Journal of Civil & Environmental Engineering

Jerome et al., J Civil Environ Eng 2017, 7:1
DOI: 10.4172/2165-784X.1000263

Research Article | Open Access

An Investigation of the Gathering System Options for a Hypothetical Field with Uniformly Distributed Production Wells

Jerome Egbe G[1]*, Desmond Ewa E[1], Emmanuel Ettah B[2], Gitu Bassey I[1] and Edem Nsifik E[3]

Department of Civil Engineering, Cross River University of Technology, Calabar, Nigeria
Department of Physics, Cross River University of Technology, Calabar, Nigeria
Department of Oil and Gas, Cranfield University, UK

Abstract

The gathering systems in the production wells are very crucial in the transportation of produced liquids from production wells to collection points such as the processing plant or central processing facilities. Liquid transmission pipelines are a part of the energy industry which involves the transportation of natural crude oil through pipelines. In this research the pipeline costs, material costs are proportional to pipeline diameter, whilst construction and design costs are approximately constant. The research shows that the bigger the length of the flow line, the bigger the total pressure drop, per unit length of the flow line for a given size and the type of pipe, the total pressure drop increases with length, whilst the pressure increases from 100 kpa to 250 kpa, and the length of the flow lines increases from 5.4 km to 12.5 km. The inlet pressure of 600 psig was used, as maximum inlet pressure with a design pressure of 1215 psig, with the assumption that protection against closed in tubing head pressure (CITHP) was protected. The investigation shows that a single flow line or trunk lines are not economical in transporting the fluids from the production wells, due to high -pressure drop in the flowline segments and it can affect pipeline diameters since pressure drop can lead to excess inlet pressure to push the liquid through the flow line and the operating costs can be excessive and result in insufficient pressure to pump or transport the fluids to the central processing facility. The modeling of the pressure drop in the flowline at different rates and for different sizes of nominal pipeline in the gathering systems was achieved.

Keywords: Pipeline; Pressure drop; Flow line; Gathering system; Nominal diameter

Introduction

In the hypothetical production wells the petroleum pipelines gathering systems that transport crude oil or liquid perform basically, three distinct roles, gathering the individual production wells en route to surface central treating facilities, the trunk lines transmit to and from the refinery to the treatment plants and the finished products are distributed uniformly to domestic and industrial users. However, in a single liquid phase field production, the gathering systems and the flow rate is normally fixed at a particular point in time to size pipeline in order to identify restrictions to flow. The systems are very crucial in the transportation of produced liquids from production wells to collection points such as the processing plant or central processing facilities (CPF).The exploitation of this production wells include all the technical aspects of the scenario such as chemical and physical characteristics of the field [1]. In the hypothetical fields, the gathering systems are connected to the central processing facility, via a network of carbon steel tubes. The major factors associated with the gathering systems are in the pressure drop due to flow in the pipeline and the structural strength of the pipeline system, which involves the pipeline thickness to withstand pressure and in respect to external loads, such as collision, earthquake, and wind.

The design pressure is considered according to the 600 flange rating, 1,350 Psig and 90% of the design. Pressure is envisaged for the maximum operating pressure for the pipeline design as studied by Egbe et al. [2]. Similarly, the fluid in the production wells is treated with a chemical and a heating process. Consequently, the separation from water and sediments including the oil are been placed in storage areas and pumped through pipelines to loading terminals where they are ready to be transported. However, the gathering systems and transmission pipelines mimic crude oil gathering line and crude oil trunk lines nevertheless, the operating conditions and equipment for oil and gathering transmission pipeline are quite different from gas. The main lines are the key factors in transporting the crude oil at high pressure over long collecting point or centres. Most mainline pipes are buried. Few are basically simple, connecting a single source to a single destination, and others are very complex involving many sources and interconnections. Several pipelines cross one or more state boundaries (interstate) and some are found within a single state (intrastate).

