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Optimization of Flow Parameters in Gas Pipeline Network System (Modified Panhandle-B as Base Equation)

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ABSTRACT: *Gas Pipeline Optimization has been a subject that has elicited considerable research interest in the gas industry, in recent times.*
This is not surprising in view of the enormous economic and operational benefits obtainable by operating gas pipelines at their optimum capacities. This is as a result of its high potential for Cost Savings in new investments and environmental safeguard. The gas industry in Nigeria is rapidly expanding to meet the ever growing demand for electrical power, for industrialization of the country.
Optimization of flow parameters in gas pipelines therefore provides a technical basis to reduce capital investments in cost intensive gas pipelines and related facilities, thereby conserving scarce resources. To this end, flow optimization models developed by the researcher applying Modified Panhandle B equation as the base equation are employed in the determination of optimal flow parameters by computational approach.
The optimization models were tested on gas pipelines operated by various Companies: Shell Petroleum Development Corporation(SPBC), ElfTotal, Agip, Nigeria Gas Company(NGC) and Nigerian National Petroleum Corporation(NNPCC). The results are very remarkable..
Analysis of the optimization results confirmed that as much as 30% to 50% additional capacity over and above normal operational levels could be accommodated by existing pipelines. The line pressure drop recovery is much significant at 50 t0 80%. The additional throughput would reduce the need for new investment on gas pipelines assets and facilities,thereby conserving scarce resources for strategic development of new gas fields.
It is recommended that the model be incorporated in the Design and Testing of new gas pipelines to adequately prescribe their allowable working stresses and maximum working pressures.
Keywords : *Pipeline Optimization; Optimum Capacities; Cost Savings; New Investment; Environmental safeguard; Electrical Power; Flow Parameters; Design and Testing; Additional Throughput; Assets and Facilities; Maximum; Working Pressures and Working Stresses.*

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Nomenclature

V_L, V_G **– liquid and gas local velocities (m/s)**

$\bar{V}_M$ **–- mixture mean flow velocity (m/s)**

μ_G**—absolute gas viscosity (Pas)**
A, B, C—virialcoefficients (J/kg)

AR—area ratio
a—Van der Waals pressure correction factor (N/m^4)
b-- Van der Waals volume correction factor (m^3)
C—empirical constant

C_p**—ratio of static pressure to dynamic pressure**
d_0**—outside diameter of pipe (inches)**

D—nominal pipe diameter (cm)
d—pipe inner diameter (inches)
E—longitudinal weld joint factor

f_0**—friction factor for single phase flow**

f_{TP}—Friction factor two phase flow
G_{ave}—average specific gravity of the mixture

G—gas specific gravity
g—gravitational acceleration (m^2/s)
H_s—hoop stress in pipe wall (psi)

K_1, K_2, K_3—constants

K_4—entrance loss coefficient

K_5—exit loss coefficient

K_p—pump loss coefficient

K_w, K_{p1}, K_{p2}—constants
$\bar{V}_L,\ \bar{V}_G$ **−liquid and gas average velocities (m/s)**
$\partial^2 V_L / \partial n^2,\ \partial^2 V_G / \partial n^2$ **− liquid and gas acceleration gradients perpendicular to the axis of the pipe (1/s^2)**
$\partial V_L / \partial Z,\ \partial V_G / \partial Z$ **− liquid and gas velocity gradients along the axis of the pipe (1/s)**

L—length of pipeline (km)
m—mass of gaseous constituents (kg)

P_1—upstream pressure (bar)

P_2—downstream pressure (bar)

P_3—average flow pressure (bar)

P_b—base pressure (bar)

Q—flow capacity (m^3/s)
Q_g—gas flow rate (m^3/day)

Re_{NS}—Reynolds number at no slip condition
R—individual gas constant (J/kgK)
R_L, R_G—liquid and gas holdup
S—allowable yield stress for pipe (psi)
SG—specific gravity of the liquid relative to water
S_Y—maximum yield stress for pipe (psi)

T_b—base temperature (K)
T—bulk flow temperature (K)
T_{ol}—manufacturers tolerance allowance (m)
t—pipe wall thickness (inches)
t_{th}—thread or groove depth (inches)
V_g—gas velocity (ft/s)
V—mean flow velocity (m/s)
W—weight of pipe filled with water (lb/ft)
Y, F—derating factors
Z—flow compressibility factor

α_2—kinetic energy flux coefficient
λ—volume fraction of gas flowing (m^3/s)

μ_{NS}—Absolute viscosity at no slip condition (Pas)
ν_f—kinematics viscosity of the fluid stream (Pas)
ρ_G—gas density (kg/m^3)
ρ_L—liquid density (Kg/m^3)

ρ_{NS}—density at no slip condition (kg/m^3)
ρ_{TP}—density for two-phase flow (Kg/m^3)
ΔH—elevation above datum (m)

ΔP_a—acceleration pressure drop (bar)

ΔP_{ec}—losses due to enlargement and contraction (bar)

ΔP_e—elevation pressure drop (bar)

ΔP_{ent}—entrance losses (bar)

ΔP_{exit}—exit losses (bar)

ΔP_f—frictional pressure drop (bar)

ΔP_{ft}—fitting losses (bar)

ΔP—overall pressure drop along the line (bar)

ΔP_p—pump losses (bar)

ΔP_v—valve losses (bar)

I. INTRODUCTION

Gas pipeline pressure-flow problem are affected by varieties of factors notably frictional pressure drop and other pressure drops components. These problems inevitably result in the reduction of the operating efficiency of gas pipelines by virtue of reduction in the line throughput and increased pressure drop along the line. It has been established that increased pressure drop will ultimately lead to increased pump power as well as higher cost of design, construction and operations of gas pipelines.

Flow optimization could enable these assets to be put to optimal use throughout their design life. Current gas reserves in Nigeria are conservatively put at approximately 185 trillion standard cubic feet [1]. Therefore, it is imperative that gas facilities be designed and operated efficiently so that available resources could be conserved and deployed for strategic development of the nation's vast gas resources. To this effect, the researcher has developed optimization models employing Weymouth equation, Panhandle A equation and Modified Panhandle B as the fundamental base equation [2, 3, 4].

Study Significance

The developed optimization models is the first of its kind. Matlab is used in coding the programming algorithm. The programming algorithmic coding is the easy to handle type. It produces optimal results of flow variables in few iteration steps. It is strongly believed that the findings in this work could provide the base for further in-depth research in gas pipeline flow optimization. The focus should be more biased on optimization of flow capacity viz-a-viz the overall pressure drop along a gas pipeline.

Thus the following objectives are imperative of this work:
(i) Predictability of performance.
(ii) Efficient utilization and deployment of gas pipeline assets and facilities.
(iv) Design efficiency in sizing gas pipelines and associated equipment.
(v) Greater economy in the design and operation of gas pipelines.
(vi) Longer service life to gas pipelines [5].

Relevant Optimization Models

Friction factor for two phase flow is expressed as :

$$f_{TP}=\left[0.00140+\frac{0.125}{\left(\rho_G\bar{V}_M D/\mu_G\right)^{0.32}}\right]\times\left[1+\frac{-\ln\left(1-R_L\right)}{S}\right] \quad (1)$$

$$\mu_G=\mu_{GHC}+\mu_{GN_2}+\mu_{GCO_2}+\mu_{GH_2S}$$

$$S=1.281-0.478(-\ln\lambda)+0.444(-\ln\lambda)^2-0.94(-\ln\lambda)^3+0.0843(-\ln\lambda)^4$$

$$\lambda=1-R_L$$

$$\lambda=R_G$$

The absolute gas viscosity for the mixture of the hydrocarbon constituents of the gas is expressed by [6] :

$$\mu_{GHC}=1.02247\times10^{-5}\left[\begin{array}{l}8.188\times10^{-3}-6.15\times10^{-3}\log\left(\gamma_G\right)\\+\left(1.709\times10^{-5}-2.062\times10^{-6}\gamma_G\right)\left(1.8T+0.27\right)\end{array}\right]. \quad (2)$$

The absolute viscosity of nitrogen is given as:

$$\mu_{GN_2}=1.02247\times10^{-5}\left[9.59\times10^{-3}+8.48\times10^{-3}\log\left(\gamma_G\right)\right]n_{N_2} \quad (3)$$

The absolute viscosity of carbon dioxide expressed as:

$$\mu_{GCO_2}=1.02247\times10^{-5}\left[6.24\times10^{-3}+9.08\times10^{-3}\log\left(\gamma_G\right)\right]n_{CO_2} \quad (4)$$

Absolute viscosity of hydrogen sulphide is given as:

$$\mu_{GH_2S}=1.02247\times10^{-5}\left[3.73\times10^{-3}+8.49\times10^{-3}\log\left(\gamma_G\right)\right]n_{H_2S} \quad (5)$$

Model for pressure drops along pump and compressor :

$$\Delta P_P=\frac{16\rho\left(1-\eta_i\right)}{\pi^2 d^4}Q^2$$

$$=K_P Q^2 \quad (6)$$

$$where \quad K_P=\frac{16\rho\left(1-\eta_i\right)}{\pi^2 d^4}$$

K_p—Pump constant

η_i=85 % to 97.5 % for most pumps and compressors [7].

