gas lift method. Additionally, best curve fit equation in the curve based method for non-linear equation has been computed to represent the gas lift performance curve. Alarcon equation is the best curve fit equation compared to Hamedi, Haiquan, and Viera. GRG Optimization has the fastest computing time and as accurate as an Evolutionary Optimization method. Binary Integer Linear intuitively has provided better gas lift allocation comparing to the GRG and Evolutionary Method.

Keywords: *gas lift allocation, Curve Based, General Reduced Gradient, Evolutionary, Binary Linear*

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LIST OF ABBREVIATIONS

ESP	-	Electrical Submersible Pump
GAP	-	General Allocation Program
GLPC	-	Gas Lift Performance Curve
GOR	-	Gas Oil Ratio
GRG	-	General Reduce Gradient
IPR	-	Inflow Performance Relationship
LP	-	Linear Programming
PI	-	Productivity Index
SQP	-	Sequential Quadratic Program
TPR	-	Tubing Performance Relationship
UTM	-	Universiti Teknologi Malaysia
VLP	-	Vertical Lift Performance
WC	-	Water Cut

LIST OF SYMBOLS

C = Constant

J = Productivity Index

P_e = External boundary radius pressure, psi

P_{wf} = Well Sand-face mid-perf pressure, psi

Q = Surface flow rate

q_{gi} = Individual Gas Injection Rate

Q_o Total = Total Production Rate

q_{oi} = Individual Production Rate

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Source of natural energy to drive oil, water, and gas towards the wellbore is the drive mechanism of that particular reservoir. There are a few types of reservoir drive mechanism such as water drive, gas cap expansion drive, solution gas drive, compaction drive and gravity drainage drive.

Water drive reservoir is a reservoir that bounded with water aquifer. The invading water aquifer assists in driving hydrocarbon to the producing well. The effectiveness of the water drive reservoir depends on the size of the water aquifer.

Gas cap expansion drive is also a common type of drive mechanism. Characteristic of the gas cap drive is a reservoir that has a segregated gas zone on top of oil column which the degree of drive index depends on the size of gas cap. The size of the gas cap is referred to as “m” is the ratio of initial reservoir gas cap volume over initial oil volume.

Solution gas reservoir does not have a gas cap, and water aquifer but it will develop free gas as pressure-depleted, which classified as solution gas. Additionally, a secondary gas cap formed from the free gas which accumulates at the crest of the reservoir.

In most of the reservoirs, the hydrocarbon produced under the influence combination of the two or more natural drive. The drive mechanism of a reservoir evaluated during production mode by analyzing the trend of the gas oil ratio (GOR), watercut (WC) and reservoir pressure. (Tarek Ahmed, 2006). However, in most cases relying on the natural energy to push the oil to surface from the well is not enough. Especially towards the end of production lifetime. Therefore, artificial lift is needed to assist in lowering the flowing bottomhole pressure inside the wellbore which allows the hydrocarbon to produce. Furthermore, artificial lift also can improve the well rate by increasing the drawdown.

The artificial lift divided into two categories which are a pump assisted process and gas assisted process. The pump-assisted process consists of rod pump, linear lift system, hydraulic piston pump, electrical submersible pump (ESP), plunger lift and progressive cavity pump (PCP). Where else the gas assisted process consists of gas lift and plunger lift. Table 1-1 is showing the comparative study of different types of artificial lift. Based on the comparative study, screening of artificial lift can be made, for example well with high WC and low GOR, Electrical Submersible Pump (ESP) can be selected as artificial lift but well with high GOR, low WC, and high production rate it is more suitable to install a continuous gas lift. (Naguib *et al.*, 2000)

Table 1-1 Comparative study of different Artificial Lift techniques (Naguib *et al.*, 2000)

Item	Gas Lift	ESP	Hydraulic	Rod pump
Workover Frequency	Low rigless	High Rig	Moderate Rig	High Rig
Shut down	Low	High	Moderate	Low
Run life year	Very good	Medium	Good	Very Low
Movable part	None	Exist	None	Exist
Wireline Operation	Easy	Difficult	Impossible	Impossible
Capital Cost	High	High	Medium	Medium