The pipeline design for gathering systems

The basic consideration of the design of the 5000 metres of equidistance of the production wells is mainly the pipeline thickness, pipeline length, type of material used, internal diameter, pipeline diameter and the pipeline roughness. To get actual distance of each of the production wells, at equidistance of 5 km, as previously mentioned, the Pythagoras Theorem and distance formula are used to determined flow line length to the central processing facility and total length which are further divided into the sixteen (16) production wells in order to calculate the pressure drop along each distance of the flow line. The Specification of the American Institute of Petroleum (API5L) was considered from 8 mm, 150 mm, 200 mm and 250 mm respectively. The roughness of pipe is a fact drop due to flow in the pipeline and the structural strength of the pipeline system, which involves the pipeline thickness to withstand pressure and in respect to external loads, such as collision, earthquake, and wind. The design pressure is considered according to the 600 flange rating, 1,350 Psig and 90% of the design pressure is envisaged for the maximum operating pressure for the pipeline design Egbe et al. [2]. Similarly, the fluid in the production

***Corresponding author:** Jerome G. Egbe, Department of Civil Engineering, Cross River University of Technology, Calabar- Nigeria, Tel.: +234 906 151 5954; E-mail: jeromelina2011@yahoo.com

Received December 26, 2016; **Accepted** February 04, 2017; **Published** February 08, 2017

Citation: Jerome EG, Desmond EE, Emmanuel EB, Gitu BI, Edem NE (2017) An Investigation of the Gathering System Options for a Hypothetical Field with Uniformly Distributed Production Wells. J Civil Environ Eng 7: 263. doi: 10.4172/2165-784X.1000263

wells is treated with a chemical and a heating process. Consequently, the separation from water and sediments including the oil are been placed in storage areas and pumped through pipelines to loading terminals where they are ready to be transported.

However, the gathering systems and transmission pipelines mimic crude oil gathering line and crude oil trunk lines nevertheless, the operating conditions and equipment for oil and gathering transmission pipeline are quite different from gas. The main lines are the key factors in transporting the crude oil at high pressure over long collecting point or centres. Most mainline pipes are buried, but other pipeline components namely pump stations are above ground level. Few are basically simple, connecting a single source to a single destination, and others are very complex involving many sources and interconnections. Several pipelines cross one or more state boundaries (interstate) and some are found within a single state (intrastate), or in the designs of flow line for steel material the pipe roughness was taken as 0.0457 mm, based on America Petroleum Institute (API 5L) can be used to calculate the minimum thickness of the pipe. There exist a numbers of piping standard globally, but arguably, the most widely used is that of America Petroleum Institute and they are group into eleven schedules starting from the least 5 through 10, 20,30,40,60,120,140 up to schedule number 160. These flow lines normally provide form of transportation from the producing wells to a central processing facility (CPF) are generally small-diameter ranges from (20 cm to 30 cm) for single well dependent on the length of pipelines functioning at relatively low pressures when the fluid pressure is very high it can function up to about 600 psig. The usually made of steel or plastic material. Importantly, the lighter fluids move along the upper side of the wells and heavier fluids to a low path, in these scenarios standard centre sampling devices cannot perfectly quantified distributions and its velocities due to incorrect volume.

Single liquid phase gathering systems

In onshore and offshore operations single liquids phase occurs frequently, in natural crude oil gathering system and transmission pipelines. Several experiment and literature investigation of hypothetical production wells shown that dispersed droplet and stratified flows pattern are obtained when small quantities of liquid flow concurrently in a pipe [3]. The single phase liquid pressure technique was first examined by Al Hussainy [4]. Single phase liquid methods is more suitable for all cases of fluids, hence the application of this method is very suitable for uniformly distributed production wells above the dew-point pressure. The crude oil from the production wells is been transported to the storage and treatment tanks from the gathering lines, and the crude oil transmission lines with the help of the pump stations and other stations to the distribution terminal. Clearly, the task of implementing a real options gathering model requires either cost data or estimates of cost. Estimating cost is difficult to obtain and investigators have approached this requirement in several ways in order to select appropriate gathering systems options for a hypothetical field with uniformly distributed production wells. Nishikori et al. [5], developed a model that uses optimisation aspect in solving the equal –slope method of liquid transmission, in their research, they quickly pointed out that flow interactions occur in wells are very significant, nonlinear optimisation tools are desired.

