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The Delineate Distribution and Quantity of Gas Production Optimization Using Linear Programming on Reverse Fishbone Diagram

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ABSTRACT
This paper presents the outcome of our research on the delineate distribution and quantity of gas production optimization using linear programming on reverse fishbone diagram in an oil field. On using the reversed fishbone model to portray produced gas distribution and quantity, the model accurately describes the Gas Production Company under study. A production line on arrival to the production facility is routed into two phased production Separator, where gas is separated and formed the primary source for compressed gas. After compression with a metered volume, the pressurized gas is shared based on production demand and dynamics. 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 will be adopted for this research work. This research will adopt 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. Then, the alternative fuel gas cost (diesel running cost) per day was calculated as per dayper day

KEYWORDS: *The Delineate Distribution, Production Optimization, Production Channeling Linear Programming, reverse fishbone diagram, Petroleum Product Recovery, Orifice Plate Size.*

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I. 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 have brought with it some major problems ranging from over-dependence to climatic change in the environment as a result of increased concentration of Green House Gas (GHG) being flared in the atmosphere during production.

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 approach combines brainstorming and a concept map. The process has four major steps: identifying the problem; working out the major factors involved; identifying possible causes and analyzing the cause and effect diagram. 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).

The ultimate goal of virtually 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 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 by the use of linear programming on reverse fishbone diagram.

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 which has thrown the oil and gas industry into transformational times and has reflected in its deep price drop resulting from trade wars between production countries to other factors. 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.

1.1 Statement of the Problem

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 as a result of intense global warming derived from flared gases. The advent of excessive flared gas and a 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 programming approach. This approach can predict the quantities of gas at a particular time, at a particular chain of distribution on a Reversed Fishbone Diagram.

1.2 Objective of the Study

The objective of this research work is to delineate distribution and quantity the reversed fish bone model

II. MATERIALS AND METHODS

2.1 Description of the Facility

The facility is provided with three parallel production trains into which production is channeled. Each train is provided with a separator and pumps that deliver the oil through pipelinesto treatment and processing points where the gas is now channeled to the inlet drum.

The gas is made to flow into four parallel low-pressure compressor units, each with two stages. At this unit, the gas is then dehydrated with tri-ethylene glycol contactor after partial compression. Some of the gasses are diverted to a supply gas pipeline while the rest is compressed in two parallel two-stage High Pressure (HP) compressor units. The product of the high-pressure compression is the interest of this work as it is further used for sales gas; injection/Gas lift; for other uses including domestic and may be flared if not used adequately.

2.2 Gas Gathering and Separations

Gas distribution headers and its associate Separation equipment of the case study facility forms the preliminary material for this research. 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 aforementioned equipment separates the input hydrocarbon fluid into gas and liquid.

Plates 1 and 2 shows the gas gathering headers, primary and secondary gas separation prior to gas compression. It should be noted that the scrubbed liquid is evacuated off the vessels by its discharge pumps.

