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Modelling of a Modular Gas Gathering and Transportation System for an Urban Centre

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ABSTRACT

In this work, natural gas gathering and transmission system has been designed for Benin City, Edo State, Nigeria. This was carried out using industry simulation software, PIPESIM in order to minimize gas flaring and take advantage of clean energy source. A number of designs were considered particularly for different pipe sizes and network patterns. They include series piping connection, two parallel piping connection and three parallel piping connection. In the light of above, given the different design patterns, two-parallel-piping connection was recommended as the optimal design for delivering the processed natural gas streams to various locations in Benin City from gas hitherto flared in a field near Benin. The two-parallel-piping connection was found to be the design pattern that would optimally deliver natural gas to the various locations and hence recommended for any real-life situation. This is because though with a two parallel-pipes connection system, there will be an increase in construction cost as well as operating cost, it still delivers the highest flow rate compared to the two other design patterns. Compared to the series piping system, the two parallel-pipes connection system delivers a natural gas flow rate of 1.146 MMSCFD higher than that of the series connection. Also, in cases when the pipelines have challenges such as corrosion, burst, delivery of natural gas will be totally impeded for a series connection until the pipe is replaced but for a two parallel-pipes connection delivery may still continue if just one pipe is affected.

1. INTRODUCTION

Nigeria has abundant reserves of associated and non-associated gas estimated in excess of 182 trillion standard cubic feet (SCF) (Ige, 2008). Though Nigeria is ranked 9th in terms of proven natural gas reserves in the world, it could increase potentially up to 600 Tcf (Ige, 2008). This can be accomplished if oil and gas companies intentionally explore for gas as against discovering gas while in search for oil.

Due to low utilization in domestic and industrial usage of natural gas and limited gas distribution infrastructure, petroleum industries producing associated gas (AG) have been compelled to flare these gases due to some of the reasons listed below:

- Limited numbers of appropriate reservoirs conducive for gas re-injection and storage and the economics of the process.
- Financial commitment of developing major and interconnecting network of gas pipelines.
- Low technology and industrial base for energy consumption in the country.

This study is limited to the Nigerian gas infrastructure blueprint of the Nigerian gas master plan and does not intend to explore the other elements of the master plan such as the gas pricing policy or the domestic gas supply obligation.

A gas infrastructure blueprint has been developed to boost the gas master plan. The gas infrastructure blueprint aim is to facilitate gas to power. The blueprint comprises two key investment categories. They include: gas gathering and processing facilities, and gas pipeline transmission systems (plus compressor stations). This study further aims at designing a gas gathering/processing and transmission system that is capable of delivering natural gas to various locations. The design is done with the use of the Schlumberger software application called PIPESIM.

2. METHODOLOGY

2.1. Design Overview

Transporting natural gas from gas wells or gas storage facilities requires the use of pipelines. There are three types of pipelines involved in this process. They are; gathering pipelines, transmission pipelines and distribution pipelines.

From Figure 1, the natural gas streams produced from wells are collected through a series of low-pressure pipelines referred to as a gathering system. The gathering pipelines provide evacuation of natural gas production to central collection points (manifold). The pipelines in a gathering system start out small. Then, as gathering lines from different wellheads converge, the downstream lines become larger, to transport the increasing volume of natural gas streams to a gas processing facility to remove impurities from the gas streams. After fractionation process (the process of extracting lean gases i.e. methane from the processed natural gas) has been carried out, lean gases as well as natural gas liquids (NGLs) are then gathered in larger pipelines (transmission pipelines) where it is often transported over long distances. Finally, from the transmission pipelines, the gas flows into a low-pressure distribution system. Natural gas distribution pipelines are usually smaller in diameter than natural gas transmission pipelines. According to Ikoku (1984), there are varying factors that affect the design of a gas transmission network. Some of these factors include:

