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The Cost of Gas Production Optimization Using Linear Programing on Reverse Fishbone Diagram: A Case Study

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ABSTRACT
This paper presents the outcome of our research on the cost of gas production optimization in an oil field. To estimate the cost of gas redistribution, the following observations were arrived at: Gas storage/reinjection take priority, if the production goal is geared towards boosting the reservoir. Export Sales Gas is prioritized over Gas Lift Gas, on condition that maximum profit derivation becomes the essence for the gas production. Gas redistribution modes were formulated, and the following results were derived: alternate gas cost $152.076 (average per week) and fuel gas cost at $124.062 (average per week) for the period under review. While Diesel fuel cost at $2000 per day. The ratio of fuel gas usage was also compared with alternate fuel gas (diesel fuel) per day, which stood at 1:128 approximate. It indicates that diesel fuel usage cost one hundred and twenty-eight times (128) higher than the cost of average fuel gas usage per day.

KEYWORDS: Aerate Well Casings, Fluid Influx, Petroleum Product Recovery, Production Channeling, Production Optimization.

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1. INTRODUCTION

The development in the world today has created a massive rise in the demand for energy. Over the years there has been a drastic increase in the consumption rate of energy. Global activities like manufacturing processes and technology boost are dependent on energy for their day-to-day activities (Aalo, 2019). So far energy consumption has been centered on fossil fuels of which natural gas makes up 21% of the world's energy supply. This massive and growing demand for natural gas has brought with it some major problems ranging from over-dependence to climatic change in the environment because of increased concentration of Green House Gas (GHG) being flared in the atmosphere during production.

As the upsurge in the demand for energy continues to increase, natural gas despite its massive demand has not till recently been heavily faced with loads of challenges. These issues have thrown the oil and gas industry into transformational times and reflected in its deep price drop. Trade wars between production countries to other factors are some of the resulting effects of the price drop. With these changes, the industry is faced with several challenges in achieving its goals of efficient and environmentally responsible operations, capital cost reduction and profit maximization. This adds up to the need for optimization in gas production.

Izuwa (2017) suggested that the development and effective management of gas sector in Nigeria remains a strong channel for expansion and will generate opportunity for multiple revenues for Nigerian economy. He stated that harnessing associated, and non- associated gas should become a thing of interest to the Government and oil industry. This will not only add value to natural gas but also monetize natural gas. The goal is ensuring that routine gas –flare could be a thing of the past if adequate measures are taken at the appropriate time.

The goal of all effort spent on gas production is to devise an optimal strategy to develop, manage, and operate the production of such gas which creates a need for a process, or methodology of making the process perfect, functional, or effective as possible called optimization (Pengju, 2003). In optimization of small systems like a single well or mild pattern

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creation simple nodal analysis may be adequate but large complex systems like gas production demand a more sophisticated optimization approach which will be done in this project using linear programing on reverse fishbone diagram.

The activities of multinational oil companies have their main objective as the production of oil and gas for improved economic development. These activities when not properly organized tend to become a major source of environmental degradation culminating into deprivation of sources of livelihood. This degradation is because of intense global warming derived from flared gasses. The advent of excessive flared gas and knowledge of the proper use of some of the flared gas, gave rise to the utilization of part of the gas for reinjection and compression, especially when in an associated form. The need therefore arises to properly estimate the rate at which these gaseous components are distributed. The technique for this estimation utilizes a linear programing approach. This approach can predict the quantities of gas at a particular time, at a particular chain of distribution on a Reversed Fishbone Diagram. The reverse fishbone diagram is an analysis tool that provides a systematic way of looking at effects and the causes that create or contribute to those effects. The structure provided by the diagram helps team members think in a very systematic way. Some of the benefits of constructing a reverse fishbone diagram are that it helps determine the root causes of a problem or quality characteristic using a structured approach, encourages group participation and utilizes group knowledge of the process, identifies areas where data should be collected for further study (Masoud, 2011).