The applicability of Quadratic Programming tools was applied linearly to the existing wells sequentially and Barnes et al. [6,7], suggested the Western Production optimization Model (WPOM) in the production wells in Prudhoe Bay and Kuparuk River which were basically constrained and the above model were introduced to address the problem. However, Litvak et al. [8] discussed gathering system model that utilises oil production and minimising the demand for liquid processing that equally uses a heuristic approach to distributing well connections to manifolds. Linear programming model was developed by Lo et al. [8] in solving a similar problem. A general methodology was proposed by Castillo [9], used in the structuring and analysis of gathering system options for uniformly distributed production wells with various approaches to the methodology with the description of the problem and subsequently followed by the model's development by [9]. The appropriate alternatives for oil gathering options, with respect to an economic suitability, operational procedures, technological and financial standpoint, were investigated and considered [9].

The Liu et al. [10] which analysed foam behaviour and calculate frictional pressure drop alongside mechanical energy equation. Kaya et al. [11] discuss a mechanistic model that was comprehensive in single phase liquid behaviour in oil flow lines which was used investigating the flow parameters in deviated wells. According to Gavignet and Sobeys [12], in their work the reported that eccentricity in drill trunk lines has a greater effect on the bed thickness. An investigation of pressure prediction in wellbore operations in vertical wells production was examined and improved and a mechanistic model steady state was introduced by Perez-Tellez [13] and the model shows an excellent good performance approximately 5% average errors. Castillo Mario [9] in their work after reviewing several relevant kinds of literature, combined an empirical thermodynamical model, a combination of Beggs and Brill model and mass and energy balances to investigate energy balanced requirements for transportation of fluid from uniformly distributed production wells.

Accordingly, the relevant of the model was to investigate fluid distribution from production wells to collection centres, putting into consideration the relevant parameters of the fluid, such as (temperature, density, viscosity), the quantity of flow of each fluid were considered and the pipelines characteristics in terms of line configuration, diameter, length, and location. The model results can be used to predict the associated In onshore and offshore operations single liquids phase occurs frequently, in natural crude oil gathering system and transmission pipelines. Several experiment and literature investigation of hypothetical production wells shown that dispersed droplet and stratified flows pattern are obtained when small quantities of liquid flow concurrently in a pipe [3]. Single phase liquid methods is more suitable for all cases of fluids, hence the application of this method is very suitable for uniformly distributed production wells above the dew-point pressure.

Water processing

Produced water (usually saline) is a waste material, but processing is often necessary to render the water suitable for disposal to the surroundings. Often additional water, frequently sea water, is also processed for water flooding. Oil removal is the first treatment for produced waters. Oil-in-water emulsions are difficult to clean up due to the small size of the particles, as well as the presence of emulsifying agents. Suspended solids may also be present in the water.

Surface gathering systems

Hydrocarbons must be separated from each other and from water before they may be processed into usable petroleum produces. The equipment used for field processing is expensive and is often installed so that several wells are served by a single process facility. The fluids produced from one or more wells are collected in a gathering system and transported to the separation facilities. The gathering system may consist of a single flow line from a well to its separation equipment

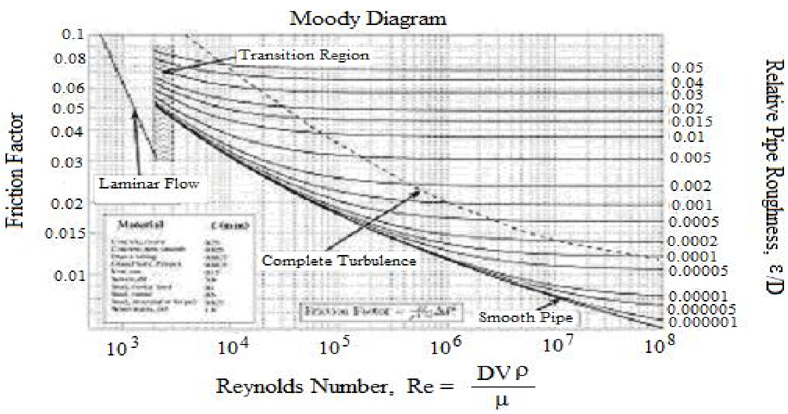

Figure 1: SI based moody chart graph.