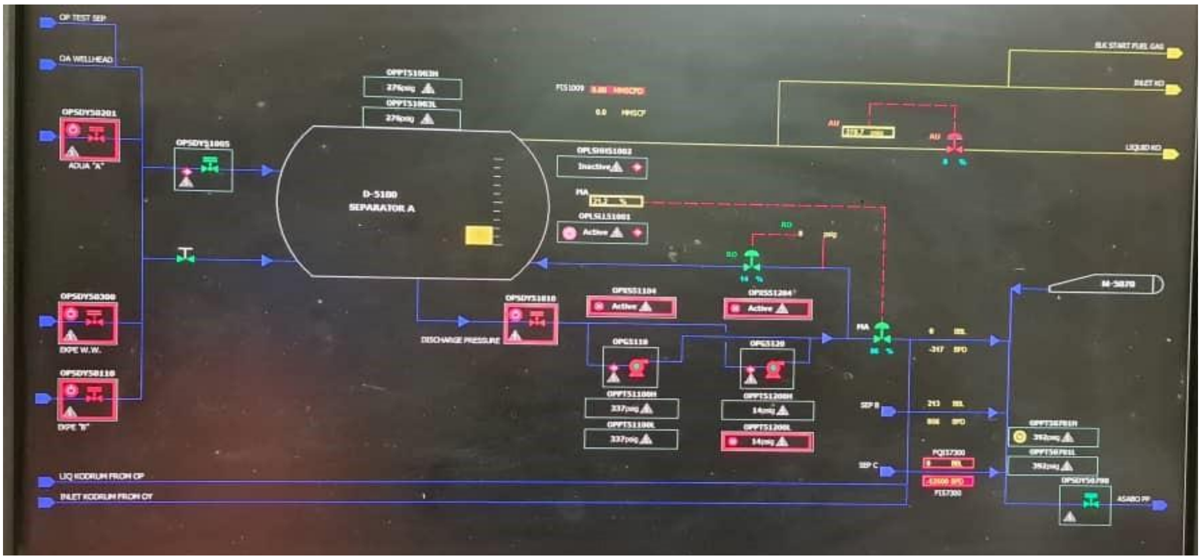


Plate 1: Gathering Header and Primary Separation

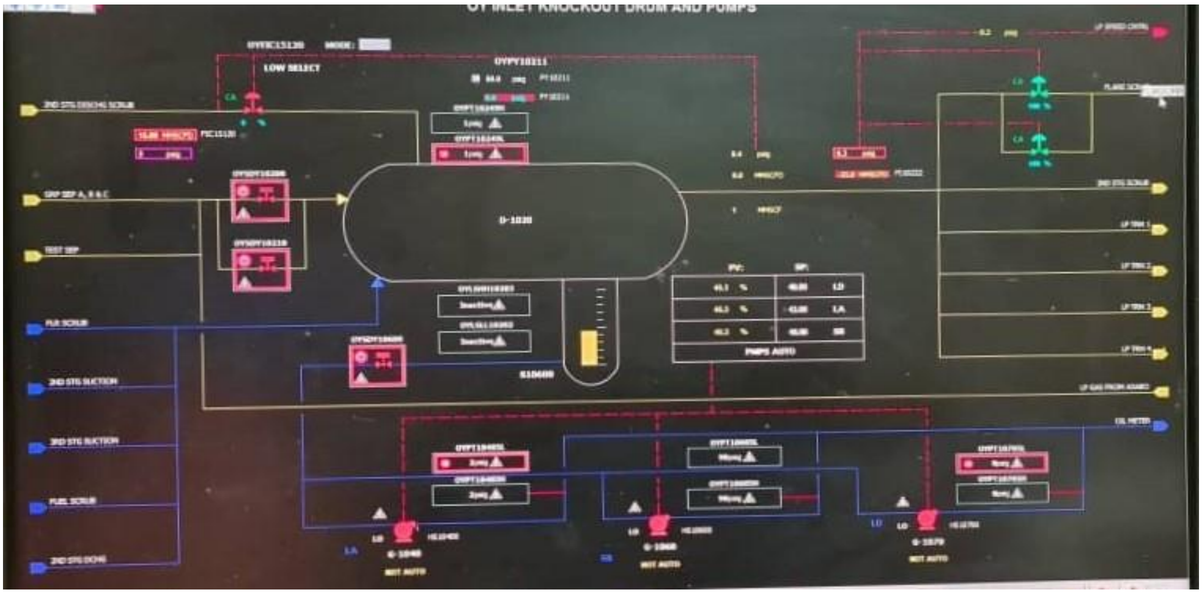


Plate 2: Gas Secondary Separation

2.3 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 the following:

2.4 Gas Measurement Equipment

The flow meters primary elements used includes the Annubar, in-line Orifice Fitting and the Daniel Senior Orifice Box. The secondary Separator deploys the Annubar which is an averaging Pitot tube used to measure the flow of gas volume going out of the vessel. Plates 3a and 3b shows the field snapshot of the Annubar element.

On the other hand, the Daniel Senior Orifice Box is a dual-chamber device with fittings, which is the most widely used means of natural gas measurement. The different between the Daniel Senior Orifice Box and the in-line Orifice Fitting is that the former has an inbuilt capability to change out the Orifice Plate Size (OPS) while the gas flow is on stream. However, both are fitted with a known orifice and pipeline sizes, coupled with the gas flow pressure differential and temperature variables, the flow volume can be derived.