Apparentmolecular weight of natural gas on the basis of the mole fractions of thedifferent constituents is expressed as:

$$M_a=\sum_{i=1}^{N}n_i M_i \quad (7)$$

The gaseous mixture specific gravity is given as:

$$\gamma_G=\frac{M_a}{M_{air}}. \quad (8)$$ **In**

terms of the pseudo reduced properties, the critical pressure of the gaseous mixture is expressed as:

$$P_c = \sum_{i=1}^{N} n_i P_{Ci} \qquad (9)$$

The critical temperature of the mixture is given as:

$$T_C = \sum_{i=1}^{N} n_i T_{Ci} \qquad (10)$$

The reduced pressure and temperature are :

$$P_r = \frac{P}{P_C} \qquad (11)$$

$$T_r = \frac{T}{T_C} \qquad .(12)$$

Average gas pressure, P is given by [5] :

$$P = \frac{2}{3}\left(\frac{P_1^3 - P_2^3}{P_1^2 - P_2^2}\right) \qquad (13)$$

Gas density is given as:

$$\rho_G = \frac{P}{ZRT} \quad \ldots\ldots\ldots \quad (14)$$

Optimization Model Based on Modified Panhandle-B Equation

The fundamental Modified Panhandle-B equatio is expressed as (Anderson, 1993) [8] :

$$Q = K_{PB}\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{1}{f}\right)^{0.51}\left[\frac{P_1^2 - P_2^2}{\bar{T}ZLG^{0.961}}\right]^{0.51} D^{2.53} \qquad (15)$$

In Equation (3.53), K_{PB}=3.46.; the unit of K_{PB} is $m^3Km^{0.53}bar^{-0.04}/K^{0.48}\ cm^{2.53}$day.

CONDITIONS OF APPLICATION

Highly invaluable in predicting flow situations in long transmission and delivery lines at high flow capacities for large diameter pipelines up to or greater than 36 ". The flow regime is fully developed turbulent flow. Referring to Equation (15), it can re-expressed as;

$$Q = K_{PB}\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{1}{f}\right)^{0.51}\left[\frac{P_1^2 - P_2^2}{\bar{T}ZLG^{0.961}}\right]^{0.51} D^{2.53}$$

$$Q = K_{PB}\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{1}{Z}\right)^{0.51}\left(\frac{1}{G}\right)^{0.49011}\left[\frac{P_1 + P_2}{f\bar{T}L}\right]^{0.51} D^{2.53}\Delta P^{0.51} \qquad (16)$$

$$\Delta P = P_1 - P_2$$

Therefore,

$$Q = K_{PB}\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{1}{Z}\right)^{0.51}\left(\frac{1}{G}\right)^{0.49011}\left[\frac{P_1+P_2}{f\bar{T}L}\right]^{0.51} D^{2.53}\Delta P^{0.51} \quad ....(3.55)$$

$$\left(\frac{1}{Z}\right)^{0.51} = \left[\frac{3\rho R_0 T\left(P_1+P_2\right)}{2\bar{M}\left(P_1^2+P_2^2+P_1P_2\right)}\right]^{0.51}$$

$$\left(\frac{1}{G}\right)^{0.49011} = \left(\frac{M_a Z}{M}\right)^{0.49011}$$

$$\left(\frac{1}{G}\right)^{0.49011}\times\left(\frac{1}{Z}\right)^{0.51} = \left(\frac{M_a Z}{M}\right)^{0.49011}\times\left(\frac{1}{Z}\right)^{0.51} = \left(\frac{M_a}{M}\right)^{0.49011}\left(\frac{1}{Z}\right)^{0.01989}$$

$$= \left(\frac{M_a}{M}\right)^{0.49011}\left[\frac{3\rho R_0 T\left(P_1+P_2\right)}{2\bar{M}\left(P_1^2+P_2^2+P_1P_2\right)}\right]^{0.01989}$$

$$Q = K_{PB}\left(\frac{T_b}{P_b}\right)^{1.0728}\left(\frac{M_a}{M}\right)^{0.49011}\left[\frac{3\rho R_0 T\left(P_1+P_2\right)}{2\bar{M}\left(P_1^2+P_2^2+P_1P_2\right)}\right]^{0.01989}\left[\frac{P_1+P_2}{\bar{T}L}\right]^{0.5394} D^{2.53}\left(\frac{1}{f}\right)^{0.51}\Delta P^{0.51}$$

$$= 1.5^{0.01989} K_{PB}\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{M_a}{\bar{M}}\right)^{0.49011}\left[\frac{\rho R_0 T\left(P_1+P_2\right)}{\bar{M}\left(P_1^2+P_2^2+P_1P_2\right)}\right]^{0.01989}\left[\frac{P_1+P_2}{\bar{T}L}\right]^{0.51} D^{2.53}\left(\frac{1}{f}\right)^{0.51}\Delta P^{0.51}$$

$$Q = K_{1PB}\left(\frac{1}{f}\right)^{0.51}\Delta P^{0.51} \qquad (17)$$

Where,

$$K_{1PB} = 1.5^{0.01989} K_{PB}\left(\frac{T_b}{P_b}\right)^{1.02}\left(\frac{M_a}{\bar{M}}\right)^{0.49011}\left[\frac{\rho R_0 T\left(P_1+P_2\right)}{\bar{M}\left(P_1^2+P_2^2+P_1P_2\right)}\right]^{0.01989}\left[\frac{P_1+P_2}{\bar{T}L}\right]^{0.51} D^{2.53}$$

Overall Pressure Drop, ΔP can be expressed as:

$$\Delta P = \Delta P_f + \Delta P_e + \Delta P_a + \Delta P_{en} + \Delta P_{ex} + \Delta P_{ec} + \Delta P_v + \Delta P_{ft} + \Delta P_p \qquad (18)$$

Substituting the various pressure drop components in Equation (19);

$$\Delta P = \begin{bmatrix} \frac{1}{\pi^2 D^5}\left[0.0112\rho L Q^2 + 0.9256\rho^{0.68} L\left(D\mu_G\right)^{0.32} Q^{1.68}\right] + \rho g \Delta H + \frac{8\rho}{\pi^2 D^4}Q^2 + \frac{8\rho\left(K_{41}+\alpha_2-1\right)}{\pi^2 D^4}Q^2 + \frac{8K_{51}\rho}{\pi^2 D^4}Q^2 + \\ \left(1-\frac{1}{AR^2}\right)\frac{8\rho}{\pi^2 D^4}Q^2 + K^{-1/n}Q^{1/n} + \frac{1}{\pi^2 D^5}\left[0.0112\rho L_{ev} Q^2 + 0.9256\rho^{0.68} L_{ev}\left(D\mu_G\right)^{0.32} Q^{1.68}\right] + \\ \frac{1}{\pi^2 D^5}\left[0.0112\rho L_{ef} Q^2 + 0.9256\rho^{0.68} L_{ef}\left(D\mu_G\right)^{0.32} Q^{1.68}\right] + \frac{16\rho(1-\eta)}{\pi^2 D^4}Q^2 \end{bmatrix}$$

$$= \begin{pmatrix} \frac{0.0112\rho L}{\pi^2 D^5}Q^2 + \frac{8\rho}{\pi^2 D^4}Q^2 + \frac{8\rho\left(K_{41}+\alpha_2-1\right)}{\pi^2 D^4}Q^2 + \frac{8K_{51}\rho}{\pi^2 D^4}Q^2 + \\ \left(1-\frac{1}{AR^2}\right)\frac{8\rho}{\pi^2 D^4}Q^2 + \frac{0.0112\rho L_{ev}}{\pi^2 D^5}Q^2 + \frac{0.0112\rho L_{ef}}{\pi^2 D^5}Q^2 + \frac{16\rho(1-\eta)}{\pi^2 D^4}Q^2 \end{pmatrix} +$$