Operating Cost	Low	High	Moderate	High
High GOR	Effective	Inefficient	Inefficient	Inefficient
High WC	Restricted	Effective	Unsuitable	Unsuitable
High rate	Effective	Effective	Unsuitable	Inefficient

The two types of gas lift are an intermittent gas lift, and a continuous gas lift. Intermittent gas lift used in low production well and operated on an intermittent basis. Periodic displacement of liquid in the production tubing using high-pressure gas injection will bring the slug of liquid from downhole of the well to the surface. However, this will cause a problem with the surface gas handling due to well surging. Intermittent gas lift is not an efficient artificial lift and used as a replacement to the continuous gas lift when the reservoir pressure depleted. (Hernandez *et al.*, 1999)

Continuous gas lift assists in lowering the hydrostatic head in the wellbore. The basis is lightening the fluid column. Gas is injected at a specific downhole depth and injected the gas at an uninterrupted flow stream. (Khamehchi and Mahdiani, 2017). Continuous gas lift method is suitable for a well with a good productivity index (PI). The productivity index is a potential of the reservoir to produce, the typical field unit is stb/psi/day, and the mathematical formula as per below:

$$J = Q / (Pe - Pwf)$$

J = Productivity Index

Q = Surface flow rate

Pe= External boundary radius pressure, psi

Pwf=Well Sand-face mid-perf pressure, psi

Currently, artificial intelligence technique has been used in the industry to enhance forecast and prediction in PI. (Alarifi, Alnuaim, and Abdulraheem, 2015)

Continuous gas lift is suitable to handle production between 200 bpd to 20000 bpd. About 95% of gas lift wells in the world produced by continuous gas lift. About 95% of gas lift wells in the world produced by continuous gas lift. Again as showing in Table 1-1, continuous gas lift is efficient to maximize well performance in high GOR well. Furthermore, gas lift is the only type of artificial lift that can easily handle sand prone production. The continuous gas lift does not have mechanical part such as a downhole pump which likely to erode by sand that flows at high velocity. (Wilson, 1990)

Commonly, the gas used comes from formation GOR or associated gas from a similar reservoir that separated at the surface via a separator. Other than that, the source of gas lift can also come from the nearby available gas well and nitrogen gas injection generated in situ (Lozada Aguilar and del Remedios Arredondo Monarrez, 2000).

There are two configurations for gas lift processing which is closed circuit and open circuit. A closed circuit is a gas lift system that recovers gas from the separator and circulates back to the well repeatedly after went through processing stages such as gasoline extraction, dehydration, and sweetening. However, for an open circuit system, the gas processing is the same as a closed circuit system. However, the balance of gas is either flared or sales as shown in Figure 1-1.

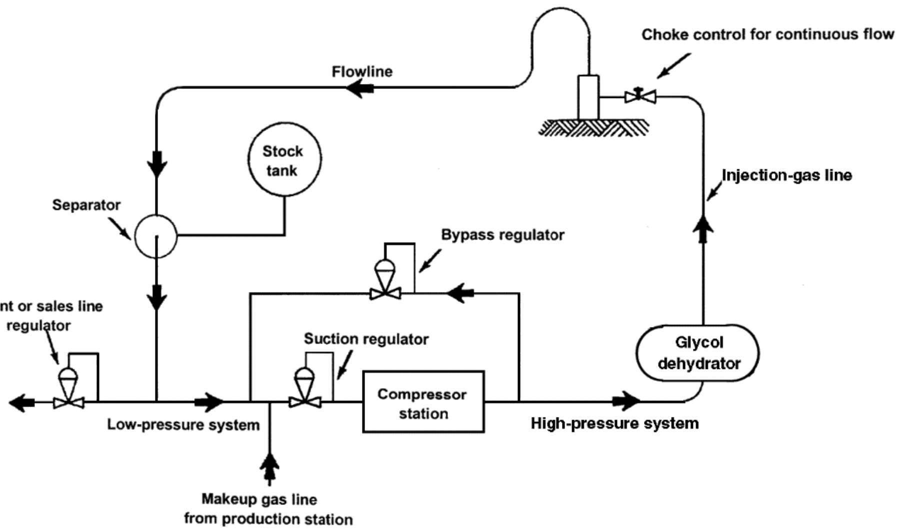

Figure 1-1 Open Loop Gas Lift Gas Processing Stage (Petrowiki, 2015)