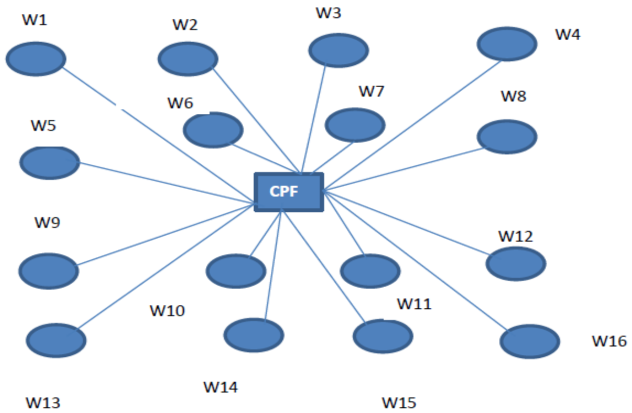

Figure 2: The gathering systems for the hypothetical wells.

or many flow lines, headers, and process facilities (Figures 1 and 2) represents gathering system for the hypothetical wells.

Usually, the wells are drilled according to specific geographical spacing. Depending on ownership of mineral rights and regulations, wells are drilled within areas called leases. The petroleum produced from different leases must be kept separate. Lease restrictions and economics determine the arrangement of gathering systems and the equipment used.

Types of gathering systems

One type of gathering system is a radial gathering system. The flow lines in this system converge at a central point where facilities are located. Flow lines are usually terminated at a header, a pipe large enough to handle the flow of all flow lines. Another gathering system is an axial or trunk-line gathering system. This gathering system is usually used on larger leases, or where it is not practical to build the process facilities at a central point. The remote headers are simply smaller versions of those used in radial systems. Leases are equipped to process fluids through equipment large enough to handle all wells simultaneously. To measure the production of individual wells simultaneously, a very complex process and metering facility is required.

Pipeline gathering systems

Pipeline Gathering System transports the produced liquid from the production field to the Central processing plants (CPF). Normally, these transmission pipelines are short and have relatively small diameters and are linked with other pipelines which provide a full network.

Types of Line Pipes

In the production wells, the trunk lines are usually 8 to 24 inches in diameter that connect regional markets, while small gathering lines are basically 2 to 6 inches in diameter operating at 600 to 2025 psig. The pipelines are constructed according to standard specifications using steel pipes that conform to America Petroleum Institute (API 1994, 2000) and American Society of Mechanical Engineers (ASME), in conjunction with the American National Standards Institute (ANSI) and the American Society of testing Materials (ASTM).When these pipelines are manufactured through seamless or welded. This describes the designation according to how each joint or lengths are produced disregarding how these joints are linked to the production wells.

Tankage

Usually pipeline gathering system have the capability to either temporarily store or received shipped product on each end of the pipeline, to aid the movements of the product and sometimes to accommodate product treating. Some of the pipelines that delivered the crude oil, which is trans- the mix of two hydrocarbons transport together are segregated via downgraded to an appropriate specification which may be re-processed. The liquid is collected and trucked to wastewater treatment and waters that are recovered in the desalter unit are often combined with other field or refinery wastewater, which are treated to meet the environmental requirements and limitations of discharge permits. Nearly, every terminal facility of pipeline system have pig launching or recovery facilities, pumps and the ability to handle pipeline sludge, which may accumulate within the walls of pipeline [14].

Flow lines and gathering lines

In the production wells flow lines offers transportation as part of a liquid gathering system and transport produced fluid from each well to a central processing facility for treatment and storage. The gathering lines are relatively short distance lines that gather the products in the good area and connect them to the central processing facilities normally between 50 mm to 305 mm. Flow lines are normally small in diameter functioning at relatively low pressure. Typical flow lines are between 5.08 -10.16 cm. Sometime in the production wells, the feeder lines also transport the fluids from the well to the processing facilities and connect it to main transmission lines within the range of 508 mm in diameter.

Liquid trunk lines

The liquid is been transported from central storage facilities from long distance trunk lines to refineries or central storage unit. And operate at higher pressure than flow lines and vary in diameters between 0.3 to 1.2 m. A case study of Alaska pipeline that transport liquid with 1.2 m diameter pipeline and transverses about 1287 km from Prudhoe Bay, in the region of North Slope of Alaska and terminate at Port of Valdez. The pipeline distribution is used to move finished products to consumers [15,16].