- Optimum pipeline diameter
- Pumping horsepower
- Nature and volume of gas to be transported
- Transmission area
- Type of terrain to be crossed
- Maximum elevation of the route
- Location of the producing field
- Gas inlet and outlet pressure
- Pipeline specification- relative roughness, yield strength

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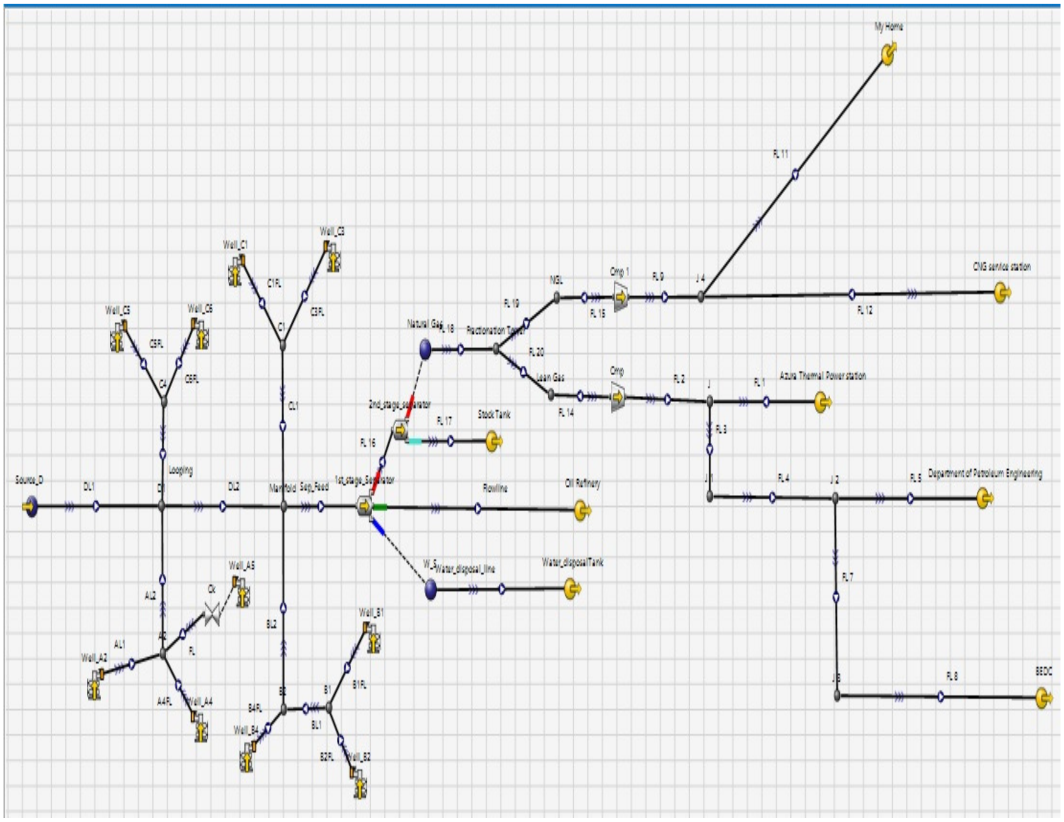

Figure 1: Design overview

2.2. Simulation

In other to successfully run the simulation model that has been designed using PipeSim, there is need to set some simulation settings as well as defining boundary conditions. The simulation settings include the following:

- The single-phase flow correlation chosen is the Weymouth's equation. The Weymouth's equation was adopted because the highest pressure drop is predicted by the Weymouth equation compared to the other flow equations and it also predicts the highest upstream pressure at any flow rate making it the most conservative flow equation (Shashi, 2005). Also, Weymouth's equation ignores pipe elevation (Ikoku, 1984) which is not considered here. The Weymouth's equation is used for pipes of 15 in. internal diameter or less (Idibge and Onaiwu, 2018) and the diameter used for the gas gathering pipelines was 12 in.

- The temperature and pressure of the environment at burial depth was set at 45 ^{o}F and 14.7 psia.