Both multiple and single zone completion can be completed using the gas lift. Gas lift gas flows through the annulus between casing and production tubing. The gas injected via gas lift valve and produced with production fluid inside production tubing. This process called the direct method. However if the gas flows through production tubing and produces together with production liquid in the casing, the process it is called the reversed method.

Furthermore, macaroni pipe and coil tubing also can use as a concentric completion for gas lift utilization. This configuration has usually been used to unload the well without gas lift mandrel such as for gas well or water injection well (Perrin, Caron and Gaillot, 1999)

Nodal Analysis can be used to evaluate well performance. Two performance curve analyzed at wellbore node. The two curves are the inflow performance relationship (IPR) and vertical lift performance (VLP). IPR is a reservoir performance curve. It considers permeability, reservoir pressure, completion type, and etc. One of the methods to calculate IPR has been discussed in the previous paragraph which the PI method. VLP is the tubing performance curve that taking into consideration three main pressure drop which is acceleration, hydrostatic and friction. (Brown, 1984).

Gas lift performance curve then can be generated by sensitive the gas lift rate function versus production rate of the particular well using Nodal Analysis calculation. Multiple gas lift well will have different gas lift performance curve (GLPC). If the same amount of gas lift supplied to multiple gas lift well, the field production not produced to the full potential. Therefore allocation optimization needs to be calculated. In regards to that, maximum total production rate within the constraint of gas lift gas availability calculated via optimization calculation.

Optimization is searching or guessing an interesting point of a function which is either maximum or minimum. A lot of optimization approach in numerical method. However, this study is only focusing on constrained optimization. Constrained optimization is a process of optimizing objective function with respect to multiple variable and in the presence of constraints of those variables (Chapra and Canale, 2010)

Step gas injection test can provide the gas lift well production behavior. The test is done by increasing gas lift injection rate and at the same time monitoring the increment of the production rate. This test gave rise to the development of tools to model and match well performance. Furthermore, this tool such as Prosper which developed by Petroleum Expert can also be used to predict the behavior of multiphase flow. This software overcomes the complication of performing costly and time-consuming step rate test. In addition to that, this tool can provide individual gas lift performance curve for multiple gases lifted well.

The gas lift performance curves of each gas lift well fitted using a mathematical model, and the curve based model developed. This curve model will consider the optimization of all gas lifted well but neglect the well to well surface interaction such as back pressure impact. Complete model with the final steady-state solution derived from the network simulator software. Network simulator software is taking consideration of pressure balance in all network's node after the gas lift allocation to that well. Hence, back pressure impact due to injection of gas lift considered in the network simulation. (Rashid, Bailey and Couët, 2012). Table 1-2 is showing the summary of a different approach for gas lift allocation optimization.

Excel data analysis capability used to navigate and to analyze the complex data. Excel includes a tool that used for optimization which is solver. This add-on used as optimization tool and data analysis. Utilizing the excel solver, the author will find the optimum gas lift allocation to increase total oil production rate in the system for the curve-based model using different optimization models such as Simplex Linear Programming, General Reduce Gradient, and Evolutionary method. (Nelson and Nelson, 2014)

General Allocation Program (GAP) has been introduced in this study as a benchmark for comparison.