The pressure drop in the pipe due to friction: The pressure drop due to friction (ΔPf) is been calculated from the friction head (Hf) which is obtained in the pipeline system and the pump must overcome friction loss in addition to the head loss. But calculating the frictional head, the velocity of the fluid (v) have to be calculated.

$$\text{pressure drop, Kpa} = 0.5pf_m LV^{2/}d \qquad (2.2.5)$$

Where p = Density, Kg/m^2

f_(m= Friction factor)

L=Pipeline length, m

V=Fluid velocity, m/s

d=Pipe internal diameter

Friction factor: For the pump to overcome friction loss and the head loss(hf) due to friction, the discharge pressure must equal the friction loss plus head loss and plus the arrival pressure. The friction undergone in the pipe in the form of fluid motion are usually calculated through the Darcy-Weisbach relation given as;

$$hf = \lambda\ L\ U\text{^}2/D2g \qquad (2.2.3)$$

In the above expression (⋋) is the Darcy friction factor, L is the pipe length characteristic, the diameter of the pipe is given as (D), where U stand for the velocity flow rate of the liquid and the acceleration due to gravity is given as (g).Similarly, the friction factor(⋋) is the shear stress that turbulent flow exerts on the pipeline wall. From the European Moody chart, the friction factor is taken as 0.005 (Figure 1).

Sizing pipes on flow rate: In selecting pipes sizes the velocity is a major factor in sizing the pipes. However, it follows then, for a given liquid flowing in particular pipelines, its velocity can be assumed as a practical sizing factor for the flow. For long distance supply lines the velocity has an effect on the pressure drop and sometimes it can be high. It is very important to restrict the speed or velocity to about 15 m/s to prevent pressure drops and it is recommended that for 50 m distance the pressure drop should be checked always, no matter the velocity. Basically, the maximum allowable pressure (Pmax), this is the pressure at squared differences that can be sustained not exceeding the pressure limit in any section of the gathering systems.

No. of wells	Length (km)	Inlet Pressure (Psi-g)	Pressure Drop (Kpa)	Outlet Pressure (Psi-g)
W1	11.2	600	222.3519742	377.6
W2	10.0	600	198.8776517	401.13
W3	10.3	600	198.8776517	401.13
W4	12.5	600	248.5970646	351.4
W5	11.2	600	222.3519742	377.6
W6	5.0	600	99.43882585	500.6
W7	9.0	600	179.2658927	420.7
W8	9.0	600	179.2658927	420.7
W9	7.1	600	140.6277361	459.4
W10	5.4	600	107.0988931	492.9
W11	5.6	600	111.1759871	488.8
W12	9.0	600	179.2658927	420.7
W13	11.2	600	222.3519742	377.6
W14	10.1	600	201.1025797	398.9
W15	10.3	600	204.9983911	395.0
W16	12.5	600	248.5970646	351.4

Table 1: Pressure drop in the gathering systems.

The Cost Estimations for the Gathering Systems

In considering the selection of the gathering systems for the liquid phase liquid, the design approach or consideration was given priority in the design system and the assumed parameters as reasonably as practicable. The cost estimations were formulated and executed in the excel spread sheets environment for accuracy. The spread sheet calculates the capital cost for the given production wells, To put this value in a right perspective, sized of pipes diameter at total unit cost in $ per million for the production wells and these values were used to compared or determine the relative economic merit of the production wells and in respect to any specific set of gathering systems options. The costs data for production wells were drawn primarily from existing projects or vendor price data.

The systems assumptions

The design assumption for the gathering systems the design pressure and optimum operating pressure along the segment of the pipeline were positioned. The assumed parameter for the design pressure in respect to flange rating of 600 and 1350 psig and 90% for the design pressure are considered, a maximum pressure of about 1215 psig and mass flow rate 2250 BPD by Egbe et al. [2].

Pressure drop: The pressure drop can be calculated by using equation (3.2) some of the parameters were assumed the friction factor was obtained from the Moody to be 0.015, the velocity of the flow length was taken to be 25 m/s, the density of the liquid was assumed to be 860 k/m^3 and the pipe internal diameter was assumed to be 202.7 mm. The flowline in the production wells is shown in (Table 1).