2.5 Gas Distribution Headers

The compressed is then channeled to the distribution header and shared based on production needs to the end users. The main distribution headers are:

i. Compressed Sales Gas
ii. Reinjection Gas
iii. Gas Lift Gas
iv. Fuel and Seal Gas.

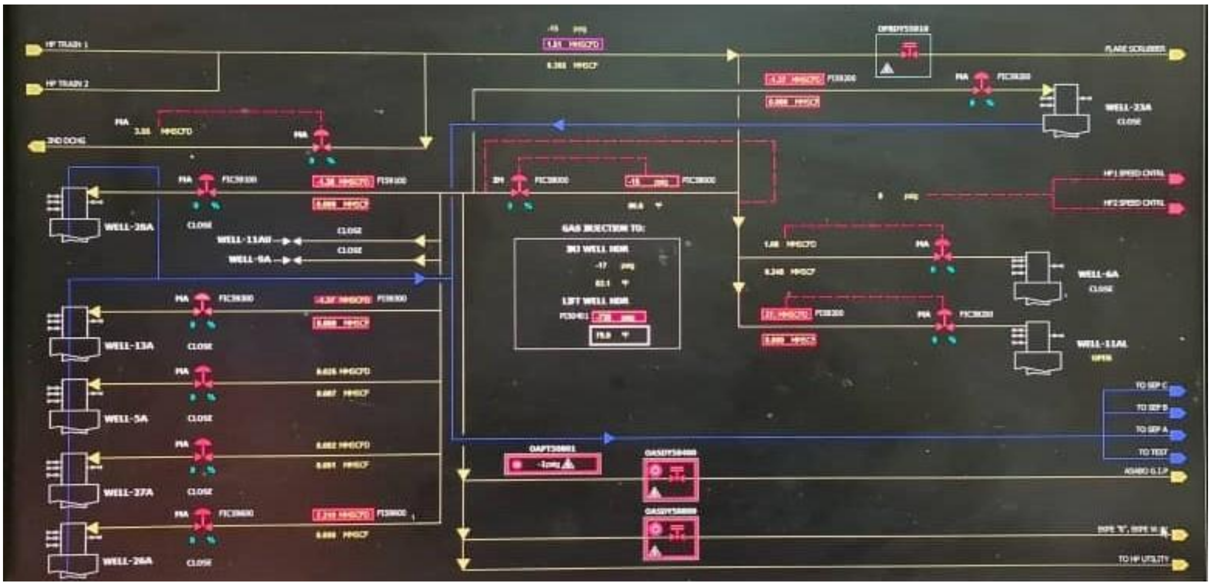


Plate 3: Compressed Gas Distribution Headers

2.6 Constraint Equations

This is the amount of gas which will be produced before compressed gas distribution can occur and is taken as C at a
cost of

$$\frac{p+q+r}{3} = sC \qquad (1)$$

where
p = net profit of compressed sales gas
q = net profit of lifting gas
r = net profit/loss of reinjection gas
3 = total number of variables observed
s = cost per unit of total compressed gas
C = constraint

The constraint equation for the cost of compressed point becomes:
Cost on A + Cost on B + Cost on D = cost on compressed gas point.ost on A + Cost on B + Cost on D = cost on compressed gas point.
as

$$fA + gB + hD = sC\ A + gB + hD = sC \qquad (2)$$

where
f = cost of A
A = Sales gas
g = cost of B
B = Gas lift gas
h = cost of D
D = Reinjection gas
The second constraint is the storage areas (total provided)

$$A + B \leq capacity\ of\ tank, store\ if\ not\ flared + B \qquad (3)$$

$$D \leq 0 \qquad (4)$$

Non-Negativity restriction

$$A \geq 0, B \geq 0\ B \geq 0 \qquad (5)$$

The Linear Programming graph is plotted for constraints to determine A; B& D. A, B& D, values are put in the objective function, (Max Z) where Max Z = maximize overall profit.