$$\frac{1}{\pi^2 D^5}\left(0.9256\rho^{0.68} L\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ev}\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ef}\left(D\mu_G\right)^{0.32}\right)Q^{1.68}$$

$$+ K^{-1/n}Q^{1/n} + \rho g \Delta H$$

$$= \left[\frac{0.0112\rho L}{\pi^2 D^5} + \frac{8\rho}{\pi^2 D^4} + \frac{8\rho\left(K_{41}+\alpha_2-1\right)}{\pi^2 D^4} + \frac{8K_{51}\rho}{\pi^2 D^4} + \left(1-\frac{1}{AR^2}\right)\frac{8\rho}{\pi^2 D^4} + \frac{0.0112\rho L_{ev}}{\pi^2 D^5} + \frac{0.0112\rho L_{ef}}{\pi^2 D^5} + \frac{16\rho(1-\eta)}{\pi^2 D^4}\right]Q^2$$

$$+ \left[\frac{1}{\pi^2 D^5}\left(0.9256\rho^{0.68} L\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ev}\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ef}\left(D\mu_G\right)^{0.32}\right)\right]Q^{1..68}$$

$$+ K^{-1/n}Q^{1/n} + \rho g \Delta H \qquad (19)$$

Considering Equation (17), Panhandle- B exponent, n=0.51 and K=$K_{1PB}(1/f)^{0.51}$, therefore,

$$K^{-1/n}Q^{1/n} = \left(Q/K\right)^{1/n} = \left(Q/K\right)^{1/0.51}$$

$$= \left[\frac{Q}{K_{1PB}\left(\frac{1}{f}\right)^{0.51}}\right]^{1/0.51} = \left[\frac{Qf^{0.51}}{K_{1PB}}\right]^{1/0.51} = \left[\frac{Qf^{0.51}}{K_{1PB}}\right]^{1.9608}$$

$$= \frac{Q^{1.9608} f}{K_{1PA}^{1.9608}} = \frac{Q^{1.9608}}{K_{1PA}^{1.9608}}\left[0.0014 + \frac{0.1157\left(D\mu_G\right)^{0.32}}{\left(\rho Q\right)^{0,32}}\right]$$

$$= K_{1PA}^{-1.9608}\left[0.0014Q^{1.9608} + 0.1157\left(\frac{D\mu_G}{\rho}\right)^{0.32} Q^{1.6408}\right]$$

$$= 0.0014K_{1PA}^{-1.9608}Q^{1.9608} + 0.1157K_{1PA}^{-1.9608}\left(\frac{D\mu_G}{\rho}\right)^{0.32} Q^{1.6408} \qquad .(20)$$

Substituting Equation (20) in (19),

$$\Delta P = \left[\frac{0.0112\rho L}{\pi^2 D^5} + \frac{8\rho}{\pi^2 D^4} + \frac{8\rho\left(K_{41} + \alpha_2 - 1\right)}{\pi^2 D^4} + \frac{8K_{51}\rho}{\pi^2 D^4} + \left(1 - \frac{1}{AR^2}\right)\frac{8\rho}{\pi^2 D^4} + \frac{0.0112\rho L_{ev}}{\pi^2 D^5} + \frac{0.0112\rho L_{ef}}{\pi^2 D^5} + \frac{16\rho(1-\eta)}{\pi^2 D^4}\right]Q^2$$

$$+\left[\frac{1}{\pi^2 D^5}\left(0.9256\rho^{0.68} L\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ev}\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ef}\left(D\mu_G\right)^{0.32}\right)\right]Q^{1..68}$$

$$+ K^{-1/n}Q^{1/n} + \rho g \Delta H$$

$$= \left[\frac{0.0112\rho L}{\pi^2 D^5} + \frac{8\rho}{\pi^2 D^4} + \frac{8\rho\left(K_{41} + \alpha_2 - 1\right)}{\pi^2 D^4} + \frac{8K_{51}\rho}{\pi^2 D^4} + \left(1 - \frac{1}{AR^2}\right)\frac{8\rho}{\pi^2 D^4} + \frac{0.0112\rho L_{ev}}{\pi^2 D^5} + \frac{0.0112\rho L_{ef}}{\pi^2 D^5} + \frac{16\rho(1-\eta)}{\pi^2 D^4}\right]Q^2$$

$$+\left[\frac{1}{\pi^2 D^5}\left(0.9256\rho^{0.68} L\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ev}\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ef}\left(D\mu_G\right)^{0.32}\right)\right]Q^{1..68}$$

$$+ 0.0014K_{1PA}^{-1.9608}Q^{1.9608} + 0.1157K_{1PA}^{-1.9608}\left(\frac{D\mu_G}{\rho}\right)^{0.32}Q^{1.6408} + \rho g \Delta H$$

$$\Delta P = K_1 Q^2 + K_2 Q^{1.9608} + K_3 Q^{1.68} + K_4 Q^{1.6408} + \rho g \Delta H \qquad .(21)$$

Where,

$$R_1 = \left[\frac{0.0112\rho L}{\pi^2 D^5} + \frac{8\rho}{\pi^2 D^4} + \frac{8\rho\left(K_{41} + \alpha_2 - 1\right)}{\pi^2 D^4} + \frac{8K_{51}\rho}{\pi^2 D^4} + \left(1 - \frac{1}{AR^2}\right)\frac{8\rho}{\pi^2 D^4} + \frac{0.0112\rho L_{ev}}{\pi^2 D^5} + \frac{0.0112\rho L_{ef}}{\pi^2 D^5} + \frac{16\rho(1-\eta)}{\pi^2 D^4}\right]$$

Making

$$K_2 = 0.0014K_{1PB}^{-1.9608}$$

$$K_3 = \left[\frac{1}{\pi^2 D^5}\left(0.9256\rho^{0.68} L\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ev}\left(D\mu_G\right)^{0.32} + 0.9256\rho^{0.68} L_{ef}\left(D\mu_G\right)^{0.32}\right)\right]$$

$$K_4 = 0.1157K_{1PB}^{-1.9608}\left(\frac{D\mu_G}{\rho}\right)^{0.32}$$

reference to Equation (17)

$$Q = K\Delta P^{0.51} = K_{1PB}\left(\frac{1}{f}\right)^{0.51}\Delta P^{0.51} \qquad .(17)$$

$$= K_{1PB}\left(\frac{\Delta P}{f}\right)^{0.51} = K_{1PB}\left[\frac{(\rho Q)^{0,32}\Delta P}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51}$$

$$= K_{1PB}\left[\frac{(\rho Q)^{0,32}\Delta P}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51}$$

$$1 = K_{1BA}\left[\frac{\dfrac{\Delta P(\rho Q)^{0,32}}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}}{Q^{1/0.51}}\right]^{0.51} = K_{1PB}\left[\frac{\dfrac{\Delta P(\rho Q)^{0,32}}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}}{Q^{1.9608}}\right]^{0.51}$$

$$= K_{1PB}\left[\frac{\Delta P(\rho Q)^{0,32} Q^{-1.9608}}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51} \quad = K_{1PB}\left[\frac{\rho^{0.32} Q^{-1.6408}\Delta P}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51}$$

$$= K_{1PB}\left[\frac{\rho^{0.32} Q^{-1.6408}\left(K_1 Q^2 + K_2 Q^{1.9608} + K_3 Q^{1.68} + K_4 Q^{1.6408} + \rho g \Delta H\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51}$$

$$= K_{1PB}\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51}$$

$$K_{1PB}\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51} - 1 = 0$$

$$F(Q) = K_{1PB}\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{0.51} - 1 \qquad (22)$$

Equation (2) is the optimization function equation

$$F(Q) = K_{1PB}\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{n} - 1 \qquad (22)$$

