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Optimization of Gas Gathering System using Aspen Plus

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Abstract – **Transportation of natural gas is a very important aspect of the oil and gas industry and as such, it must be done with a much efficiency. Pipelines have been recognized as the most economic, effective and safest way of transporting natural gas. A lot of capital is needed, due to cost of pipeline, compressor stations and also in its maintenance. Therefore, in order to minimize cost, optimization of gas transportation process is necessary. In this study, optimization procedure of gas transportation network was developed using Successive Quadratic Programming algorithm, (SQP), in ASPEN PLUS software v8.8 using FORTRAN code. It determines the optimum economic diameter for which gas can be transported through series of pipelines. The model developed, which is, "tree branch type pattern" showed that the total cost of transporting gas depends on the amount of gas to be transported and also the outlet pressure required. The total cost is a function of the capital cost, operational cost, and diameter of the pipes. The capital cost increases with increase in diameter, whereas, the operational cost increases with decrease in diameter. The developed model can be extended to treat much larger and more complex network.**

Keywords – **Aspen Plus, FORTRAN, Optimization Tool, Successive Quadratic Programming Algorithm, Total annual Cost , Tree Branch Type Pattern.**

I. INTRODUCTION

Natural gas consists primarily of methane which is found in associated with other fossil fuels, in coal beds, as methane clathrates, and is created by methanogenic organisms in marshes, bogs, and landfills [1]. It is an important fuel source, a major feedstock for fertilizers, and a potent greenhouse gas. Before natural gas can be used as a fuel, it must undergo extensive processing to remove almost all materials other than methane. The by-products of that processing include; ethane, propane, butane, pentane, and higher molecular weight hydrocarbon, elemental sulphur, carbon dioxide, water vapour and sometimes helium and nitrogen [2]. Natural gas is often informally referred to as simple gas, especially when compared to other energy sources, such as, oil or coal [3].

The Nigerian natural gas can be described as "solution gas" because it dissolved naturally as oil is been produced and occur in a large number of small, widely scattered reservoirs. It is concentrated in the Niger-Delta which covers an area of about 41000 sq. miles (106189.50 km^2). Nigeria's proven and probable reserves form about 1.1% of the world's proven reserves [4]. It is estimated that Nigeria's proven and probable reserves are in the order of about 182Tcf [5]. This is about 17 billion barrel of oil equivalent. Of the totals, Nigeria's proven reserves, 70% is located on land and 30% is offshore. About 60% are located east of River Niger, while the rest are to the west of River Niger [6]. Nigeria has an undiscovered reserve of oil/gas of about 65 E scf (1.841 E m^3) [7]. Associated gas counts for about 50% of the proven reserve. Of these, about 75% exist as gas caps. Experts estimates that the reserves locked in the Nigerian soil is enough to last about 500 years, fuelling our industries, homes and for exports [8].

Transportation of gas by pipeline is a very vital commercial activity which happens on a day to day basis and is a somewhat tricky business, because of its expensive and poor management of cost, could lead to bankruptcy. The gas dispatcher must balance supply and demand under certain circumstances through a proper sequencing of equipment, which is both expensive to run and maintained [8].

Pipeline transportation has become an important means of moving natural gas and with the expansion of market and large demand, millions of pipelines have been laid. Therefore, in moving large quantity of this fuel from the gathering station to the refinery and to transportation and distribution company, and finally to the customers, it can be moved through pipeline [8].

In its development, large input of capital and investment cost is required. Most of these costs are related to two main components, pipeline system, and cost related to compressor station. The cost of pipeline depends on its length and diameter, and the cost of the pipeline is proportional to the diameter, while the cost of the compressor station depends on the operating power, which is a function of both suction and discharge pressure [9]. The use of small pipe will increase the pressure drop and consequently will need compressor with high power. Therefore, in order to minimize cost or maximize profit, we need to obtain a proper balance between pipeline cost and compressor cost. Due to the cost complexities, optimization of the pipeline network is necessary. Cost effective design of gas pipeline and its operation, cost of gas pipeline transportation must be low enough to provide adequate profit in financial investment [10].

The aim of this work is to optimize annual cost of gas gathering pipeline network using sequential quadratic programming (SQP).