2.7 Theory of The Reversed Fishbone Diagram

This is a schematic model which hitherto was used as an effect to cause model but will be used in this work as a single input, multiple output system. The reversed fishbone diagram is a direct fallout of the fishbone diagram which is also seen as multiple input single output system.

The single input system in this case is contrived to be the highly pressured well head crude, which on pre-processing liberates Natural gas, after the removal of Natural Gas Liquids (NGLs). The natural gas constitutes or is modelled into the multiple output systems viz: compressed gas: injection gas for gas lifting and flaring gas. The compressed gas is stored according to the capacity of storage available and are sent out to various distribution lines.

The gas lifting components are stored and released into well casing to lift oil from low producing or non-producing wells. The utilization of the gas lifting component is premised on the principle of solubility of the mixture, thereby increasing the fluidity and flow of crude. Another principle is the use of non-soluble gas to increase underground pressure and flow head of the crude. The method notwithstanding, the gas friction pressure increases till crude flow reduces. This becomes a constraining factor for gas lift.

Excess gas that cannot be compressed or stored, becomes flared, not minding the restriction in form of tax placed on flared gas. This simple reversed fishbone diagram gives a soft landing for the application of linear programming to determine

i. How cost effective the processes are
ii. How to maximize profit
iii. The point at which flaring of gas is inevitable.

2.8 Reversed Fishbone Analytical Steps

The single input system is the wellhead crude gas. The quantity is defined and may also include some NGLs. The cost equivalent is also analyzed.

The next step is to analyze the compressed sales gas (A), the cost of production (P) and selling price (F) are also noted.

The gas lifting gas component (B) will be considered. The cost of this gas is given as (q) and the selling price (g). The selling price of the gas lifting component is determined by finding the volume difference between the application of the gas lifting without the gas lifting. The equivalent cost of this price is the selling price.

The end product is determined by whether an excess exist or not and will be used as a constraint in the linear programming model.

To formulate

i. Identify the decision variable
ii. Write the objective function
iii. Mention the constraints
iv. Explicitly state the Non negativity restriction.

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) by the equation

$\mathrm{Max}\ (Z) = 10A + 20B + 10D$ax (Z) = 10A + 20B + 10D (6)

In the event that the gas produced exceeds compression capacity and therefore requires to be flared at an extra flaring cost of #15 per cubic meter of compress gas.

Let the maximum amount of gas that compression system can conveniently contain and handle before allowing extra flaring be 2000m^3, then the constraint equation will be

$30A + 20B + 10D \leq 2000$0A + 20B + 10D ≤ 2000

(7)

Formulating the problem into a mathematical model produces gas that could be stored and/or flared.

Let selling price of A = P
B = Q

D = R

Max (Z) = PA + QB + RD ax (Z) = PA + QB + RD

roduced is constrained or limited by factors.

The decision variables: that determine output, are the variables P, Q & R.

The objective function: could be maximizing profit and reducing flaring.

Constraints: limit the values of the decision variables.

Non-Negative Restriction; decision variable should take > 0 value.

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.

Tables 1 and 2 depict the cost of Natural gas in the past 4 years. This research will adopt 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. Source: U.S. Energy Information Administration (www.eia.gov))

Gas Price	**Year**				**Average**
(mcf)	**2017**	**2018**	**2019**	**2020**	
Price in US Dollar	6.52	8.84	5.56	3.5	6.105

Table: 3 Price of Liquefied Natural Gas(Dollar per Thousand Cubic Feet. Source: World Bank Commodity Pink Sheet)

Gas Price	**Year**				**Average**
(mcf)	**2017**	**2018**	**2019**	**2020**	
U S (Henry Hub)	2.96	3.16	2.57	2.01	2.675
Europe	5.72	7.68	4.8	3.24	5.36
Liquefied Natural Gas Japan	8.61	10.67	10.56	8.31	9.5375

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 will be adopted for this research work.