The Weymouth's equation is given as:

$$Q = 433.5E\left(\frac{Tb}{Pb}\right)\left(\frac{P_1^2 - e^s P_2^2}{GT_f Z L_e}\right)^{0.5} D^{2.667} \quad (1)$$

Where:

Q = flow rate, standard ft^3/day (SCFD)
E = pipeline efficiency, a decimal value less than or equal to 1.0
P_b = base pressure, psia
T_b = base temperature, °R
P_1 = upstream pressure, psia
P_2 = downstream pressure, psia
G = gas gravity (air = 1.00)
T_f = average gas flow temperature, °R
Le = equivalent length of pipe segment, mi
Z = gas compressibility factor, dimensionless
D = pipe inside diameter, in.

The boundary conditions are needed so that the simulation model can run. Table 1 shows various assumed flow rates and pressures as well as temperature at which the sources and sink act.

This simulation model has the following characteristics:

1. Eleven sources (A source is a generic point where fluids enter the network). The type of gas reservoir from which the well produces that is considered in this model is a wet gas reservoir.
2. Five sinks (A boundary point in the network where fluids leave the system)
3. Gas gathering location is at Ologbo, Edo state.
4. Gas Distribution locations is at:
    a) BEDC (Approximately 65 kilometers from processing plant. Delivers Lean gas)
    b) Department of Petroleum Engineering (Approximately 45 kilometers from processing plant. Delivers Lean gas)
    c) Azura Thermal Power station (Approximately 57 kilometers from processing plant. Delivers Lean gas)
    d) CNG service station (Approximately 68 kilometers from processing plant. Delivers Natural Gas Liquids- LPG; Butane blended with propane)
    e) My Home (Approximately 65 kilometers from processing plant. Delivers Natural Gas Liquids- LPG; Propane gas)
5. A manifold
6. Two separators; One Liquid-Liquid separator and One Gas-Liquid separator
7. A fractionation tower (De-methanization, De-ethanization, De-propanization, De-butanization etc. is carried out here)
8. Two compressor stations
9. A City gate (The city gate is where a transmission system feeds into a lower pressure distribution system that brings natural gas directly to homes and businesses)
10. Elevation is assumed to be horizontal, i.e. elevation = 0.
11. Burial depth of pipeline is assumed to be 13inches
12. The Weymouth's equation is flow equation adopted with an efficiency of 0.95
13. Base temperature and pressure are 60 °F and 14.7 psia
14. Three categories of pipeline:
    a) Gathering pipelines (NPS 12, Inside diameter = 12in, Wall thickness = 0.375in.)
    b) Transmission pipelines (NPS 24, Inside diameter = 23.5in, Wall thickness = 0.25in.)
    c) Distribution pipelines (NPS 24, Inside diameter = 23.5in, Wall thickness = 0.25in.)

Table 1: Boundary conditions (input data)

Name	Pressure (psia)	Flow rate (MMSCF/D)	Flow rate unit	Temperature (°F)
Well_A2	4300		STB/d	150
Well_A4	3900		STB/d	175
Well_A5	4200		STB/d	175
Well_B1	4600		STB/d	175
Well_B2	4650		STB/d	150
Well_B4	4550		STB/d	200
Well_C1	4650		STB/d	175
Well_C3	4640		STB/d	155
Well_C5	4650		STB/d	200
Well_C6	4650		STB/d	200
Source D		100	MMSCF/d	60
Azura thermal power station	65		MMSCF/d	___
BEDC	68		MMSCF/d	___
CNG service station	45		MMSCF/d	___
Department of Petroleum Engineering	68	___	MMSCF/d	___
My Home	10	___	MMSCF/d	___
Oil Refinery	100	___	STB/d	___
Stock Tank	14.7	___	STB/d	___
Water disposal Tank	57	___	STB/d	___

Well_A2, Well_A4, Well_A5, Well_B1, Well_B2, Well_C1, Well_B4, Well_C3, Well_C5, Well_C6 and Source_D are Gas wells producing the Natural Gas streams. Azura Thermal Power station, BEDC, CNG service station, Department of Petroleum Engineering and My Home are the Gas delivering centres.