II. MATERIALS AND METHOD

A. Model Development

The model for gas gathering pipe network is presented in Figure 1. The overall network consists of three clusters, symbolized as A, B, and C, each cluster is comprised of four gas wells. The gas wells for the clusters A, B and C have symbols PA1, PA2, PA3, PA4; PB1, PB2, PB3, PB; and PC1, PC2, PC3 and PC4 respectively. The thermodynamic parameters of the oil and gas streams at the wellhead are presented in Table 1.

The model for simulation of gas gathering pipe network was developed using ASPEN PLUS. From the software, the following components were selected: methane, ethane, propane, i-butane, n-butane, i-pentane, n-pentane, n-hexane, carbon dioxide, nitrogen, hydrogen sulphide, water, and user-defined components C7+ from heptane upwards. Peng Robinson was selected as a fluid package and property analysis was run.

In the simulation environment, Pipeline was inserted from Pressure Changers in the model palette, and was named Branch 1, 2, 3 … 12, respectively. Material stream for the branches are named as follows; branch-1 inlet stream is PA1 while the outlet Stream is PA1-Out, for branch-2, inlet is PA2 and Outlet is PA2-Out, and similarly repeated for the rest as shown in Figure 1. The properties of oil and gas at the well head are shown in Table 1. The same procedure was followed for the second and third cluster. A junction (mixer) is added at each cluster, these are Mix-1, Mix-2 and Mix-3 for cluster 1 to 3 respectively. The outlet streams of each branch is then connected to its designated junction, as shown in Figure 1. A fourth mixer, Mix-4 connects the outlet streams from Mix-1, Mix-2 and Mix-3, as shown in Figure 1. A heater is added from Exchanger in the Model Palette, to the outlet stream of Mix-4 so as to obtain an overall vapour fraction of 1.00, by raising the fluid temperature to 75^{o}C. A compressor is finally added from Pressure Changers in the Palette and a pipe that connects the outlet of the compressor (Figure 1).

Table 1. Data for the Gas Gathering System

Gas Wells	**PA1**	**PA2**	**PA3**	**PA4**	**PB1**	**PB2**	**PB3**	**PB4**
Temperature (^{o}C)	40	45	35	41	43	46	38	39
Pressure (kPa)	4135	3450	3580	4115	3850	4005	4185	3875
Flow rate (Kgmol/hr)	425	375	480	350	280	320	330	520

Gas Wells	**PC1**	**PC2**	**PC3**	**PC4**
Temperature (^{o}C)	45	42	35	41
Pressure (kPa)	398	4115	3547	4145
Flowrate (Kgmol/hr)	515	520	485	470

The sub-stations for each of the cluster was denoted as MIX-1, MIX-2, MIX-3, and MIX-4 which is the substation for MIX-1, MIX-2, MIX-3, respectively. In order to obtain complete phase, at the substation, MIX-4, the gathered gas was heated from 34.5 to 75 oC in E-100 and compressed from 26 to 30 bar in COMP-1. , finally, the gases are then transported into a gas station, through a pipe (p-100) with a length of 200m, and are stored in a gas tank, T. The iconic model is presented in Figure 1.

B. Gas Gathering and Transportation Systems

When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

The pipes' nominal size and length in the network is presented in Table 2.

C. Optimization Approach

An optimum cost for the gas gathering system was obtained through optimization using the model. A Successive Quadratic Programming (SQP) algorithm was used for the optimization which is located in optimization toolbox in ASPEN PLUS.

Total pipe cost consists of two parameters: Capital (Fixed) cost and Operational cost. The most economic pipe diameter will be the one which gives the lowest annual cost [11].

The annual fixed cost can be expressed as [12]:

$$C_F = XD^xL(1+F)(a+b) \qquad (1)$$

Where F is the factor that involves the cost of valves, fittings and erection, a is the amortization or capital charge (annual), b is annual maintenance costs, D is Pipe diameter (m), L is pipe length (m), X is a parameter that depends on the type of pipe material, and x is the pipe wall thickness.