Using average field data for year 2020 on table 5:

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

$= \quad ((14.21 \times 2501) - (14.21 \times 1))A + ((5.97 \times 35.85) - (5.97 \times 1))B + ((3.37 \times 0) - (3.37 \times 1))D$(14.21 ×2501)-(14.21×1))A + ((5.97×35.85)-(5.97×1))B + ((3.37×0)-(3.37×1))D
$= (35{,}539.21 - 14.21)A + (214.025 - 5.97)B + (0 - 3.37)D$ 35,539.21-14.21)A + (214.025-5.97)B + (0-3.37)D 7)D
$A35{,}525 + B208.055 - D3.37$35,525 + B208.055 - D3.37 (8)
On the same year, the average gas production based on streaming wells = 31.97Mscf
It implies that for year 2020, $A + B + D = 31.97\text{Mscf(Avg)}$ + B+D=31.97Mscf(Avg)
where
$A : B : D = 2.4 : 1 : 0.6$:B :D=2.4 :1 : 0.6 average gas production data.
where
$A \leq 2.4$ 2.4(3.15)
It implies that B is to D as 2 is to 1 approximately.
$B : D \leq 2 : 1$:D:1(3.16)
Multiplying both sides by D
$B \leq 2D$ D(3.17)
Where the slack capacity due to well downtime (on high water rate, high sand production and pipeline rupture etc) equals to 22.7Mscf.
The general inventory constraint, implies that
$A + B + D = 55.0\text{Mscf}$ + B+D=55.0Mscf

2.9 Reversed Fishbone Redistribution Modes

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

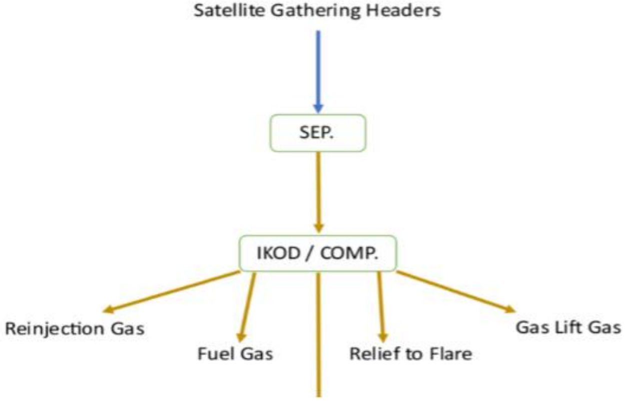


Figure 1: Normal Gas Production Network

Figure 1: 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.

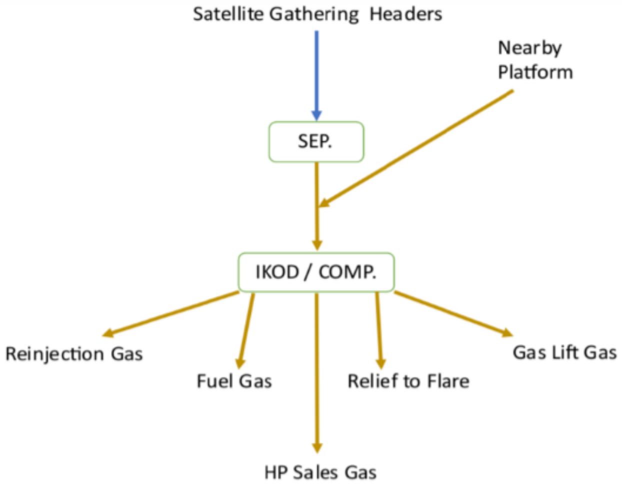


Figure 2: Alternate Support Gas Production Network

Figure 3. explains an alternate gas line-up, on condition that the facility needs only fuel gas to runs its equipment. Blackstart condition indicates a total plant shutdown mode and has a need of a fuel gas lined-up only for end users, for example Gas Power Generator. The main aim is to supply fuel gas, however the relief to flare is unavoidable so as to maintain operating pressure in the lined-up equipment.