Raw natural gas is known to be produced from three diverse types of well viz: oil wells, gas wells and condensate wells. Gas processing may be done partly at the well head and at process separators. Caudle and Mcleroy (2019) detailed that the recovery of petroleum product in wells reduces as exploration continues and reservoir pressure declines. It therefore encourages the use of artificial lift since most of the petroleum product may enter the tubing but will be unable to reach the surface due to this pressure reduction. This method used and installed lift pump to achieve lifting. They concluded that as part of safety and the environmental commitment, reducing greenhouse gas (GHG) emissions should be part of Operations' plan.

Stauffer (2014), in a related study on recovering of oil at gas wells, stipulated that most gasses are flared. The technological works on the use of Reformers have progressed tremendously. The Reformers convert gas to usable liquids (synthesis gas). The initial work was targeted at production of diesel from biofuel bit. The work further deployed models to simulate engine operation, using a conventional spark-ignition (SI) engine to run with an exceptional amount of excess fuel. The work concluded that, at sites where gas is flared, the small system could be supplied with natural gas at reduced or no cost. Result shows that, it is difficult to design a solution procedure that is both robust and computationally feasible and proposed a unique approach for the efficient optimization of the entire system. The proposal was achieved by optimizing continuous variables and discrete variables using different optimization algorithms.

Buitrago *et al*. (1996) in their research encountered oil production optimization problem from a set of 56 Wells with 225,000 MSCF/D of available gas. Leading from Wells low well head pressure and requiring gas lift gas. A stochastic algorithm method (Equal-Slope and Ex-In) was used to solve the problem. However, Wang et al. (2003) introduce a mixed integer variable for each well to formulate the branch and bound method. The method was used to resolve gas lift optimization problem. The research addresses the operational decisions to enhance production, which includes how to control well rates with chokes and distribute available lift-gas among specified wells.

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Igwilo (2018) noted that with Gas lift, the field operators are faced with the charge to develop optimum operational approaches to accomplish definite operational goals. The goal of all efforts to form an oil and gas field is to develop an optimal strategy for the development, management, and operation of the field. Optimizing production operations for certain fields can be a crucial factor if the production volumes are to be increased to reduce production costs. The study considered the solution methods to determine optimal production rates and the rates of lift gas to optimize regular operational objectives. Analysis result show that lowering the well head pressure to 100 psi is recommended if the desired production optimization is to extend the well's life by 70% water cut, which can optimize production. The gas lift method is economical in this case, since it produced an optimum economic water cut of 80 percent when gas was injected at the rate of 2 - 4 MM scf/day to produce 1800 - 2000 STB/day of gas.

Rios-Mercado and Borraz-Sanchez (2014) presented a state-of-the-art survey method. The study adopted and discussed works based on deterministic models, i.e., where each parameter is assumed known in advance. It reviewed relevant works targeted at solving gas transportation via pipelines. The work considered line-packing problems which are short-term storage, gas quality satisfaction which relate with pooling problems, and compressor station modelling a pointer to fuel cost minimization problems. In the outcomes, pipelines were adjudged to be the most economical method of moving gasses since it was easy to weld and form materials with good metallurgical qualities. The study result revealed the nonconvex nature of the problem and proposed global optimization techniques are necessary for handling this type of problems. The work concluded that, one of the major challenges to efficiently exploit the natural gas supplies arises from the limitation of the optimization techniques. The aim of this paper is to optimize the cost of gas production using linear programing on Reverse Fishbone Diagram.

2. MATERIALS AND METHODS

The following listed items form the materials that were used for this paper:

2.1 Gas Gathering and Separations

Gas distribution headers and its associate Separation equipment of the case study facility form the preliminary material for this paper. The gas route is observed to have a single source gas input from the satellite platform with option of alternate support route from a nearby independent facility. The gas is routed from an external/satellite platform to a manned production platform. On arrival the gas passed through the gas gathering headers and is lined up into a Separator. On condition that the inflow is expected to be high, another Separator is commissioned to handle the fluid influx. The equipment separates the input hydrocarbon fluid into gas and liquid.