Differentiating Equation (22) with respect to Q

$$\frac{\partial F(Q)}{\partial Q} = K_{1PB}\rho^{0.32} n\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{n-1} \times$$

$$\frac{\left\{\begin{array}{l}\left(0.0014(\rho Q)^{0.32} + 0.1157(D\mu_G)^{0.32}\right)\left(\rho^{0.32}\left(\begin{array}{l}0.3592K_1 Q^{-0.6408} + 0.32K_2 Q^{-0.68} + 0.0392K_3 Q^{-0.9608}\\ -1.6408\rho g \Delta H Q^{-2.6408}\end{array}\right)\right)\\ -\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)\left(4.48\times 10^{-4}\rho^{0.32} Q^{-0.68}\right)\end{array}\right\}}{\left(0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}\right)^2}$$

$$= K_{1PB}\rho^{0.32} n\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{n-1} \times$$

$$\frac{\left\{\begin{array}{l}K_1\left(0.1149\rho^{0.64} - 4.48\times 10^{-4}\rho^{0.32}\right)Q^{-0.3208} + 4.48\times 10^{-4}K_2\left(\rho^{0.64} - \rho^{0.32}\right)Q^{-0.36}\\ \left(5.488\times 10^{-5}\rho^{0.64}K_3 + 0.0416\rho^{0.32}\left(D\mu_G\right)^{0.32}K_1 - 4.48\times 10^{-4}\rho^{0.32}K_3\right)Q^{-0.6408}\\ -2.7451\times 10^{-3}\rho^{0.32}\rho g \Delta H Q^{-2.3208} + \left(0.037\rho^{0.32}\left(D\mu_G\right)^{0.32}K_2 - 4.48\times 10^{-4}\rho^{0.32}K_4\right)Q^{-0.68}\\ +4.5394\times 10^{-3}K_3\left(D\mu_G\right)^{0.32}Q^{-0.9608} - 0.1898\rho^{0.32}\left(D\mu_G\right)^{0.32}\rho g \Delta H Q^{-2.6408}\end{array}\right\}}{\left(0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}\right)^2} \qquad .(23)$$

Differentiating Equation (3.62) with respect to Q

$$\frac{\partial F^2(Q)}{\partial Q^2} = A \times B + \frac{C(D-E)}{F} \tag{24}$$

Where:

$$A = K_{1PB}\rho^{0.32} n(n-1)\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{n-2}$$

$$B = \left\{\frac{\left\{\begin{array}{l} K_1\left(0.1149\rho^{0.64} - 4.48\times10^{-4}\rho^{0.32}\right)Q^{-0.3208} + 4.48\times10^{-4}K_2\left(\rho^{0.64} - \rho^{0.32}\right)Q^{-0.36} \\ \left(5.488\times10^{-5}\rho^{0.64}K_3 + 0.0416\rho^{0.32}\left(D\mu_G\right)^{0.32}K_1 - 4.48\times10^{-4}\rho^{0.32}K_3\right)Q^{-0.6408} \\ -2.7451\times10^{-3}\rho^{0.32}\rho g\Delta H Q^{-2.3208} + \left(0.037\rho^{0.32}\left(D\mu_G\right)^{0.32}K_2 - 4.48\times10^{-4}\rho^{0.32}K_4\right)Q^{-0.68} \\ 4.5394\times10^{-3}K_3\left(D\mu_G\right)^{0.32}Q^{-0.9608} - 0.1898\rho^{0.32}\left(D\mu_G\right)^{0.32}\rho g\Delta H Q^{-2.6408} \end{array}\right\}}{\left(0.0014(\rho Q)^{0,32} + 0.1157\left(D\mu_G\right)^{0.32}\right)^2}\right\}^2$$

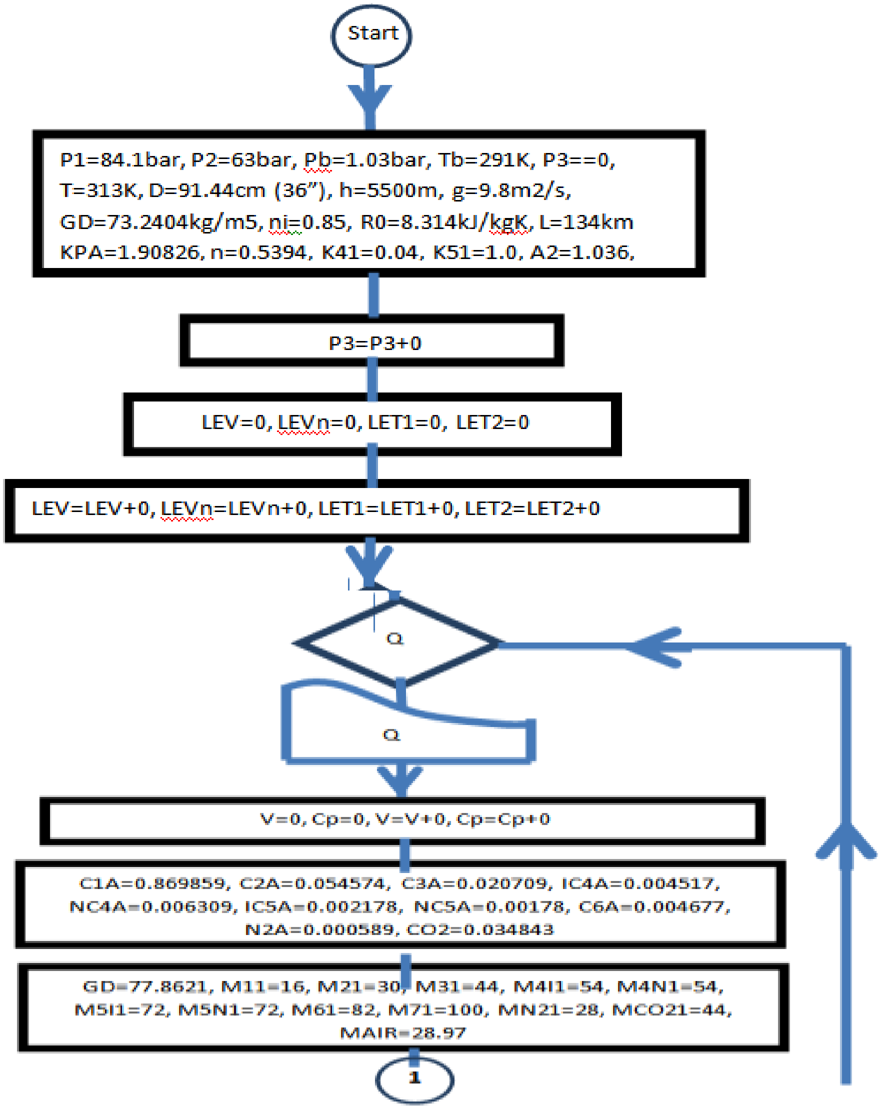
$$C = K_{1PA}\rho^{0.32} n\left[\frac{\rho^{0.32}\left(K_1 Q^{0.3592} + K_2 Q^{0.32} + K_3 Q^{0.0392} + K_4 + \rho g \Delta H Q^{-1.6408}\right)}{0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}}\right]^{n-1}$$