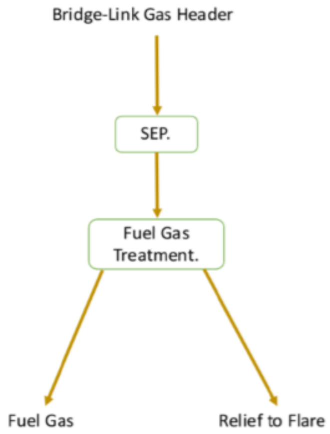


Figure 3: Blackstart Fuel Gas Production Network

There are occasions where a planned sectional or overall turnaround maintenance is carried out in the facility. In these period vessels and pipeline are seldom exposed to atmospheric condition hence the need to evacuate oxygen from the production equipment prior to production startup. Figure 4. shows a distribution mode used for vessel and pipeline purging.

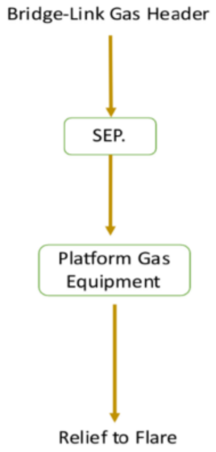


Figure 4: Purge Gas Line-Up

2.10 Data Collection Source

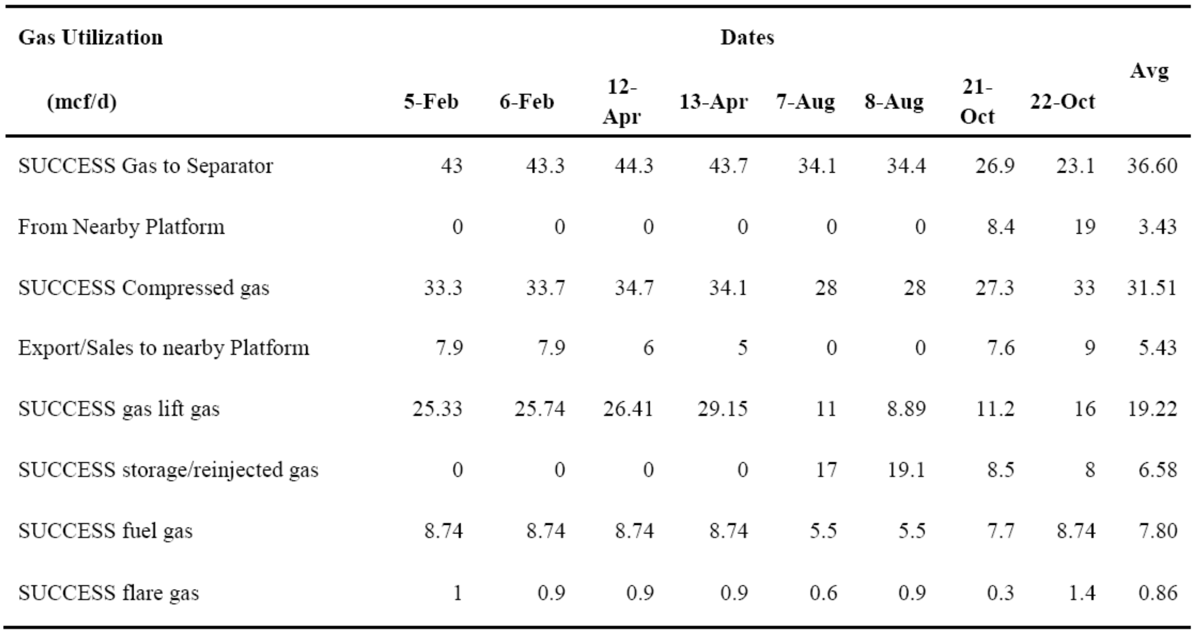
This research derived its data from SUCCESS production platform field raw data. The Company majors is petroleum extraction and components (oil and gas) production. The gas production component and its optimization were applied in this study.

III. RESULTS AND DISCUSSION

3.1 Field Data Analysis 2019

Raw field data in Table 4 represent values obtained between January to December 2019. To optimize gas production, these values are needed for computation.