According to 2015 prices for carbon steel pipes,

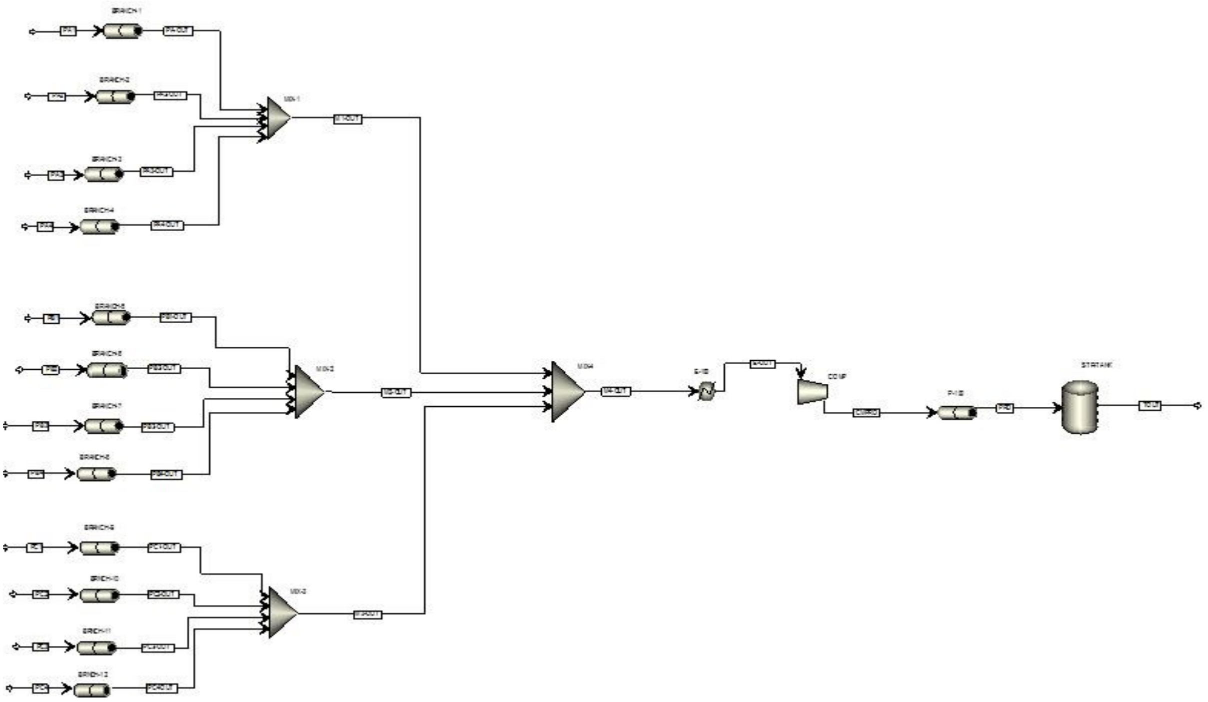

Fig. 1. Gas Gathering System Piping Network

Table 2. Pipe Nominal size and length

Branch	Segment	Length (m)	Elevation (m)	Diameter (mm)
1	1	150	645	76
	2	125	636.5	76.2
2	1	200	637	101.6
	2	214	648	101.6
3	1	160	634	76.2
4	1	355	633	101.6
5	1	300	617	152.4
	2	315	612	152.4
6	1	180	625	76.2
	2	165	617	76.2
7	1	340	604	152.4
	2	345	585	152.4
8	1	200	638	76.2
	2	195	628	76.2
9	1	180	580	101.6
	2	175	565	101.6
10	1	125	560	76.2
	2	100	553	76.2
11	1	185	520	152.4
	2	165	512	152.4
12	1	154	501	76.2
	2	124	480	76.2

Equation (1) becomes:

$$C_F = 229.8D^{1.472}L \qquad (2)$$

The annual operational cost of the pipeline can be expressed as [12]:

$$\mathrm{Co} = 8\frac{YCen(1+J)\xi L}{\pi^{\wedge}2ED^{\wedge}5}\,(G3/\rho 2) \qquad (3)$$

Where cost of energy consumption by pumps, C_{en} is 0.055 US$/KWh, pump overall efficiency, E is taking as 0.5, ratio of minor pressure losses to frictional pressure drop, J is 0.5, the plant attainment, Y is 8000 (hr/year), mass flowrate of the fluid, G (kg/s), the frictional factor, $\xi = 0.11(\varepsilon/D)\ 0.25$, density, ρ (kg/m3), and ε is roughness of the pipe.