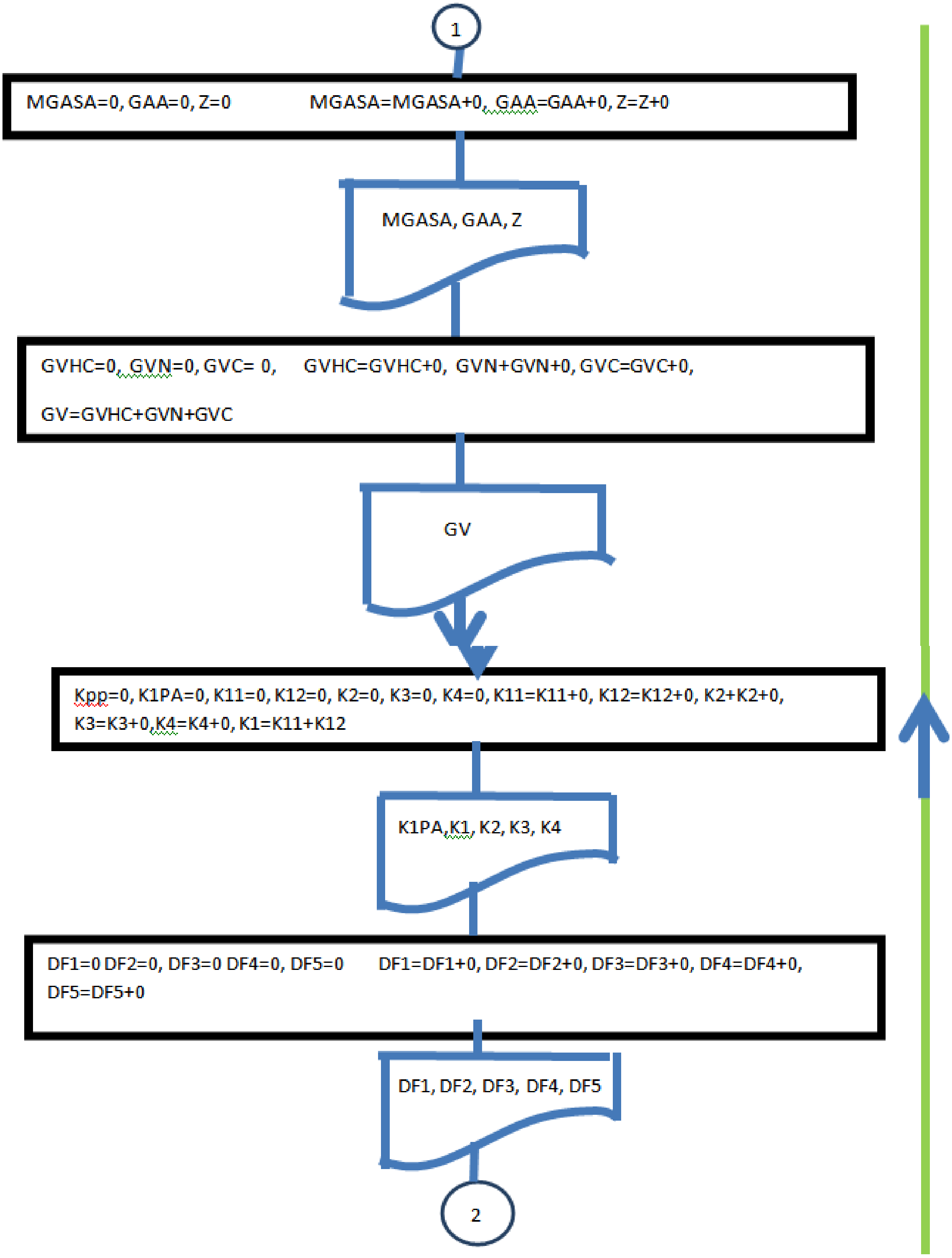
$$D = \left\{\left(0.0014(\rho Q)^{0,32} + 0.1157\left(D\mu_G\right)^{0.32}\right)^2\right\}\left[\begin{array}{l} K_1\left(1.4372\times10^{-4}\rho^{0.32} - 0.0369\rho^{0.64}\right)Q^{-1.3208} - 1.6128\times10^{-4}K_2\left(\rho^{0.64} - \rho^{0.32}\right)Q^{-1.36} \\ \left(2.8708\times10^{-4}\rho^{0.32}K_3 - 0.0267\rho^{0.32}\left(D\mu_G\right)^{0.32}K_1 - 3.5167\times10^{-5}\rho^{0.64}K_3\right)Q^{-1.6408} \\ +6.3708\times10^{-3}\rho^{0.32}\rho g\Delta H Q^{-3.3208} + \left(3.0464\times10^{-4}\rho^{0.32}K_4 - 0.0252\rho^{0.32}\left(D\mu_G\right)^{0.32}K_2\right)Q^{-1.68} \\ -4.3615\times10^{-3}\left(D\mu_G\right)^{0.32}K_3 Q^{-1.9608} + 0.5012\rho^{0.32}\left(D\mu_G\right)^{0.32}\rho g\Delta H Q^{-3.6408} \end{array}\right]$$

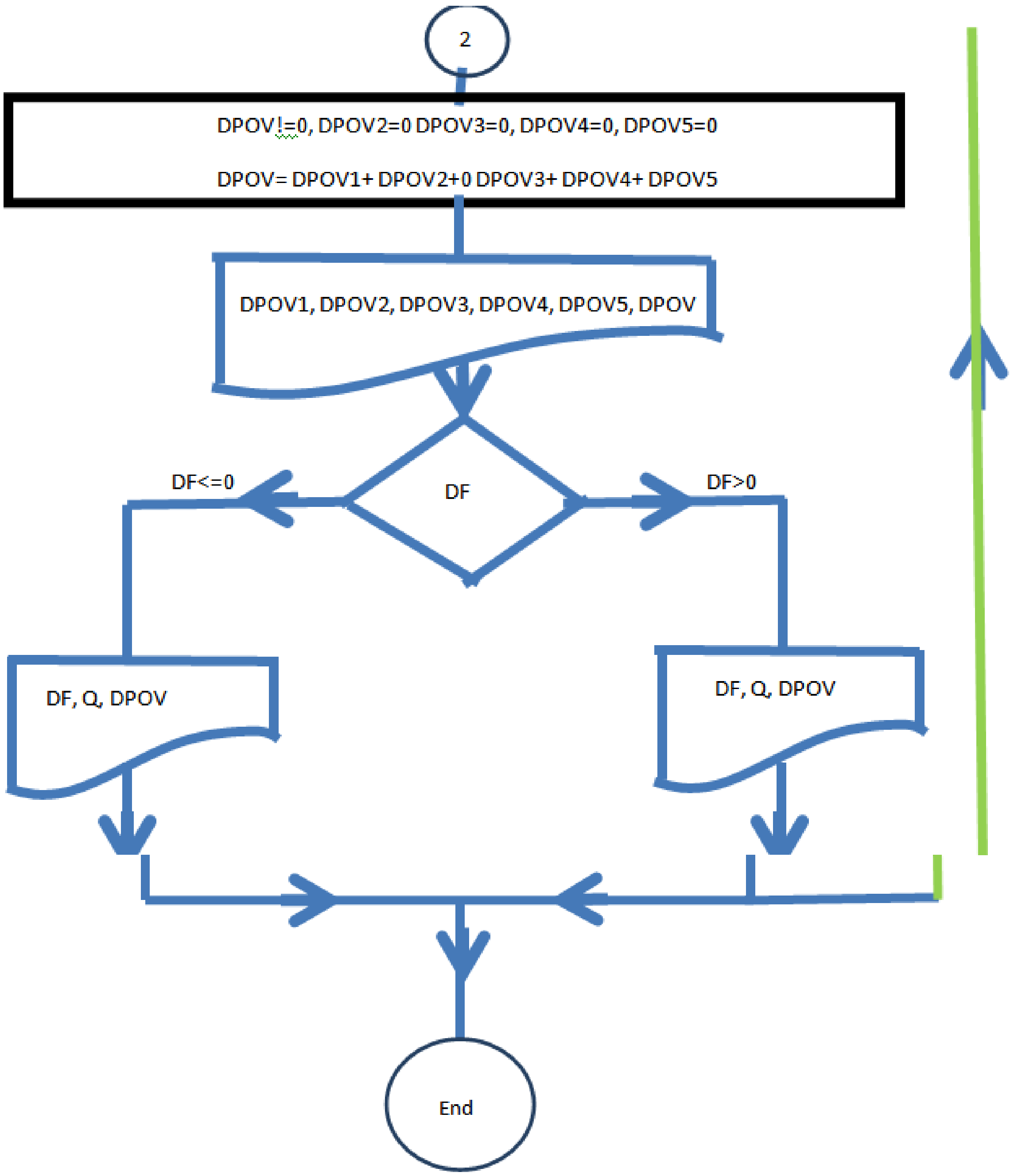
$$E = 8.96\times10^{-4}\rho^{0.32}\left(0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}\right)Q^{-0.68}\left\{\begin{array}{l} K_1\left(0.1149\rho^{0.64} - 4.48\times10^{-4}\rho^{0.32}\right)Q^{-0.3208} \\ + 4.48\times10^{-4}K_2\left(\rho^{0.64} - \rho^{0.32}\right)Q^{-0.36} \\ \left(\begin{array}{l} 5.488\times10^{-5}\rho^{0.64}K_3 + 0.0416\rho^{0.32}\left(D\mu_G\right)^{0.32}K_1 \\ - 4.48\times10^{-4}\rho^{0.32}K_3 \end{array}\right)Q^{-0.6408} \\ - 2.7451\times10^{-3}\rho^{0.32}\rho g\Delta HQ^{-2.3208} \\ + \left(0.037\rho^{0.32}\left(D\mu_G\right)^{0.32}K_2 - 4.48\times10^{-4}\rho^{0.32}K_4\right)Q^{-0.68} \\ 4.5394\times10^{-3}K_3\left(D\mu_G\right)^{0.32}Q^{-0.9608} \\ - 0.1898\rho^{0.32}\left(D\mu_G\right)^{0.32}\rho g\Delta HQ^{-2.6408} \end{array}\right\}$$

$$F = \left(0.0014(\rho Q)^{0,32} + 0.1157(D\mu_G)^{0.32}\right)^4$$

Flowchart for The Programing Algorithmic Coding




1
MGASA=0, GAA=0, Z=0 MGASA=MGASA+0, GAA=GAA+0, Z=Z+0
MGASA, GAA, Z
GVHC=0, GVN=0, GVC= 0, GVHC=GVHC+0, GVN+GVN+0, GVC=GVC+0,
GV=GVHC+GVN+GVC
GV
Kpp=0, K1PA=0, K11=0, K12=0, K2=0, K3=0, K4=0, K11=K11+0, K12=K12+0, K2+K2+0,
K3=K3+0,K4=K4+0, K1=K11+K12
K1PA,K1, K2, K3, K4
DF1=0 DF2=0, DF3=0 DF4=0, DF5=0 DF1=DF1+0, DF2=DF2+0, DF3=DF3+0, DF4=DF4+0,
DF5=DF5+0
DF1, DF2, DF3, DF4, DF5
2