2.2 Gas Measurement and Monitoring

As the source gas goes through the Separation equipment, it is metered for gas volume accountability. The gas volume is also used to predict business viability. The gas measurement and monitoring equipment used, includes Annubar (a device that uses Pitot tube to measure the gas flow rate), in-line Orifice Fitting and the Daniel Senior Orifice Box.

Plate 1: In-Line Orifice Fitting

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While the gas monitoring equipment used are Discreet Control System, Pressure, and temperature gauges.

Plate 2: Pressure Gauge

2.3 Problem Formulation

The reversed fishbone diagram identifies five outputs viz: Sales gas (to nearby platform), gas lift gas (GLG), Fuel/Seal gas, gas reinjection and relief to flare gas. It is the target intention of this program, to reduce flaring to as much as possible and as such increase or maximize profit.

The decision variables that determine output are the variables P, Q & R: refer to Table (1).

Let profit = Z

The Objective function is expressed as Equation (1):

$$\text{Max } Z = PA + QB + SD + RE$$

$$\text{Max } Z = PA + QB + SD + RE \quad (1)$$

where P = Profit of sales gas

A = Compressed sales gas determinant

Q = Profit of gas lift gas

B = Gas lift gas determinant

S = Profit/Loss of reinjection gas

D = Reinjected gas determinant

R = Profit/Loss of relief to flare gas

E = Flare gas determinant

However, where the 'Compression Production' decision variable is applied then, the objective function becomes Equation (2).

$$\text{Max } Z = PA + QB + SD$$

$$\text{Max } Z = PA + QB + SD \quad (2)$$

Since the amount of gas can be qualified in volume and associated cost attached then the objective function is as follows:

(A)

If $1m^3$ of compressed sales gas cost #10 and

(B)

$1m^3$ of gas lift gas cost #20

(D)

$1m^3$ of reinjection gas cost #10

Then the total profit (z) could be maximized (max) using Equation (3).

$$\text{Max } (Z) = 10A + 20B + 10D$$

$$\text{Max } (Z) = 10A + 20B + 10D \quad (3)$$

Table 1: Revenue and Cost Models

Models	Revenue	Cost	Net Profit
A	P	F	P
B	Q	G	Q
D	R	H	r
Total			

Given that:

i. Natural gas price = \$2.501 per kcf
ii. Brent oil = \$68.93 per barrel
iii. WTI oil = \$65.4 per barrel (source: https: nnpcgroup.com/pages/home on 15th March 2021)
iv. Crude production on 30th Jan. 2020 = 5.142kb.

Table 2 shows the cost of Natural gas in the past 4 years. This research adopted the Nigerian National Petroleum Company (NNPC) natural gas price of \$2.501 of 15th March 2021 over USA (Henry Hub) average gas price of \$2.675 per mcf.

Table 2: Price of U.S. Liquefied Natural Gas Import from Nigeria (Dollar per Thousand Cubic Feet)

Gas Price (mcf)	**Year**				**Average**
	2017	2018	2019	2020	

Journal of Newviews in Engineering and Technology (JNET)
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Price in US Dollar	6.52	8.84	5.56	3.5	6.105

Source: U.S. Energy Information Administration (www.eia.gov)

For planning purposes, the strategic gas plan for Nigeria (2004) pegs a conservative gas cost per one Mcf between less than \$0.25 to about \$0.70 (source: The National Gas Strategy Plan for Nigeria (2004), joint UNDP World Bank Energy Sector Management Assistance Programme (ESMAP). The gas production cost of \$0.5 was adopted for this research work.

Using average field data for year 2020 on Table 3a:

$$Max\ (Z) = (P - f)A + (Q - g)B + (R - h)D$$

$$Max\ (Z) = (P - f)A + (Q - g)B + (R - h)D \quad (4)$$

$$A35{,}525 + B208.055 - D3.37$$

$$A35{,}525 + B208.055 - D3.37 \quad (5)$$

On the same year, the average gas production based on streaming wells = 31.97Mscf

It implies that for year 2020,

$$A + B + D = 31.97Mscf(Avg)$$

$$A + B + D = 31.97Mscf(Avg)$$

2.4 Reversed Fishbone Redistribution Modes

Applying the RFB model on the case study, four modes were obtained as follow:

i. Normal gas production network: refer to Figure (1)

ii. Alternate support gas production network: refer to Figure (2)

iii. Blackstart fuel gas network: deploy where an alternate fuel gas source is required, which feed vital end users in the facility during a total plant shutdown condition

iv. Purge gas network: used prior to planned sectional or overall turnaround maintenance in the facility and when need arises to evacuate oxygen from process network prior to production startup.