Cost estimation for the gathering systems

The costs for the flow line estimation for the production wells were estimated using excels spreadsheet with an existing cost data. Most cost estimation is done by an onshore version of cost estimating package of IHS CERA (QUE$TORTM 9.9) Egbe et al. [2].The costing of the combined flowline from the production wells using the equation (3.1.1) for the selected nominal diameter was modelled with the fixed inlet pressure of 600 psig.

PMC = 0.0246(D - T)TLC (3.2)

where

PMC = Pipe Material Cost, $

L = Length of Pipe, Km

D = Pipe Outside diameter, mm

T = Pipe Wall Thickness, mm

C = Pipe Material Cost, $/(Metric Ton)

Flow line overall cost

The optimisation of the Gathering Systems in the production wells for the selected diameters were obtained by investigating the minimum cost for the Gathering Systems from the 16 initials production wells subsequently, followed by combining of flows from each of the production wells with selected nominal pipes diameters connecting the combined flows from the wells to the Central processing facility (CPF). The flow line installation costs for each of the selected 80 mm, 150 mm, 200 mm, 300 mm, 350 mm and 500 mm diameter pipelines or flow lines were assigned with cost and the total costs are calculated respectively. The total costs are shown in (Table 2). The cost for each of the selected flow line diameters is obtained by addition of the material costs, labour cost and the right of way cost.

Pipe Diameter (mm)	Material Cost ($)	Labour Cost ($)	Misc. Cost ($)	Right of Way Cost ($)	Total Cost ($)/Ton
80	60,017	268,585	101,668	56,222	486,492
150	57,863	239,916	115,264	54,364	467,407
200	93,436	208,658	139,034	36,947	478,075
300	102,258	246,771	264,771	110,033	723,833
350	150,324	407,615	214,930	82,542	855,411
500	201,178	491,082	273,170	81,100	1,046,530

Table 2: Flow line total costs.

Results and Discussion

This chapter deals with the results of the investigation of the production wells with the in-depth analysis of the results obtained from the calculations in chapter 3 in order to minimize the total cost of the gathering systems options of the hypothetical production wells. It also shows an overview of the effects of the pressure drop of the flow line with respect to the combining of the wells flows and the spacing of the flow line The modelling of the pressure drop in the flowline at different rates and for different sizes of nominal pipeline gathering systems, was achieved and different pump stations spacing are not considered for each different diameter range in this research work, and the gathering system was optimized for relative minimum cost of the system at a fixed pipeline diameter respectively.

Material cost

The material installation cost was estimated for the production wells in (Table 2) the inlet pressures of the flow line diameters was assumed to be 600 psig. The graph of Material costs, versus the nominal diameter shown (Figures 3 and 4), it can be observed from that the material cost of the flow line increases linearly from 100 mm to 200 m and rises to 500 mm diameter nonlinearly, due to variation in the material sizes of the flow line. When the diameter of the pipeline increases, there is a corresponding or proportional increase in the flow line cost estimation as wells as the labour cost shown in Figures 5 and 6 respectively. The larger the diameter of the flow line, likewise the cost of the material, which means more fluid can be transported or connected to a central processing facility(CPF) assuming other parameters are fixed.

Pressure drop in gathering systems

The pressure is a function of the wells flow rate and the flow line length. The pressure drop is shown in Table 1 and the plotted graph in Figure 3 the velocity of each well was taken as 25 m/s, the friction factor was taken to be 0.015 based on Moody chart and the internal diameter

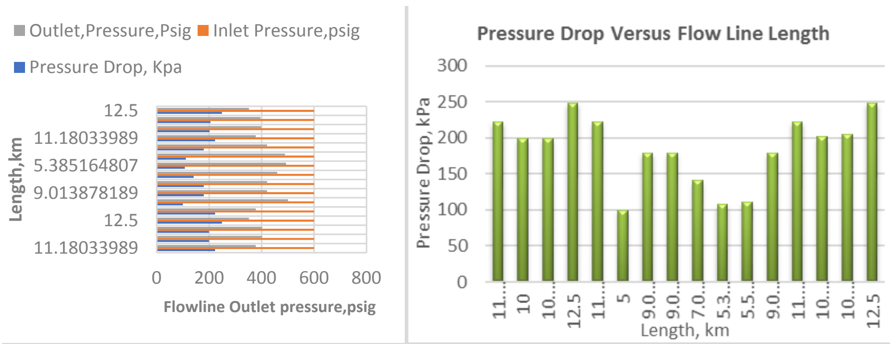

Figure 3: Depict the pressure drop in the flow line.