2
DPOV!=0, DPOV2=0 DPOV3=0, DPOV4=0, DPOV5=0
DPOV= DPOV1+ DPOV2+0 DPOV3+ DPOV4+ DPOV5
DPOV1, DPOV2, DPOV3, DPOV4, DPOV5, DPOV
DF
DF<=0
DF>0
DF, Q, DPOV
DF, Q, DPOV
End

Input Parameters

Table 1: Geometric, Configuration and Operational Data for The Case study Gas Pipelines

ElfTotal Nig. Ltd Physical Configuration: From Obite to Bonny NLNG Terrain transversed: From Obite to Ndele to Bonny NLNG Design Standard Code: ANSI/ASME B31.8 Standard Code						
Length(km)	Diameter(cm)	Manifolds	Design Pressure(bar)	Input/Output Pressure(bar)	Flow Rate(m^3/s	Operating Temperature ($^{(0}$C)
134	36”(91.44cm)	2	100	84/63	1.8	40
Allowable Pressure Drop(bar)	Coated/ Uncoated	Flow Reynolds Number	Specific Gravity	Buried/Surface	Compressibility Factor	
20	coated	4000	0.6657	Buried	0.749	
Shell Petroleum Development Company Physical Configuration: From Soku to Bonny NLNG Terrain transversed: From Soku to Ndele to Bonny NLNG Design Standard Code: ANSI/ASME B31.8 Standard Code						
Length(km)	Diameter(cm)	Manifolds	Design Pressure(bar)	Input/Output Pressure(bar)	Flow Rate(m^3/s	Operating Temperature ($^{(0}$C)
116	36”(91.44cm)	1	100	81/63	1.8	40
Allowable Pressure Drop(bar)	Coated/ Uncoated	Flow Reynolds Number	Specific Gravity	Buried/Surface	Compressibility Factor	
20	coated	4000	0.6978	Buried	1.273	
Agipl Nig. Ltd Physical Configuration: From Obiafu to Bonny NLNG Terrain transversed: From Obiafu to Bonny NLNG Design Standard Code: ANSI/ASME B31.8 Standard Code						
Length(km)	Diameter(cm)	Manifolds	Design Pressure(bar)	Input/Output Pressure(bar)	Flow Rate(m^3/s	Operating Temperature ($^{(0}$C)
134	36”(91.44cm)	2	100	84/63	1.8	40
Allowable Pressure Drop(bar)	Coated/ Uncoated	Flow Reynolds Number	Specific Gravity	Buried/Surface	Compressibility Factor	
20	coated	4000	0.6657	Buried	0.749	
Nigeria Gas Company (NGC) Eastern Division Physical Configuration: From Warri to Okitipupa Terrain transversed: From Ogharepe Warri to Okitipupa Ondo Design Standard Code: ANSI/ASME B31.8 Standard Code						
Length(km)	Diameter(cm)	Manifolds	Design Pressure(bar)	Input/Output Pressure(bar)	Flow Rate(m^3/s	Operating Temperature ($^{(0}$C)
122	36”(91.44cm)	2	100	80.6/64	1.8	40
Allowable Pressure Drop(bar)	Coated/ Uncoated	Flow Reynolds Number	Specific Gravity	Buried/Surface	Compressibility Factor	
16.6	coated	4000	1.326	Buried	1.383	
Nigeria Gas Company (NGC) Western Division Physical Configuration: From Okitipupa Ondo to Shagamu Lagos Terrain transversed: From Okitipupa Ondo to Shagamu Lagos Design Standard Code: ANSI/ASME B31.8 Standard Code						
Length(km)	Diameter(cm)	Manifolds	Design Pressure(bar)	Input/Output Pressure(bar)	Flow Rate(m^3/s	Operating Temperature ($^{(0}$C)
153	36”(91.44cm)	2	100	64/44.4	1.8	40
Allowable Pressure Drop(bar)	Coated/ Uncoated	Flow Reynolds Number	Specific Gravity	Buried/Surface	Compressibility Factor	
19.6	coated	4000	1.326	Buried	1.383	

(Source :ElfTotal Nig. Ltd, Shell Petroleum Development Company, Agip Nig. Ltd, Nigeria Gas Company (Eastern Division), Nigeria Gas Company (Western Division))

Table 2: Gas Composition for The Case Study Pipelines

C_1	C_2	C_3	IC_4	NC_4	IC_5	NC_5	C_6	C_7	N_2	CO_2
ElfTotalNig. Ltd										
0.8450	0.0427	0.025	0.010	0.009	0.007	0.006	0.0015	0.00	0.00	0.047
Shell Petroleum Development Company										
0.88800	0.05423	0.2882	0.0072	0.009	0.0038	0.00	0.0018	0.00166	0.0002	0.0076
Agip Nig. Ltd										
0.8436	0.04116	0.2315	0.0165	0.0111	0.004	0.0033	0.0045	0.0033	0.00645	0.05
Nigeria Gas Company (Eastern Division)										
0.85	0.03795	0.02915	0.0155	0.0101	0.004	0.0033	0.00045	0.0003	0.00645	0.05
Nigeria Gas Company (Western Division)										
0.85	0.03795	0.02915	0.0155	0.0101	0.004	0.0033	0.00045	0.0003	0.00645	0.05

(Source :ElfTotal Nig. Ltd, Shell Petroleum Development Company, Agip Nig. Ltd, Nigeria Gas Company (Eastern Division), Nigeria Gas Company (Western Division))