Therefore,
Total Annual, Cost = CF + Co

$$C_T(D) = 229.8\mathrm{D}^{1.472}\,\mathrm{L} + 8\,\frac{YCen(1+J)\xi L}{\pi^{2ED^5}}\left(\frac{G3}{\rho 2}\right) \qquad (4)$$

The optimization process is summarized mathematically as

$$\begin{array}{ll} minimize & C_T(D) \\ subject\ to & h(\boldsymbol{x}) = 0 \\ 0.1\,m \le \boldsymbol{x} \le 10\,m & \end{array} \qquad (5)$$

Where $C_T(D)$ is the objective function (Total annual cost) that needs to be minimized, $h(x)$ are the equations that describe the performance of the system, the variable bounds are the maximum and minimum values of the decision variable (internal diameter).

III. RESULTS AND DISCUSSION

This section presents an analysis of the result obtained from the "tree branch type pattern" gas gathering and transportation network.

In Table 3 to Table 5 stream variables for the three clusters obtained via model simulation are provided., we can see the different operating conditions of the gas wells (PA, PA2, PA3, PA4, PB1, PB2, PB3, PB4, PC1, PC2, PC3 and PC4) as well as the molar flowrates of the stream. The change in these flowrates is as a result of changes in operating conditions. Table 6 gives simulation variables for the junction while these parameters are shown in Table 7 for various network facilities. It can be deduced from these tables that high temperature and low pressure favours the formation of vapours. This is in accordance with the basic principles of thermodynamics. For example, in Table 3, the temperature and pressure for stream PA-OUT are 40oC and 36.488 bar respectively, the vapour fraction is 0.978. When these values changed to 45oC and 32.873 bars for stream PA2-OUT the vapour pressure raised to 0.982. This represent a 0.41% increase in vapour pressure for a corresponding 11.11% increase in temperature and a 9.91% decrease in pressure. A similar trend can be observed in Table 4 for streams PB1-OUT and PB2-OUT. Here, a 0.31% rise in vapour fraction is as a result of 6.62% increase in temperature and 4.55% drop in pressure. Furthermore, despite the drastic fall in temperature associated with stream M2-OUT, the vapour fraction is seen to have a relative high value due to a drastic drop in pressure (Table 4).

The accuracy of the simulation can be easily confirmed from either mass or mole balance. For instance, in Table 3, by summing either the mass or mole flow rates of streams PA-OUT, PA2-OUT, PA3-OUT AND PA4-OUT gives the respective mass or molar flow rates for stream M1-OUT.

To obtain a clean dried gas without traces of liquid for efficient transportation, the vapour fraction has to be 1.00; unfortunately this is not the case as evidenced from Table 3 to Table 5. In order to achieve that, the temperature of stream MIX-4 needed to be raised and this was achieved by installing a heater just before the compressor.

Finally, from the figure above, it can be seen that the total annual cost tends to increase with decrease in the internal diameter of the pipelines, but this is not held constant, or goes linearly, because it makes an impulse alongside; the total cost increases with a bit increase in diameter. This is so, because of the data generated from the optimization solver.

Table 3. Stream Results from the First Cluster

	PA-OUT	PA2-OUT	PA3-OUT	PA4-OUT	M1-OUT
Temperature (°C)	40	45	35	41	37.9
Pressure (bar)	36.488	32.873	31.582	40.346	31.582
Vapor Fraction	0.978	0.982	0.977	0.977	0.979
Mole Flow kmol/hr	425	375	480	350	1630
Mass Flow kg/hr	10127.971	8936.445	11438.649	8340.682	38843.747
Volume Flow cum/hr	258.195	263.063	335.62	190.171	1156.076
Enthalpy Gcal/hr	-8.913	-7.824	-10.081	-7.346	-34.164
Mole Flow kmol/hr					
METHA-01	264.775	233.625	299.04	218.05	1015.49
ETHAN-01	119	105	134.4	98	456.4
PROPA-01	6.928	6.112	7.824	5.705	26.569
ISOBU-01	1.827	1.613	2.064	1.505	7.009
N-BUT-01	3.485	3.075	3.936	2.87	13.366
2-MET-01	1.785	1.575	2.016	1.47	6.846
N-PEN-01	1.7	1.5	1.92	1.4	6.52
N-HEX-01	2.805	2.475	3.168	2.31	10.758
NITRO-01	2.337	2.063	2.64	1.925	8.965
CARBO-01	9.563	8.438	10.8	7.875	36.675
HYDRO-01	6.549	5.779	7.397	5.394	25.118
WATER	0	0	0	0	0
C7+	4.246	3.746	4.795	3.497	16.284