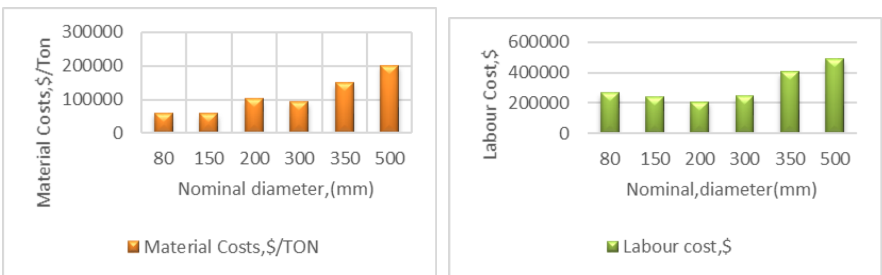

Figure 4: Depict the material and labour costs.

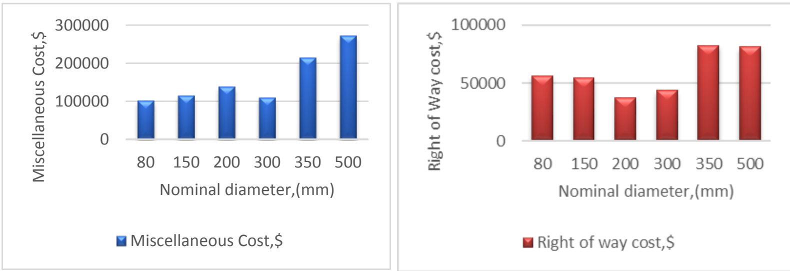

Figure 5: Depict the cost of miscellaneous and right of costs.

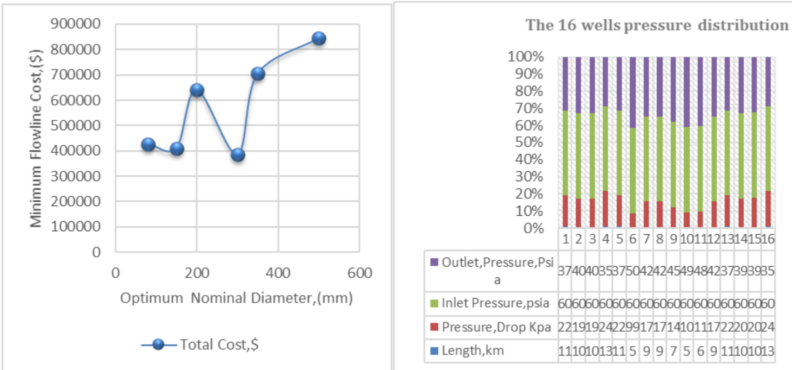

Figure 6: The total cost and wells pressure % distribution.

of the pipes as 202.5 mm and the density of the liquid as 860 km/m^3. From the plotted graph on (Figure 3), it can be clearly observed that the bigger the length of the flow line, the bigger the total pressure drop can be per unit length of the flow line for a given size and type of pipe, but total pressure drop increase with length, the pressure increases from 100 kpa to 250 kpa as the length increases from 5.4 km to 12.5 km respectively. The inlet pressure was taken to be 600 psig as maximum inlet pressure and the design pressure was assumed to be 1215 psig with the assumption that protection against closed in tubing head pressure (CITHP) was assumed. The outlet pressure of the flow line was obtained from the calculation of the difference in inlet pressure as shown in Table 1 and the plotted graph is shown in Figure 3. The wells pressure distribution in Figure 5, it clearly revealed that about 10% of wells pressure is above the operating pressure of the production wells. It can be deduced from the graph in (Figure 3) that the well flow rate increases from the combined w9 and w13 having higher flow rate of 49,093,375 m^3/s due to increase in the flow line and w10 and w14 having less flow rate of about 125,680 m^3/s due to less flow line length, it this crystal clear that as the sizes of diameter increases the flow rate equally increases and whilst the diameter of the pipeline increases the pressure drop decreases.