From Table 1, it is observed that almost all the flow rates were set to null (except “Source D”) as a boundary condition because in reality, there is no way of determining ahead what the future delivery volumes will be along the pipeline (Shashi, 2005). As a result of this, one of the objectives of this research was to determine the flow rate at which the gas will be delivered to locations (BEDC, CNG service station, Department of Petroleum Engineering, My Home) stated above. However, an estimated delivery rate of 100MMSCFD of natural gas is being considered because “Source D” has a production capacity of 100 MMSCFD.

3. RESULT AND DISCUSSIONS

Three different design patterns were considered (Shashi, 2005). These are:

- Series piping simulation
- Two-pipes-parallel piping simulation
- Three-pipes-parallel piping simulation

Table 2: Pipeline data (Shashi, 2005)

Type of Pipeline	Inside diameter (in)	Wall thickness (in)	Internal Roughness (in)
Gas gathering pipeline	12	0.375	0.0018
Gas transmission pipeline	23.5	0.25	0.0018
Gas distribution pipeline	23.5	0.25	0.0018

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3.1. Series Piping Simulation

Series piping means connecting pipes of different diameters together (Shashi, 2005). In this paper, the pipeline properties are shown in Table 2. Figure 2 shows the connection in series to a particular delivery location (CNG service station).