Table 4. Stream Results from the Second Cluster

	PB1-OUT	PB2-OUT	PB3-OUT	PB4-OUT	M2-OUT
Temperature C	43	46	38	39	35.9
Pressure bar	37.873	36.15	39.994	24.633	24.633
Vapor Fraction	0.979	0.982	0.975	0.983	0.981
Mole Flow kmol/hr	280	320	330	520	1450
Mass Flow kg/hr	6672.545	7625.766	7864.071	12391.87	34554.253
Volume Flow cum/hr	165.446	202.466	178.28	489.914	1346.632
Enthalpy Gcal/hr	-5.862	-6.681	-6.941	-10.857	-30.341
Mole Flow kmol/hr					
METHA-01	174.44	199.36	205.59	323.96	903.35
ETHAN-01	78.4	89.6	92.4	145.6	406
PROPA-01	4.564	5.216	5.379	8.476	23.635
ISOBU-01	1.204	1.376	1.419	2.236	6.235
N-BUT-01	2.296	2.624	2.706	4.264	11.89
2-MET-01	1.176	1.344	1.386	2.184	6.09
N-PEN-01	1.12	1.28	1.32	2.08	5.8
N-HEX-01	1.848	2.112	2.178	3.432	9.57
NITRO-01	1.54	1.76	1.815	2.86	7.975
CARBO-01	6.3	7.2	7.425	11.7	32.625
HYDRO-01	4.315	4.931	5.085	8.013	22.345
WATER	0	0	0	0	0
C7+	2.797	3.197	3.297	5.195	14.486

Table 5. Stream Results from the Third Cluster

	PC1-OUT	PC2-OUT	PC3-OUT	PC4-OUT	M3-OUT
Temperature C	45	42	35	41	40
Pressure bar	36.862	34.776	33.617	34.813	33.617
Vapor Fraction	0.981	0.98	0.976	0.979	0.979
Mole Flow kmol/hr	515	520	485	470	1990
Mass Flow kg/hr	12272.717	12391.87	11557.802	11200.34	47422.733
Volume Flow cum/hr	317.085	337.226	315.662	302.917	1328.431
Enthalpy Gcal/hr	-10.763	-10.881	-10.195	-9.842	-41.681
Mole Flow kmol/hr					
METHA-01	320.845	323.96	302.155	292.81	1239.77
ETHAN-01	144.2	145.6	135.8	131.6	557.2
PROPA-01	8.395	8.476	7.906	7.661	32.437
ISOBU-01	2.215	2.236	2.086	2.021	8.557
N-BUT-01	4.223	4.264	3.977	3.854	16.318
2-MET-01	2.163	2.184	2.037	1.974	8.358
N-PEN-01	2.06	2.08	1.94	1.88	7.96
N-HEX-01	3.399	3.432	3.201	3.102	13.134
NITRO-01	2.833	2.86	2.668	2.585	10.945
CARBO-01	11.588	11.7	10.913	10.575	44.775
HYDRO-01	7.936	8.013	7.474	7.243	30.666
WATER	0	0	0	0	0
C7+	5.145	5.195	4.845	4.695	19.88

Table 6. Stream Results from the Junctions (Gathering Gas Wells)

	M1-OUT	**M2-OUT**	**M3-OUT**	**M4-OUT**
Temperature C	37.9	35.9	40	34.5
Pressure bar	31.582	24.633	33.617	24.633
Vapor Frac	0.979	0.981	0.979	0.98
Mole Flow kmol/hr	1630	1450	1990	5070
Mass Flow kg/hr	38843.747	34554.25	47422.733	120820.7
Volume Flow cum/hr	1156.076	1346.632	1328.431	4679.596
Enthalpy Gcal/hr	-34.164	-30.341	-41.681	-106.186
Mole Flow kmol/hr				
METHA-01	1015.49	903.35	1239.77	3158.61
ETHAN-01	456.4	406	557.2	1419.6
PROPA-01	26.569	23.635	32.437	82.641
ISOBU-01	7.009	6.235	8.557	21.801
N-BUT-01	13.366	11.89	16.318	41.574
2-MET-01	6.846	6.09	8.358	21.294
N-PEN-01	6.52	5.8	7.96	20.28
N-HEX-01	10.758	9.57	13.134	33.462
NITRO-01	8.965	7.975	10.945	27.885
CARBO-01	36.675	32.625	44.775	114.075
HYDRO-01	25.118	22.345	30.666	78.129
WATER				
C7+	16.284	14.486	19.88	50.649