Conclusions and Future Work

From the investigation and results achieved, conclusions can be drawn that in the pipeline costs, material costs are proportional to pipeline diameter, whilst construction and design costs are approximately constant. Therefore minimising the pipeline diameter will reduce the pipeline total installed cost by a significant amount. In the pipeline network, isolation valves have usually placed either side of river, railway and major road crossings to reduce inventory in an emergency, to enable isolation of sections for repair or maintenance. Similarly, the miscellaneous and right of ways costs also increases as the sizes of flow lines diameters increases as shown (Figure 3). The graph of material costs, versus the nominal flow lines diameter shown, that the material cost of the flow line increases linearly from 100 mm to 200 mm and rises to 500 mm diameter nonlinearly, due to variation in the material sizes of the flow line. When the diameter of the pipeline increases, there is a corresponding or proportionate increase in the flow line cost estimation as wells as the labour cost. The larger the diameter of the flow line, likewise the cost of the material, which means more fluid can be transported or connected to a central processing facility(CPF) assuming other parameters are fixed. The valves must be able to be operated against full operation pressure. The valves should be capable of being operated by remote, automatic or manual actuation. Future work to extend this analysis of capital cost could include the effect of operating cost on the project life cycle costs, this would include operating and maintenance cost of individual compressor stations and the effect of change in pressure for the change in diameter.

References

1. Castillo M (2008) Toma de Decision en las Empresas: Entre el Arte yla Tecnica. Me-todologias, modelosy Herramientas. Bogota, Colombia: Ediciones Uni Andes.
2. Egbe JG, Takim SA, Ibeh MI, Onyewudiala JI (2016) Design approach for trans–sahara gas pipeline transmission. International Journal of Engineering Research & Science, 2: 143-154.
3. www.psig.org/Papers/2000/02W3.pd accessed on 3/8/2016.
4. Al-Hussainy R, Ramey HJ, Crawford PB (1966) The flow of real gases through porous media. Journal of Petroleum Technology 18: 624-636.
5. Nishikiori N, Redner RA, Doty DR, Schmidt Z (1995) An improved method for gas lift allocation optimization. InSPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers 117: 87-92.
6. Barnes DA, Humphrey K, Muellenberg L (1990) A production optimization system for western Prudhoe Bay Field, Alaska. In: SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers. p: 23-26.

7. Litvak ML, Clark AJ, Fairchild JW, Fossum MP, Macdonald CJ, et al. (1997) Integration of Prudhoe Bay surface pipeline network and full field reservoir models. In: SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers, p: 435-443.
8. Lo KK, Starley GP, Holden CW (1995) Application of linear programming to reservoir development evaluations. SPE Reservoir Engineering. 10: 52-58.
9. Castillo M (2009) Analysis and evaluation of technological and operational alternatives for heavy oil gathering systems in the fields of Castilla and Chichimene.
10. Liu G, Medley GH (1996) Foam computer model helps in analysis of underbalanced drilling. Oil and Gas Journal. 94: 114-119.
11. Kaya AS, Sarica C, Brill JP (1999) Comprehensive mechanistic modeling of two-phase flow in deviated wells. In: SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers.
12. Gavignet AA, Sobeys IJ (1986) A model for the transport of cuttings in highly deviated wells. SPE ATCE Conference.
13. Perez-Tellez C, Smith JR, Edwards JK (2002) A new comprehensive, mechanistic model for underbalanced drilling improves wellbore pressure predictions. IPCEM Conference.
14. Kennedy JL (1993) Oil and gas pipeline fundamentals. A comprehensive textbook on the subject with chapters outlining the design, construction and materials.
15. Economides M, Kappos L (2009) Energy, energy system analysis and optimization. Petroleum Network Optimization.
16. Konkel JH (1987) Rule-of-thumb cost estimating for building mechanical systems: Accurate estimating and budgeting using unit assembly costs. McGraw-Hill Companies.