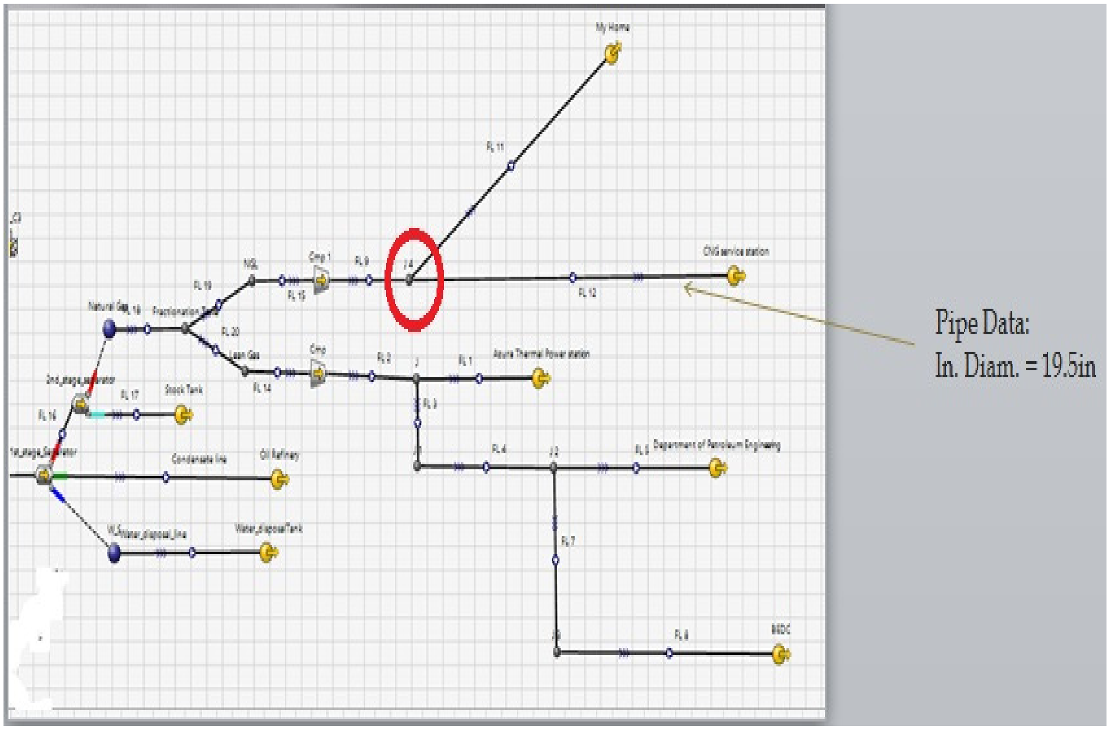

Figure 2: Series piping connection

From the Figure 2, a red circle is around the junction "J4" and this junction is referred to as the city gate. The city gate is where a transmission system feeds into a lower pressure distribution system that brings natural gas directly to homes and businesses (Pipeline Safety Trust, 2015). At the city gate the pressure of the gas is reduced, and it is normally the location where odorant (typically mercaptan) is added to the gas, giving it the characteristic smell of rotten eggs so leaks can be detected (Pipeline Safety Trust, 2015). Also, from the Figure 2, the transmission pipeline remains as a 24 in. internal diameter pipeline with a wall thickness of 0.25 in. The pipeline diameter distributing to "CNG service station" is reduced from a 24 in. internal diameter pipeline with a wall thickness of 0.25 in. (as shown in table 3) to a 19.5 in. internal diameter pipeline with a wall thickness of 0.25 in. This is how pipelines are connected in series.

Running the simulation model for a series piping connection for CNG service station, the result obtained is shown in the Table 3. The result shows how the names of the various sources and delivery points as well as their output pressures, temperatures and natural gas flowrate.

Table 3: Series piping simulation result

Name	Type	Output pressure (psia)	Stock-tank gas flow rate (MMSCF/D)	Output temperature (°F)
Well_A2	Well	391.2993	7.217932	63.13931
Well_A4	Well	394.4987	10.18605	80.63951
Well_A5	Well	1317.802	8.443227	111.4255
Well_B1	Well	339.8628	7.167962	86.74938
Well_B2	Well	332.6099	4.120223	70.74219
Well_B4	Well	337.8175	5.539098	104.3572
Well_C1	Well	342.5886	7.912293	82.00577
Well_C3	Well	340.7742	4.132243	71.31796
Well_C5	Well	391.3818	5.813794	102.9508
Well_C6	Well	393.356	5.341939	102.8556
Source D	Source	446.5086	100	60
Manifold	Junction	334.2813	165.8748	62.97611
1st_stage_Separator	Three phase separator	20.39104	158.2256	11.19703
2nd_stage_separator	Two phase separator	19.84541	155.3363	16.40255
Azura Thermal Power station	Delivery	65	40.94388	60.57442
BEDC	Delivery	68	38.42762	61.07239
CNG service station	Delivery	45	5.251214	59.98946
Department of Petroleum Engineering	Delivery	67.98826	40.39139	64.6465
My Home	Delivery	10	30.30369	58.74573

3.2. Two-parallel-pipes Piping Simulation

When two or more pipes are connected such that the gas flow splits among the branch pipes and eventually combines downstream into a single pipe, such a piping system is referred to as parallel pipes (Shashi, 2005). It is also called a looped piping system, where each parallel pipe is known as a loop (Shashi, 2005). Two-parallel piping for CNG service station is shown in the Figure 3.

Two-parallel-pipes piping connection is shown in the black circle region in the figure. After running the simulation, the result obtained is shown in the Table 4. The result shows how the names of the various sources and delivery points as well as their output pressures, temperatures and natural gas flowrate.