Computer Simulation of The Optimization Models

```
% Computer Programme To Test For Optimality(PAN B)
% Initialization
% Upstream Pressure at OBITE, P1(bar))
  P1=84.1;
% Downstream presssure at BONNY, P2(bar)
  P2=71.0;
% Base pressure, Pbj
Pb=1.03;
% Base temperature, Tb
 Tb=291;
% To calculate average flow pressure, P3
  P3=((2/3)*(P1^3-P2^3)/(P1^2-P2^2));
disp('P3')
fprintf('%7.3f\n',P3)
%  Average flow temperature
   T=313;
% Line diameter(cm), D
  D=92.44;
% Elevation above datum, h
  h=-100;
%  Acceleration due gravity, g
  g=9.8;
%  Gsa density
  GD=73.2404/10^4;
% Pump isentropin efficiency, ni
ni=0.85;
% Universal gas constant, R0
  R0=8314/10^5;
% Weymouth constant
%  KW=78.85;
% Panhandle B constsnt
  KPB=3.46;
```

```
% Modified Panhandle B constant
%   KPB=45.03;
% Weymouth exponent, nw
%  nw=0.5;
% Panhandle A exponent, np
%  n=0.53;
% Modified Panhandle B exponent, nb
  n=0.51;
% Pipe inlet and exit conditions
% Well rounded inlet coeffient, k4
 K41=0.04;
% Well rounded exit coefficient, k5
 K51=1.0;
% Pump isentropic efficiency, n1
 n1=0.95;
% Kinetic energy flux coeffiicient, A2
 A2=1.036;
% Area ratio, AR
 AR=1.0;
% Equivalent length of one globe valves, LEV(m)
  LEV=350*D;
% Equivalent length of 13 globe valves
LEVn=(13*LEV)/1000;
% Equivalent length of one Tee-joint
% Flow through run
  LET1=20*D;
% Flow through branch
  LET2=60*D;
% Total effective length for 13 Tee-joint
LETn=(13*(LET1+LET2))/1000;
% Line lehgth(Km), LL
 L=131+(LEVn+LETn);
for Q=86400:43200:518400
disp('When Q is')
fprintf('%6.2f\n',Q)
% Mean flow velocity, Vm/s)
 V=(4*Q)/(pi*D^2);
% Pressure ratio, CP
  CP=2*(P2-P1)/(GD*V^2);
%  Average composition of the gas from production line for the month of August 2008(mole fraction)
C1A=0.869859;C2A=0.054574;C3A=0.020709;IC4A=0.004517;NC4A=0.006309;IC5A=0.002178;NC5A=0.0
01787;C6A=0.004627;N2A=0.000598;CO2A=0.034843;
%  Gas density
%   GD=73.2924
%   Average composition of the gas from production line for the month of January 2006(mole fraction)
%
C1J=0.707881;C2J=0.052663;C3J=0.026519;IC4J=0.005379;NC4J=0.007883;IC5J=0.002642;NC5J=0.002116
;C6J=0.004207;N2J=0.001332;CO2J=0.028088;
%  Gas density
%   GD=77.8621
%  Molar mass of gaseous components
M11=16;M21=30;M31=44;M4I1=54;M4N1=54;M5I1=72;M5N1=72;M61=86;M71=100;M81=114;M91=128;
M101=142;MN21=28;MCO21=44;
 MAIR=28.97;
%  Average molecular mass of gaseous mixture(PRODUCTION) in January, 2006
MGASJ=(C1J*M11+C2J*M21+C3J*M31+IC4J*M4I1+NC4J*M4N1+IC5J*M5I1+NC5J*M5N1+C6J*M61+
N2J*MN21+CO2J*MCO21);
%  Specific gravity of the mixture for the month of January, 2006
%   GAJ=MGASJ/MAIR;
```

```
% Average molecular mass of gaseous mixture(PRODUCTION) in August, 2008
MGASA=(C1A*M11+C2A*M21+C3A*M31+IC4A*M4I1+NC4A*M4N1+IC5A*M5I1+NC5A*M5N1+C6A*
M61+N2A*MN21+CO2A*MCO21);
% Specific gravity of the mixture for the month of August, 2008
     GAA=MGASA/MAIR;
% Gas density, GD
%      GD=(P3*MGASA)/(R0*T);
% Gas compressibility factor, Z
   Z=((P3*MGASA)/(GD*8314*T))*10;
disp(' MGASA     GAA       Z')
fprintf('%12.6f\n',MGASA,GAA,Z)
% To calculate gas absolute viscosity, GV(Pas--Ns/m2)
% Absolute viscosity of the hydrocarbon components, GVHC, is expressed as:
  GVHC=(8.188E-3-6.15E-3*(GAA)+(1.709E-5-2.062E-6*log10(GAA))*(1.8*T+0.27))*1.02247E-
5*1.15741E-10;
%   *1.15741E-10;
% Absolute viscosity of Nitrogen component
   GVN=(9.59E-3+8.48E-3*log10(GAA))*N2A*1.02247E-5*1.15741E-10;
% Absolute viscosity of carbon dioxide component
  GVC=(6.24E-3+9.08E-3*log10(GAA))*CO2A*1.02247E-5*1.15741E-10;
  GV=GVHC+GVN+GVC;
disp('GV'  )
fprintf('%30.25f\n',GV)
% At the optimal value of Q, dF/dQ=0
% Pump constant, kpp
kpp=(16*GD*(1-n1)/(pi^2*D^4));
% Determination of the optimal flow capacity
K1PB=1.5^(0.01989)*(1/10^5)^0.01989*KPB*(Tb/Pb)^(1.02)*(MAIR/MGASA)^(0.49011)*((GD*R0*T*(P1+
P2))/(MGASA*(P1^2+P2^2+P1*P2)))^0.01989*((P1+P2)/(T*L))^0.51*D^2.53;
K11=((0.0112*GD*L)/(pi^2*D^5))+((8*GD)/(pi^2*D^4))+((8*GD*(K41+A2-
1))/(pi^2*D^4))+((8*K51*GD)/(pi^2*D^4));
  K12=(1-
1/AR^2)*((8*GD)/(pi^2*D^4))+((0.0112*GD*LEVn)/(pi^2*D^5))+((0.0112*GD*LETn)/(pi^2*D^5))+((16*G
D*(1-ni))/(pi^2*D^4));
  K1=(K11+K12);
  K2=0.0014*K1PB^(-1.9608);
K3=(1/(pi^2*D^5))*(0.9256*GD^0.68*L*(D*GV)^0.32+0.9256*GD^0.68*LEVn*(D*GV)^0.32+0.9256*GD^
0.68*LETn*(D*GV)^0.32);
  K4=0.1157*K1PB^(-1.8539)*((D*GV)/GD)^0.32;
disp('K1PB,  K1.  K2,  K3,   K4')
fprintf('%20.15f\n',K1PB,K1,K2,K3,K4)
DF1=K1PB*GD^0.32*n*(GD^0.32*(K1*Q^0.3592+K2*Q^0.32+K3*Q^0.0392+K4+GD*g*h*Q^(-
1.6408))/(0.0014*(GD*Q)^0.32+0.1157*(D*GV)^0.32))^(n-1);
  DF2=(0.0014*(GD*Q)^0.32+0.1157*(D*GV)^0.32);
  DF3=-(K1*Q^0.3592+K2*Q^0.32+K3*Q^0.0392+K4+GD*g*h*Q^(-1.6408))*(4.48*10^(-4)*GD^0.32*Q^(-
0.68));
  DF4=GD^0.32*(0.3592*K1*Q^(-0.6408)+0.0392*K2*Q^(-0.68)+0.0392*K3*Q^(-0.9608)-
1.6408*GD*g*h*Q^(-2.6408)/1000);
% DF5=(0.0014*(GD*Q)^(0.32)+0.1157*(D*GV)^(0.32))^(2);
   DF5=DF2^2;
  DF=DF1*((DF2*DF4)+DF3)/DF5;
DPov=(K1*Q^2)+K2*Q^1.8539+K3*Q^1.68+K4*Q^1.5339+(GD*g*h)/1000;
  DPov1=(K1*Q^2);
  DPov2=K2*Q^1.8539;
  DPov3=K3*Q^1.68;
  DPov4=K4*Q^1.5339;
  DPov5=GD*g*h/1000;
disp('DPov1,DPov2,DPov3,DPov4,DPov5')  fprintf('%20.15f\n',DPov1,DPov2,DPov3,DPov4,DPov5)
% At the optimal flow capacity, DF=0
```

```
if DF<=0
disp(' DF        Q       DPov')
fprintf('%8.5f\n',DF,Q,DPov)
else
disp('conditions not met')
fprintf('%8.5f\n',DF,Q,DPov)
end
end
% Computer ProgrammeFor The Determination of The Optimal Maximum or
% Minimum Values of Flow Capacity and Pressure Drop((PANHANDLE   B)
Q=Oop;
DF1=K1PB*GD^(0.32)*n*(n-1);      DF2=K1*Q^(0.3592)+K2*Q^(0.32)+K3*Q^(0.0392)+K4+GD*g**h*Q^(-
1.6408);      DF3=0.0014*(GD*Q)^(0.32)+0.1157*(D*GV)^(0.32);
DF4=K1*(0.1149*GD^(0.64)-4.48*E4*GD^(0.32))*Q^(-0.3208);
DF5=4.48^E-4*K2*(GD^(0.64)-GD^(0.32))*Q^(-0.36);
DF6=(5.488*E-5*GD^(0.64)*K3+0.0416*GD^(0.32) *(D*GV)^(0.32)-4.48E-6*GD^(0.32)*K3)*Q^(-0.6408);
DF7=-2.7451E-4*GD^(0.32)**GD*g*h*Q^(-2.3208);
DF8=(0.037*GD^(0.32)*(D*GV)^*K2-4.48E-4*GD^(0.32))*Q^(-0.68);
DF9=4.5394E-3*K3*(D*GV)^(0.32)*Q^(-0.9608);
DF10=-0.1898*GD^(0.32)*(D*GV)^(0.32)*GD*g*h*Q^(-2.6408);
DF11=DF3;
DF12=K1PB*GD^(0.32)*n;
DF13=DF2;
DF14=DF3;
DF15=DF3^2;
DF16=K1*(1.4372E-4*GD^(0.32)0.0369*GD^(0.64))*Q^(-1.308)DF17=-1.6128E-4*K2*(GD^0.64-
GD^0.32)*Q^(-1.36);DF18=(2.8707E-4*GD^0.32*K3-0.0867*GD^0.32*(D*GV)^0.32*K1-3.5167E-
5*GD^0.68*K3)*Q^(-1.6408);
DF19=-6.3708E-3*GD^0.32*GD*g*h*Q(-3.3208);
DF20=(3.0464E-4*GD^0.32*K4-0.0252*GD^0.32*(D*GV)^0.32*K2)*Q^(-1.68);
DF21=-4.3615E-3*(D*GV)^0.32*K3*Q^(-1.9608);
DF22=0.5012*GD^0.32*(D*GV)^0.32*GD*g*h*Q(-3.6408).DF23=-8.96E4*GD^0.32*(0.001
*(GD*Q)^0.32+0.1157*(D*GV)^0.32)*Q^(-0.68);
DF24=K1*(0.1149*GD^0.64-4.48E-4*GD^0.32*Q(-0.3208);
DF25=-4.48E-4*K2*(GD^0.64-GD^0.32)*Q(-0.36);
DF26=(5.488E-5*GD^0.64*K3-0.0416*GD^0.32*(D*GV)^0.32*K1-4.48E-4*GD^0.32*K3)*Q^(0.640F27=-
2.7451*E-3*GD^0.32*GD*g*h*Q(-2.3208);
DF28=-(0.037*GD^0.32*(D*GV)^0.32*K2-4.48E-4*GD^0.32*K4)*Q(-0.68);
DF29=4.5394E-3*K3*(D*GV)^0.32*Q^(-0.9608);
DF30=-0.1898*GD^0.32*(D*GV)^0.32*GD*g*h*Q(-2.6408);
DF31=DF3^4;FDD=DF1*(DF2/DF3)^(n-
2)*((DF4+DF5+DF6+DF7+DF8+DF9+DF10)/DF11)^2;+DF12*(DF11)^(n1)*((DF15*(DF16+DF17+DF18+D
F19+DF20+DF21)(DF22*(DF23+DF24+DF25+DF26+DF27+DF28+DF29)))/DF30);
if FDD>0
disp('The optimal Minimum value of Q is')
fprintf('%20.10f\',Q)
else
disp('The optimal Maximum value of Qis')
fprintf('%20.10f\',Q)
end
```