Table 1-2 The evolution of approaches developed for the treatment of the gas lift optimization problem (Rashid, Bailey and Couët, 2012)

Merits	Limitation
Performance Curve Generation	
Provides well production relationship with a gas lift injection rate	Well test requirement
	Well test data quality
Nodal Analysis	
Well model simulation	Fluid data assumptions
Multi-phase flow modeling	P and T assumptions
Performance curve generation	Primarily for a single well
Curve-based models	
Fast, analytical models	Neglect well interaction
Consider all wells	Curve fitting and quality
Simple to evaluate	Steady State Solution
Network Simulation	
Rigorous simulation model	Evaluation cost
Includes well interaction	Model Smoothness
Handles looped models	Steady State Solution
Handles facility components	Gradient Information

1.2 Problem Statement

Performance of gas lift well is not identical. Even with the similar amount of gas lift injection rate, each gas lift well can perform differently. This subject to the gas lift performance curve (GLPC) of an individual well. Figure 1-2 shows an example of gas lift performance curves for 5 gas lift wells (Fitra, Sukarno, and Soewono, 2015).

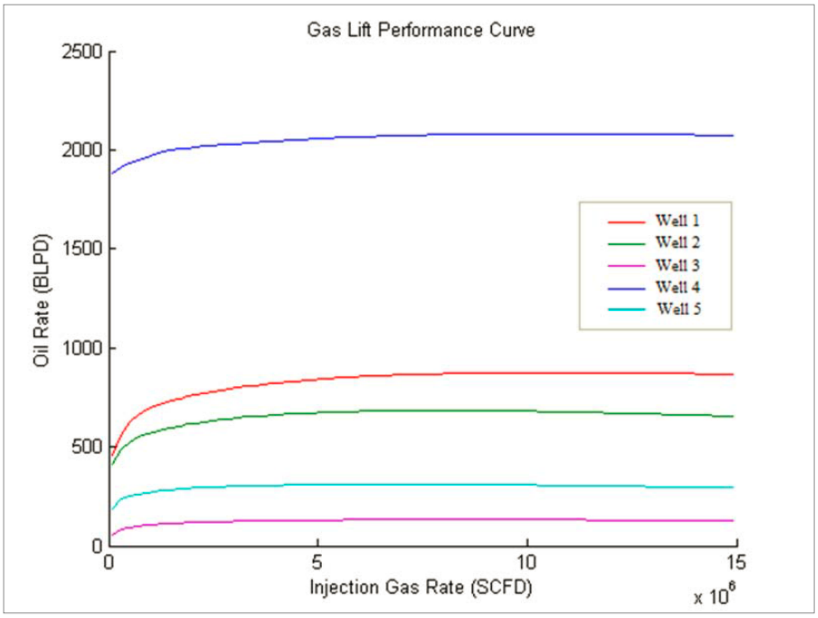

Figure 1-2 Example of gas lift performance curve for 5 gas lifted well (Fitra, Sukarno, and Soewono, 2015)

Continuous gas lift is necessary to maintain and improve hydrocarbon production in a field. The most common constraint for gas lift system is the maximum available lift gas. In fact that, gas lift allocation in a field is rarely unlimited. Maximum gas lift availability limit is constraint by surface facilities such as a compressor, separation capacity and lack of high-pressure gas well source. Besides that, it is also expensive to upgrade the existing gas lift compressor (Rivero *et al.*, 2014). Besides that, there are several methods available for gas lift gas allocation. Methods Comparison will be performed to determine the differences between the available methods.

This problem has led to the need of allocating gas lift with the constraint of the associated gas and facilities. Therefore with optimum gas lift allocation to each well, it is anticipated to improve total production rate of the field (Lu and Fleming, 2011)(Monfared and Helalizadeh, 2013). Moreover, it anticipated that GRG Calculation gives faster result compare to Evolutionary Method. (Young, 2017). Binary Integer Linear will have better allocation compare to other curve-based optimization model.

1.3 Objectives

The objectives of this project are:

1. To identify the curve-based allocation method.

2. To compare different type of equation to represent the gas lift performance curve.

3. To compare different types of curve based allocation method.

1.4 Research Scope

- Literature review to identify different type of gas lift allocation method.

- Creating the well model using nodal analysis software and generating gas lift performance curve (GLPC).

- Performing best curve fitting to GLPC and developing curve based models.

- Calculating gas lift allocation utilizing the curve based models.

- Constructing General Allocation Production (GAP) model and calculating gas lift allocation.

- GAP software as a comparison benchmark.

- Comparing different types of optimization in curve based models.

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