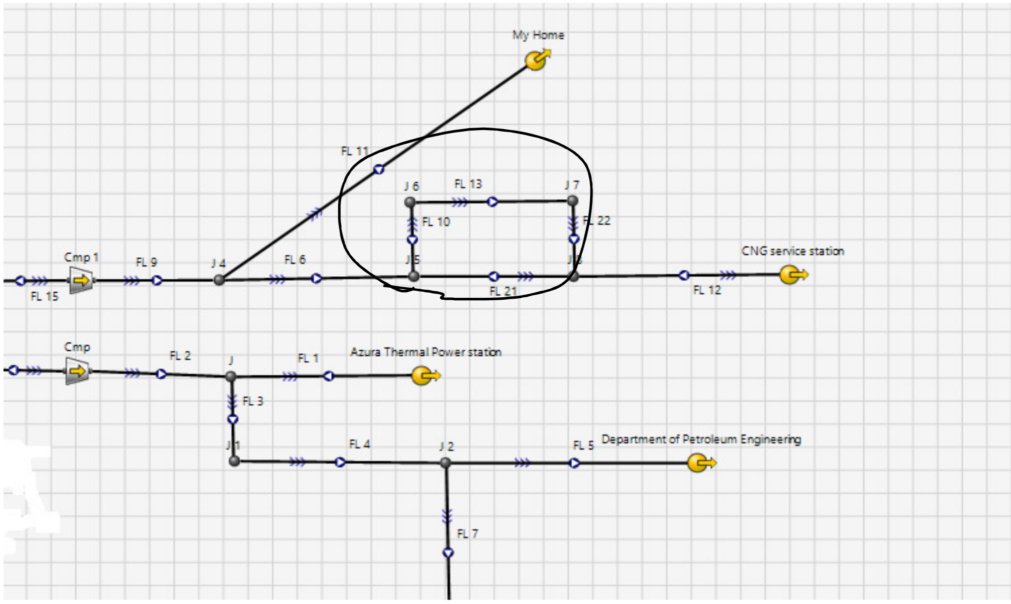

Figure 3: Two-parallel-pipes piping for CNG service station

Table 4: Simulation result for two-parallel-pipes piping connection

Name	Type	Output pressure (psia)	Stock-tank gas flow rate (MMSCF/D)	Output temperature (°F)
Well_A2	Well	391.2993	7.217932	63.13931
Well_A4	Well	394.4987	10.18605	80.63951
Well_A5	Well	1317.802	8.443227	111.4255
Well_B1	Well	339.8628	7.167962	86.74938
Well_B2	Well	332.6099	4.120223	70.74219
Well_B4	Well	337.8175	5.539098	104.3572
Well_C1	Well	342.5886	7.912293	82.00577
Well_C3	Well	340.7742	4.132243	71.31796
Well_C5	Well	391.3818	5.813794	102.9508
Well_C6	Well	393.356	5.341939	102.8556
Source D	Source	446.5086	100	60
Manifold	Junction	332.2644	165.8859	62.88263
1st_stage_Separator	Three phase separator	20.27798	158.224	11.04509
2nd_stage_separator	Two phase separator	19.72371	155.3629	16.30938
Azura thermal power station	Delivery	65.00797	40.53214	60.55549
BEDC	Delivery	68	38.26469	61.08181
CNG service station	Delivery	45	6.397427	59.99413
Department of Petroleum Engineering	Delivery	68	40.58637	64.81776
My Home	Delivery	10	29.6078	58.80323

3.3. Three-parallel-pipes Piping Simulation

Three-parallel piping for CNG service station is shown in the Figure 4. Three-parallel-pipes piping connection is shown in the black circle region in the Figure. After running the simulation, the result obtained is shown in the Table 5. The result shows how the names of the various sources and delivery points as well as their output pressures, temperatures and natural gas flowrate.