Figure 1 parades the normal gas production channeling of the case study. In an abnormal gas production targets other distribution network will be deploy.

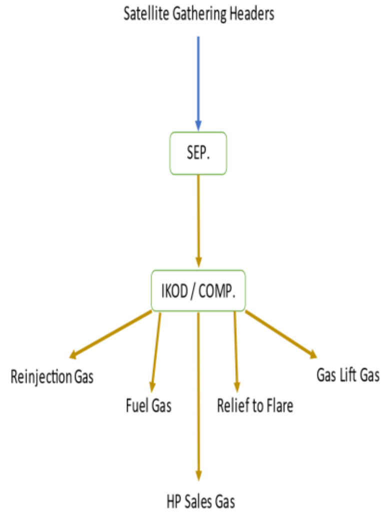

Figure 1: Normal Gas Production Network

Figure 2 illustrates an additional gas channel. It is a bi-directional pipeline design to either boost source gas for compression or export gas to a nearby facility.

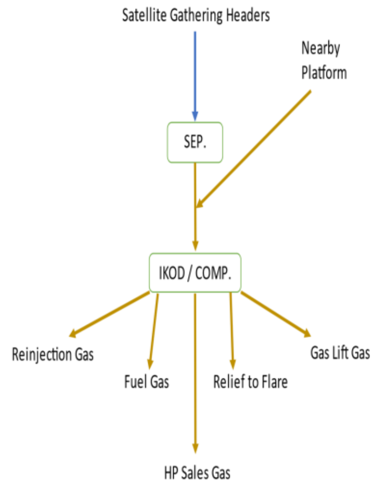

Figure 2: Alternate Support Gas Production Network

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2.5 Data Collection Source

This paper publication derived its data from SUCCESS production platform field raw data. The Company specializes in petroleum extraction and components (oil and gas) production. The daily gas production component constitutes the data collected: refer to Tables 3a to 3c. The major parameters considered are:

i. Sales Gas
ii. Gas Lift Gas (GLG) and
iii. Storage Gas.

2.6 Alternate Support Gas Cost Estimate

The total volume of gas that flows through the alternate gas line, during the period under review, stood at 76 Mcf approximately.
Recall the gas production cost of $0.5 adopted for this project work: refer to derived equations in Session 2.4.
Mathematically, it can be expressed as

$$(u + x) + (y + z) = w$$

$$(u + x) + (y + z) = w \qquad (6)$$

where x = Sales Cost
u = Cost of flaring at destination facility
y = Cost of flaring at source facility
z = Environmental degradation Cost
w = Actual Cost

Where the determinant for u, y, and z equal to zero: that is not applicable.
Then,

$$x = w \; x = w \qquad (7)$$

Applying the sales and cost component of x,

$$(76 \times 2.501) - (76 \times 0.5) = w$$

$$(76 \times 2.501) - (76 \times 0.5) = w$$

3. RESULTS AND DISCUSSION

3.1 Field Data Analysis

Raw field data were obtained from 2012 to 2020. Data were computed per year and average values derived. To optimize gas production, these values are needed for computation. It was used to compute and deduce into the constraint equation.

3.2 Gas Redistribution Cost Result

Applying the Equations in Section 2.6 to estimate the cost of gas redistribution, the derived linear formulas will be used in this Section.