Table 4: Gas Production and Utilization Field Data 2019

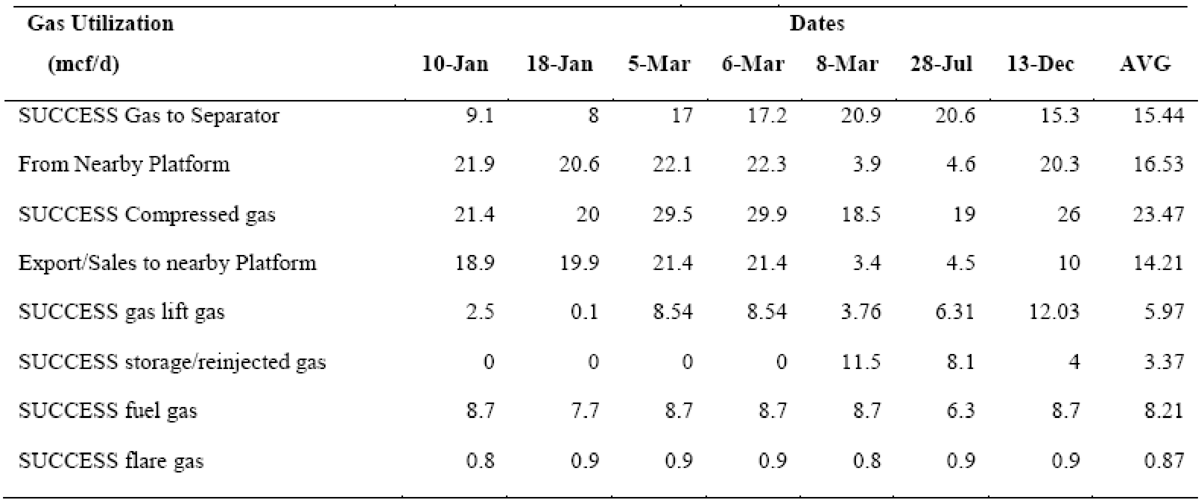


Gas Utilization (mcf/d)	5-Feb	6-Feb	12-Apr	13-Apr	7-Aug	8-Aug	21-Oct	22-Oct	Avg
SUCCESS Gas to Separator	43	43.3	44.3	43.7	34.1	34.4	26.9	23.1	36.60
From Nearby Platform	0	0	0	0	0	0	8.4	19	3.43
SUCCESS Compressed gas	33.3	33.7	34.7	34.1	28	28	27.3	33	31.51
Export/Sales to nearby Platform	7.9	7.9	6	5	0	0	7.6	9	5.43
SUCCESS gas lift gas	25.33	25.74	26.41	29.15	11	8.89	11.2	16	19.22
SUCCESS storage/reinjected gas	0	0	0	0	17	19.1	8.5	8	6.58
SUCCESS fuel gas	8.74	8.74	8.74	8.74	5.5	5.5	7.7	8.74	7.80
SUCCESS flare gas	1	0.9	0.9	0.9	0.6	0.9	0.3	1.4	0.86

3.2 Field Data Analysis 2020

Raw field data below represent values obtained between January to December 2020. To optimize gas production, these values are needed for computation. It will be use to compute and deduce into the constraint equation.

Table 5: Gas Production and Utilization Field Data 2020



Gas Utilization (mcf/d)	10-Jan	18-Jan	5-Mar	6-Mar	8-Mar	28-Jul	13-Dec	AVG
SUCCESS Gas to Separator	9.1	8	17	17.2	20.9	20.6	15.3	15.44
From Nearby Platform	21.9	20.6	22.1	22.3	3.9	4.6	20.3	16.53
SUCCESS Compressed gas	21.4	20	29.5	29.9	18.5	19	26	23.47
Export/Sales to nearby Platform	18.9	19.9	21.4	21.4	3.4	4.5	10	14.21
SUCCESS gas lift gas	2.5	0.1	8.54	8.54	3.76	6.31	12.03	5.97
SUCCESS storage/reinjected gas	0	0	0	0	11.5	8.1	4	3.37
SUCCESS fuel gas	8.7	7.7	8.7	8.7	8.7	6.3	8.7	8.21
SUCCESS flare gas	0.8	0.9	0.9	0.9	0.8	0.9	0.9	0.87

3.3 Data Optimization and Result

Raw field data in Table 6 represent average values obtained between Year 2012 to 2020. These values were used for optimization computation.