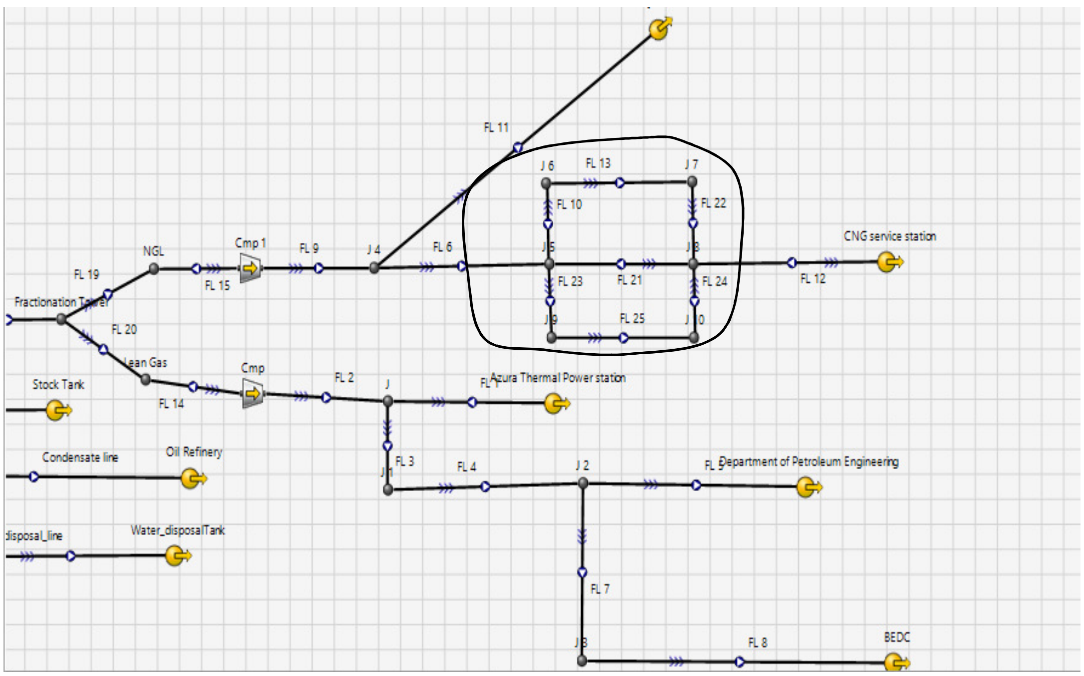

Figure 4: Three-parallel-pipes piping for CNG service station

Table 5: Simulation result for three-parallel-pipes piping connection

Name	Type	Output pressure (psia)	Stock-tank gas flow rate (MMSCF/D)	Output temperature (°F)
Well_A2	Well	391.2993	7.217932	63.13931
Well_A4	Well	394.4987	10.18605	80.63951
Well_A5	Well	1317.802	8.443227	111.4255
Well_B1	Well	339.8628	7.167962	86.74938
Well_B2	Well	332.6099	4.120223	70.74219
Well_B4	Well	337.8175	5.539098	104.3572
Well_C1	Well	342.5886	7.912293	82.00577
Well_C3	Well	340.7742	4.132243	71.31796
Well_C5	Well	391.3818	5.813794	102.9508
Well_C6	Well	393.356	5.341939	102.8556
Source D	Source	446.5086	100	60
Manifold	Junction	334.1533	165.8704	62.98022
1st_stage_Separator	Three phase separator	20.56962	158.2221	11.30234
2nd_stage_separator	Two phase separator	20.03841	155.3136	16.41108
Azura thermal power station	Delivery	65	40.38976	60.49801

BEDC	Delivery	68	38.24183	61.03867
CNG service station	Delivery	45	6.290741	59.99443
Department of Petroleum Engineering	Delivery	68	40.70396	64.78886
My Home	Delivery	10	29.68129	58.79823

4. CONCLUSION

The two-parallel-piping connection was found to be the design pattern that would optimally deliver natural gas to the various locations and hence recommended for any real-life situation. This is because though with a two parallel-pipes connection system, there will be an increase in construction cost as well as operating cost, it still delivers the highest flow rate compared to the three different scenarios analysed above. Compared to the series piping system, the two parallel-pipes connection system delivers a natural gas flow rate of 1.146 MMSCFD higher than that of the series connection. Also, in cases when the pipelines have challenges such as corrosion, burst, delivery of natural gas will be totally impeded for a series connection until the pipe is replaced but for a two parallel-pipes connection delivery may still continue if just one pipe is affected. It should be noted that the referenced delivery location was the CNG service station.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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