3.2.1 Alternate Support Gas Cost Result

Applying the sales and cost component of sales gas cost into Equation 7.
Then,

$$(76 \times 2.501) - (76 \times 0.5) = w$$

$$(76 \times 2.501) - (76 \times 0.5) = w$$

Therefore, the actual cost (w) for alternate gas line for the period under review was calculated as

$$w = \$152.076 w = \$152.076$$

3.3 Data Optimization and Result

Raw field data in Tables 3a to 3c represent average values obtained between Year 2012 to 2020. These values were used for optimization computation.

Table 3a: Average Yearly Gas Production and Utilization Field Data

Gas Utilization (mcf/d)	Year 2012	2013	2014
Gas to Separator (X1)	44	34	30
From nearby Platform (X2)	0	0	16
Compressed gas (X3)	34	28	32
Sales to nearby Platform (X4)	9	0	8
Gas lift gas (X5)	24	17	18
Storage/reinjected gas (X6)	1	11	6
Fuel gas (X7)	9	6	7
Flare gas (X8)	1	1	6

Table 3b: Average Yearly Gas Production and Utilization Field Data

Gas Utilization (mcf/d)	Year 2015	2016	2018
Gas to Separator (X1)	29	27	40
From nearby Platform (X2)	20	20	0
Compressed gas (X3)	35	34	31
Sales to nearby Platform (X4)	9	11	5

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Gas lift gas (X5)	25	25	22
Storage/reinjected gas (X6)	1	1	3
Fuel gas (X7)	8	8	8
Flare gas (X8)	6	4	1

Table 3c: Average Yearly Gas Production and Utilization Field Data

Gas Utilization (mcf/d)	Year	
	2019	2020
Gas to Separator (X1)	37	15
From nearby Platform (X2)	3	17
Compressed gas (X3)	32	23
Sales to nearby Platform (X4)	5	14
Gas lift gas (X5)	19	6
Storage/reinjected gas (X6)	7	3
Fuel gas (X7)	8	8
Flare gas (X8)	1	1

Figures 3a and 3b tagged "Gas Optimization Graph for Objective functions", display the trend of the objective functions in a graphical trend. The graph derived details on objective function data processing.

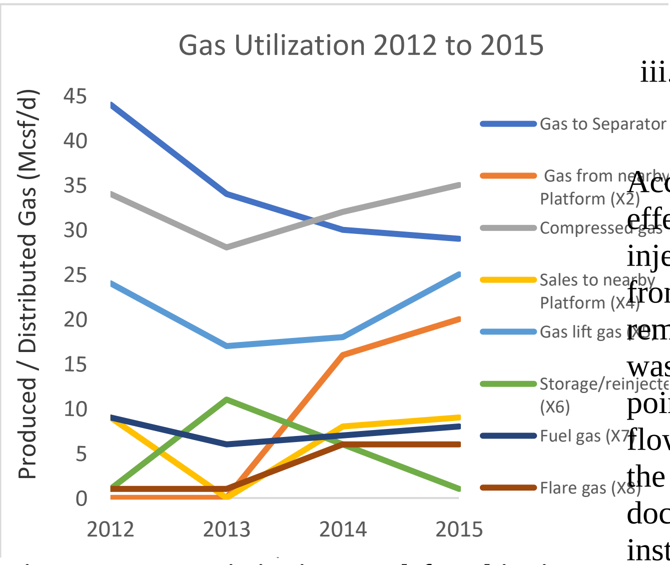

Figure 3a: Gas Optimization Graph for Objective Functions

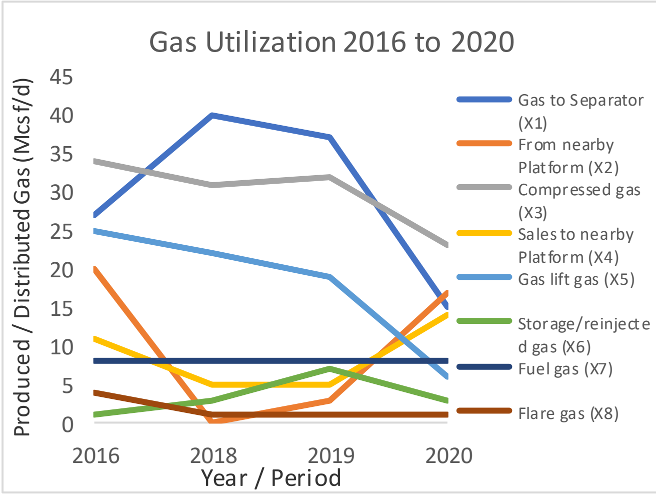

Figure 3b: Gas Optimization Graph for Objective Functions

Figures 3a and 3b show how the objective functions are optimized. It displays the interrelation between each other and their distribution patterns. Three parameters were tested over the period which are:

i. X4 representing, high pressure compressed gas, discharge of the high compression packages
ii. X5 connoting success platform gas lift route, used to aerate well casings with low well head pressure, boosting crude production and
iii. X6: Gas injection into reservoir formation for preservation and storage, it also serves as an alternate gas production route.

According to Sun *et al*. (2021) maintaining a high gas effectively enhanced the migration and spread of the injected gas, eventually increasing gas recovery ratio from 25% to 60%. While the produced gas ratio remains low at 12.6 ST kg/m3 (Huang, *et al*. 2021). It was also noted that the gas compression discharge point, maintained a high-pressure gas and volume flow rate throughout the period of this study. From the raw data obtained on the daily/monthly documented reports, it was observed that at some instances process adjustments were made to suit the realities that evolve during gas compression and production activities.

Figure 4 displays the trend of the maximum gas production over the period of eight year, based on the optimization linear code used.
It indicates that gas production and compression in 2012, 2013 and 2018 were maximized which could

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help in production and distribution chains to increase the pressure of natural gas by reducing its volume. Studying the trend, looking at the average between 2014, 2015 and 2016, it is observed that gas production obtained a slight high gas value which could be because of high cost of production, the same trend was observed for 2019 and 2020.

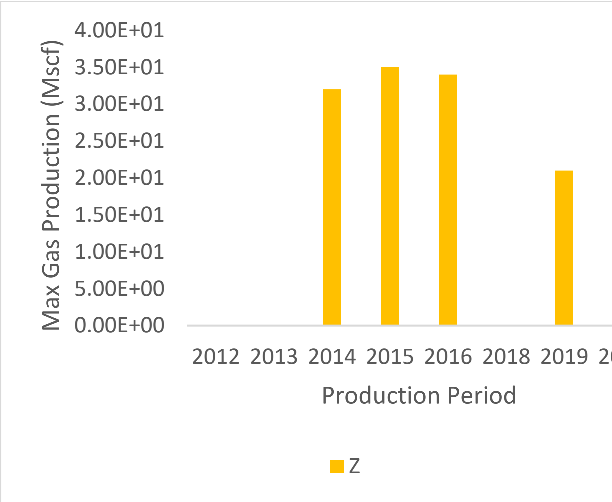

Figure 4: Max Gas Optimization Chart

4. CONCLUSION

In the onset of this paper, objective was benchmarked which is:

i. To estimate the cost of gas redistribution after optimization.

Findings indicate that the cost of gas production and redistribution depend on the following observations:

i. If the production goal is geared towards boosting the reservoir, gas storage/reinjection should take priority.
ii. On condition that maximum profit derivation becomes the essence for the gas production, Export Sales Gas should be prioritized over Gas Lift Gas.

Gas redistribution modes were also formulated, and the following results were derived:

i. Alternate gas cost $152.076 (average per week) for the period under review
ii. Fuel gas cost at $124.062 (average per week) for the period under review
iii. Diesel fuel cost at $2000 per day.

The ratio of fuel gas usage was also compared with alternate fuel gas (diesel fuel) per day, which stood at 1:128 approximate. It indicates that diesel fuel usage cost one hundred and twenty-eight times (128) higher than the cost of average fuel gas usage per day.

In view of the results and findings, the following recommendations have been made:

i. Field data must be verified by competent personnel to be true and representative of the actual field values.
ii. Effective and timely training of field personnel is highly required.

Further studies in comparing the results with other applications e.g., particle swamp optimization for wider decision is required.

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