Table 6: Average Yearly Gas Production and Utilization Field Data

Gas Utilization	Year							
(mcf/d)	2012	2013	2014	2015	2016	2018	2019	2020
Gas to Separator	44	34	30	29	27	40	37	15
From Nearby Platform	0	0	16	20	20	0	3	17
Compressed gas	34	28	32	35	34	31	32	23
Export/Sales to nearby Platform	9	0	8	9	11	5	5	14
Gas lift gas	24	17	18	25	25	22	19	6
Storage/reinjected gas	1	11	6	1	1	3	7	3
Fuel gas	9	6	7	8	8	8	8	8
Flare gas	1	1	6	6	4	1	1	1

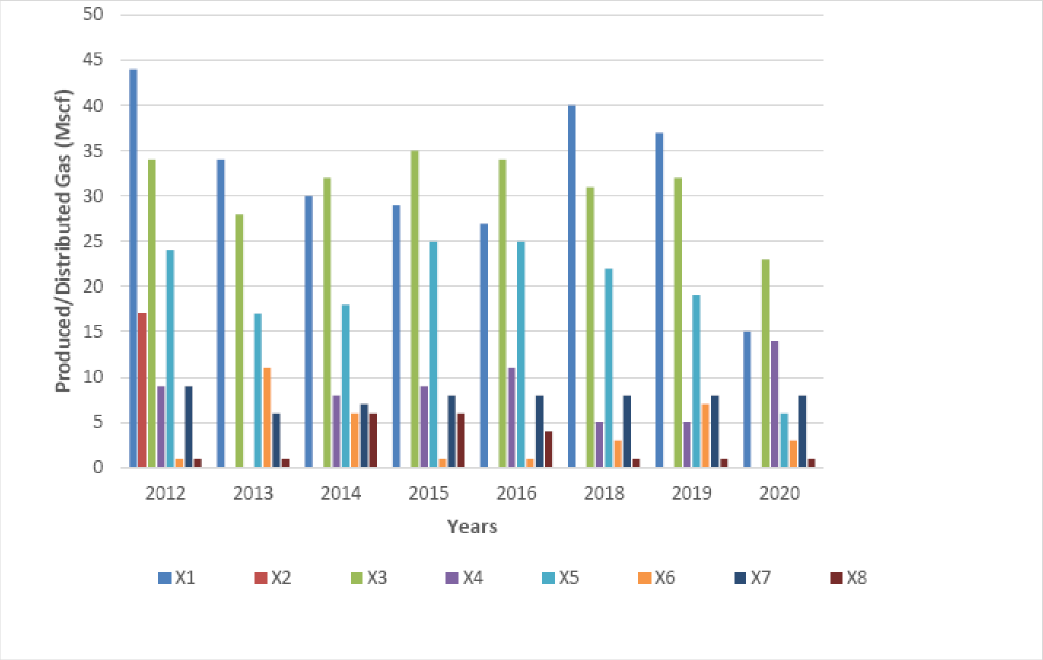


Figure 5: Average Gas Production and Distribution Field Data Per Year

4.0 CONCLUSION

In the onset of this research, objective is to use the reversed fish bone model to delineate distribution and quantity.

On using the reversed fishbone model to portray produced gas distribution and quantity, the model accurately describes the Gas Production Company under study. A production line on arrival to the production facility is routed into two phased production Separator, where gas is separated and formed the primary source for compressed gas. After compression with a metered volume, the pressurized gas is shared based on production demand and dynamics. The gas production revealed a single source intake and multiple distribution routes, hence the reversed fishbone modelling.

The importance of gas optimization of the produced wells in attaining the desired production goals cannot be overstated. Production goal include profit maximization and lost minimization.

With the application of data optimization tool to the field data, the following conclusion were pinched:

i. Three parameters were tested over the period of eight years from field data obtained on a case studied.

ii. Gas production has alternate routes which helps in evaluation of production routes, techno-economic performance, storage, and safety. Also, the gas production route could be in a more stable form and can be easily transported to the place of use.

iii. Maximization of gas production could help in production and distribution chains to increase the pressure of natural gas by reducing its volume.

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