Appendix C: Computer Program for Graphical Presentation of Results

```
% ELF Panhandle B for 36"(0.9144m)
DQop=[-25.413,-24.2427,-8.868,6.608,20.301,41.18,52.9,64.413,77.868,86.991,104.559,118.285];
DD=[-15,-10,-5,5,10,20,25,30,35,40,45,50];
DP1=[-30,-20,-10,10,20,40,50,60,70,80,90,100];
DP2=[-30,-20,-10,10,20,40,50,60,70,80,90,100];
DL=[-15,-10,-5,5,10,20,25,30,35,40,45,50];
```

```
%PD=[15.48,12.91,12.34,11.06,10.33,6.56];
plot(DD,DQop,DP1,DQop,DP2,DQop,DL,DQop)
%xlabel('P1/P1')
ylabel('Qopt/Qopt')
title('Graph of Change in Optimal Flow Capacity to Optimal flow Capacity and Change in Upstream Pressure to Upstream Pressure ')
%gtext('Upstream/Optimal Line Pressure Drop'),gtext('Downstrean/Optimal Line Pressure Drop')
```

II. RESULTS AND DISCUSSION

The results of optimization of flow variables are in the tables below :

Table 3 : Results of Optimal Flow-- ElfTotal Nig. Ltd

	MODEL FLOW EQUATIONS		OPTIMIZATION MODELS	
	OPEATING CONDITIONS	PAN A	OPEATING CONDITIONS	PAN B
FLOW CAPACITY	1.8m³/s	1.5m³/s	1.8m³/s	2.83m³/s
PRESSURE DROP	20bar	21.1bar	20bar	11.57bar
AMBIENT TETEMPERATURE	29K		291K	
BULK TEMPERATURE	313		313	

Table 4 : Results of Optimal Flow--Shell Company (SPDC)

	MODEL FLOW EQUATIONS		OPTIMIZATION MODELS	
	OPEATING CONDITIONS	PAN A	OPEATING CONDITIONS	PAN B
FLOW CAPACITY	1.8m³/s	1.5m³/s	1.8m³/s	2.6983m³/s
PRESSURE DROP	19.6bar	18bar	19.6bar	11.134bar
AMBIENT TETEMPERATURE	29K		29K	
BULK TEMPERATURE	313		313	

Table 5 : Results of Optimal Flow--Agip Nig. Ltd

	MODEL FLOW EQUATIONS		OPTIMIZATION MODELS	
	OPEATING CONDITIONS	PAN A	OPEATING CONDITIONS	PAN B
FLOW CAPACITY	1.8m³/s	1.5m³/s	1.8m³/s	3.01m³/s
PRESSURE DROP	21.1bar	21.1bar	21.1bar	8.8bar
AMBIENT TETEMPERATURE	291		291K	
BULK TEMPERATURE	313		313	

Table 6 : Results of Optimal Flow--Nigeria Gas Company (NGC) Eastern Division

	MODEL FLOW EQUATIONS		OPTIMIZATION MODELS	
	OPEATING CONDITIONS	PAN A	OPEATING CONDITIONS	PAN B
FLOW CAPACITY	$1.8m^3/s$	$1.59m^3/s$	$1.8m^3/s$	$3.30m^3/s$
PRESSURE DROP	16.6bar	16.6bar	16.6bar	11.85bar
AMBIENT TETEMPERATURE	291		291	
BULK TEMPERATURE	313		313	

Table 7 : Results of Optimal Flow--Nigeria Gas Company (NGC) Western Division

	MODEL FLOW EQUATIONS		OPTIMIZATION MODELS	
	OPEATING CONDITIONS	PAN A	OPEATING CONDITIONS	PAN B
FLOW CAPACITY	$1.8m^3/s$	$1.59m^3/s$	$1.8m^3/s$	$3.00m^3/s$
PRESSURE DROP	19.6bar	19.6bar	19.6bar	9.7bar
AMBIENT TETEMPERATURE	291		291	
BULK TEMPERATURE	313		313	

Tables 3 to 7 show the conditions of the pipelines subject to the operational and optimized conditions. The percentage reduction in pressure drop viz-a-viz the percentage increase in flow throughput under the optimized conditions for all the case study pipelines are as shown in Table 8.

Table 8 : Reduction in Line Pressure Drop-Increase in Flow Throughput Under Optimized Condition

Case Study Gas Pipelines	% Reduction in Line Pressure Drop (bar)	% Increase in Flow Throughput (m^3/s)
ElfTotal Nig. Ltd	42.65	57.22
Shell Company (SPDC)	28.62	49.91
Agip Nig. Ltd	-58.29	67.22
Nigeria Gas Company (Eastern Division)	28.61	83.33
Nigeria Gas Company (Western Division)	50.00	66.67

Apparently, there could be a significant improvement on the line pressure drop to the tune of 10 to 45%. Additional flow throughput of 8% above the normal operational level could also be accommodated.

III. RECOMMENDATION AND CONCLUSION

(i) The optimization scheme clearly confirmed that the present operating conditions of our gas pipelines are truly not optimal. There is therefore urgent need to generate new Design equations incorporating the optimal models for the production of efficient pipelines for future applications. This is to ensure that the operating pipelines and new pipelines networks for gas transmission are not under operated in terms of Pressure-Flow capacity requirements. The design review and analysis would clearly reduce the cost of design, construction and operations of gas pipelines, associated equipment and facilities. Thus, to plan, set up, operate and execute a gas pipeline at effective cost could be realizable if the optimal pressure-flow capacity requirements are ascertained at the Design and material specification stages.

(ii) In-depth research work is recommended in the area of theoretical, practical and economic consideration of flow compressibility effects as well as hydration problems in sub-cooled under water offshore pipelines. Adequate knowledge of compressibility effects on pressure drop and pressure gradient will go a long way in ascertaining the operating pressure-temperature characteristics of pipelines so as to correlate the operating measured conditions.

(iii) Critical review of as-installed physical, geometric and flow features of gas pipelines for more exact evaluation of losses in fluid energy. If the factors influencing the loss of fluid energy are thoroughly evaluated, the required overall pressure drop in a gas pipeline could be closely specified. This will off-set the problem of underrating or overrating the Pressure–Flow capacity requirements for gas pipelines. This would also aid the sizing of compressors, pumps, valves, fittings and metering devices.

(iv) This optimization and sensitivity analysis is limited to single phase flow of gas. Future research is envisaged to also address optimization models for two phase flow of gas in gas transmission pipelines[PhD Yhesis].

Conclusion

Gas Pipeline flow optimization models developed by the researcher for single phase flow of gas had been simulated by computationalapproach. The simulation results clearly confirmed that there could drastic reduction in pressure drop for the optimized gas pipelines. Additional throughput of about 30% to 50% could be accommodated over the normal operational level. Analysis of the optimization results clearly confirmed that operating optimally would have significant impact in reducing the cost of investment and operation of as installed gas pipelines, even the future generation of gas pipelines to be in Nigerian terrain. It is also imperative that pumping cost would be greatly offset by virtue of the fact that pumping power directly depends on the magnitude of the line pressure drop.

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