Table 7. Stream Results from the Process Facilities

	E-OUT	CMPRD	PRD	T-OUT
Temperature C	75	86.8	86.8	86.8
Pressure bar	26	30	29.995	29.995
Vapor Fraction	1	1	1	1
Mole Flow kmol/hr	5070	5070	5070	5070
Mass Flow kg/hr	120820.73	120820.7	120820.73	120820.7
Volume Flow cum/hr	5231.516	4680.942	4681.795	4681.794
Enthalpy Gcal/hr	-103.17	-102.543	-102.543	-102.543
Mole Flow kmol/hr				
METHA-01	3158.61	3158.61	3158.61	3158.61
ETHAN-01	1419.6	1419.6	1419.6	1419.6
PROPA-01	82.641	82.641	82.641	82.641
ISOBU-01	21.801	21.801	21.801	21.801
N-BUT-01	41.574	41.574	41.574	41.574
2-MET-01	21.294	21.294	21.294	21.294
N-PEN-01	20.28	20.28	20.28	20.28
N-HEX-01	33.462	33.462	33.462	33.462
NITRO-01	27.885	27.885	27.885	27.885
CARBO-01	114.075	114.075	114.075	114.075
HYDRO-01	78.129	78.129	78.129	78.129
WATER				
C7+	50.649	50.649	50.649	50.649

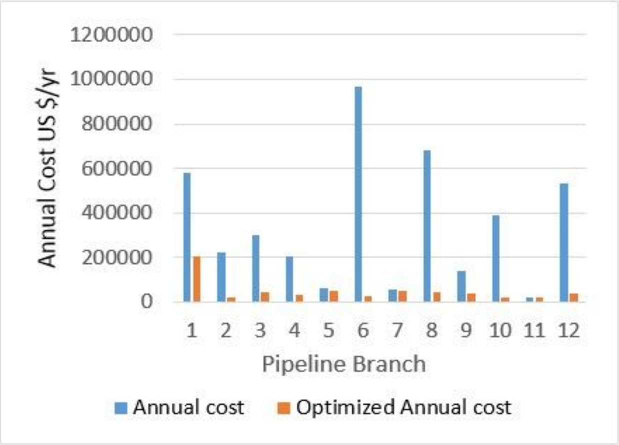

Fig. 2. Optimized and Non-optimized Annual Costs for Different Pipeline Branches

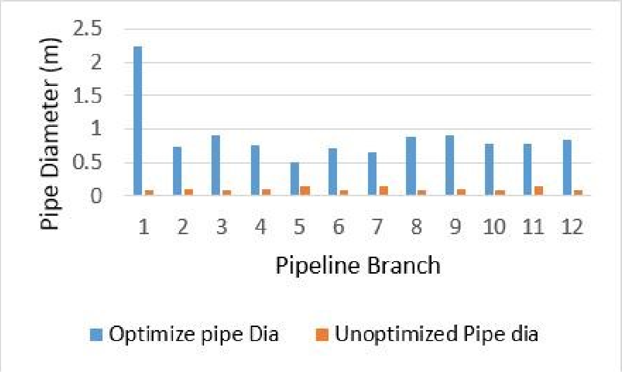

Fig. 3. Plot of Total Annual Cost against the Internal Diameters

IV. CONCLUSION

Simulation of Gas Gathering and Transportation systems was developed using ASPEN PLUS software v8.8, and the optimization of the annual cost was performed using SQP techniques. The following conclusion were reached from the studies:

The optimum diameter that gives the lowest annual cost, is not the smallest pipe diameter. This implies that fixed cost is higher at optimum annual cost.

The annual cost depends on the fluid conditions, compositions, piping configuration and pipe diameter. Presence of heavier components pose problems in transportation, thus, heating is required to achieve a homogeneous gas phase, this may lead to additional cost.

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