OPERATIONAL SUSTAINABILITY THROUGH INFINITE REVIEW OF VARIABLES

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ABSTRACT

One of the Federal Government mandates on the Nigerian National Petroleum Corporation is to make petroleum products available in all parts of the nation. One of the pump stations set aside to accomplish this obligation is the Port Harcourt Area Systems 2E and 2EX pump Station nearly written off due to perceived low efficiency. The aim is to certify the newly and locally developed quality assurance protocol formula using the current real time pumping parameters. The objective of this work was to establish the relationship between data used for the formulation of the previous rule of thumb and current field data irrespective of the pump used and product type being moved. The previous rule of thumb confirmed optimum operating pressure and flow rate as 26.8 bar and 240 m^3/hr respectively, against the over 30 years designed parameters. This rule can be used to predict the pressure drop in fluid flow through the referenced pipeline. The result showed 0.01% deviation from the original work. This is evidence that the formula can still be used to authenticate the efficiency of the pipeline with assured product delivery and distribution.

***Keywords**: pumping, pressure, delivery, quality assurance, parameters.*

INTRODUCTION

One of the fastest and cheapest means of transporting large volume of petroleum products from one location to another is through the pipeline network. The product delivery is enhanced by pumps which is part of the pump station configurations. The pumps are either driven by electric motors, diesel engines or gas turbines. The pumps are classified according to pipeline design, topography and capacity requirements. The pumps were designed alongside workstation that remotely control the entire pump house and other aspects of pipeline operations. The station is also designed with instruments that predict real-time information on products densities, flash points and operational parameters like suction, discharge and mainline pressure. Pipeline control rooms utilize data acquisition systems that return real-time information about the rate of flow, the pressure, the speed and other characteristics. Both computers and trained operators evaluate the information continuously, (Ross, 2014 and Runge, 2014). Pump performance can be affected by the pump's physical properties like tensile strength, limit of proportionality, elongation, reduction in area, hardness, impact strength, fatigue strength, creep resistance, chemical composition, and corrosion resistance. The effects of these are felt more when the pump factory spares are unavailable and Operators resort to in-house fabrications of parts.

The pumps used for this review are diesel engine pumps. They were designed for oil-field environments with speed range maintained between 2,975 and 2,985 rpm. The engines employ a pneumatic control system to ensure no hazard is generated, (Singh, 2013 and Goyal, 2015).The initial research consideration used field data obtained from the then lone functional diesel driven pump. The operational performance was affected by:

- Aged and upkeep issues (workshop upgrading).
- Dearth of skilled young Engineers/Operators.
- Disguised succession plan due to apprehensions; as most of the people trained to operate the pumps have retired from service.
- Observed downtime occasioned to shortage of factory spare parts.
- Micro misalliance on some fabricated parts.

The direct measurable variables considered are pressure drop, flow rate, internal diameter and length of the pipe. Other variables considered are the internal roughness of the pipe, fittings, elevation change, types of flow, Reynold's number, friction factor, and fluid velocity.

RELATIONSHIP BETWEEN FLOW RATE AND PRESSURE DROP

From the previous work, the flow rate was measured in volume per time, this gave the volumetric flow rate Q_v (m^3/s) as area A (m^2) of the pipe multiplied by the velocity *v* (m/s) of the fluid.

Thus $Q_v = A \times \boldsymbol{v} = A\boldsymbol{v}$ (1)

The mass flow rate Q_m (kg/s) of the fluid (product) is given as:

$Q_m = Q_v\rho = A\boldsymbol{v}\rho$ (2)

As the A in equation (1) is substituted with $\pi \frac{d^2}{4}$, it implies that

$Q_v = \pi \frac{d^2 v}{4} = 0.785\, d^2\boldsymbol{v}$ (3)

Where *d i*s the internal diameter of the pipe (Ujile, 2014).

PRESSURE DROP

One of the key calculations considered in the pipeline operation is pressure. The critical pressure types are the pressure drop in a given length of pipe for a given flow volume, the allowable working pressure and the delivery pressure. The allowable working pressure of the pipe in all operation conditions is important, and is taken as the maximum gauge pressure permissible.

Darcy's equation presented in S. I Unit has pressure drop expressed as

$$\Delta P = \frac{\rho f L v^2}{2d}, N/m^2 \quad (4)$$

Where ΔP = Pressure drop (N/m^2) over the length L (m).
ρ = density of fluid, (kg/m^3);
f = friction factor, dimensionless; L = length of pipe, (m); v = velocity of the fluid, (m/sec);
d = Inside diameter of the pipe, (m) and Acceleration due to gravity (9.81 m/s^2).

The total change in the static pressure of the fluid (product) as it flows along the pipeline is determined using the components of the Bernoulli equation.

$$\Delta\left(\frac{v^2}{2}\right) + gc\Delta Z + \int_1^2 VdP + Ws + F = 0 \quad (5)$$

The work and friction were neglected in the review hence,

$$\frac{\Delta P}{\rho} + \frac{\Delta v^2}{2gc} + \frac{g}{gc}\Delta Z = 0 \quad (6)$$

g is regarded as acceleration due to gravity acting in the same direction as force and can also be expressed as $g = \frac{dv}{dt}$ *; gc = Acceleration due to gravity (9.81 m/s^2)*

These components were considered separately and added together. It was observed that a change in elevation can result to pressure decrease. Also a change in velocity may cause it to increase, and that the head loss may cause it to decrease. The cumulative effect depends on the relative magnitudes of each change, (McAllister, 2015; Shashi-Menon, 2015 and Bratland, 2013). It was confirmed that in the uniform diameter pipe, the inlet flow rate cannot completely be equal to the discharge.

The previous research work revealed that the designed flows rates were never achieved and using the then available main line pumps. The optimum operating parameter was consolidated as 26.8015 bar and $240m^3/hr$ based on 2011 to 2014 field data. Meanwhile, the maximum and minimum designed pressure and flow rate is 35 bar to 25 bar and 290 m^3/hr to 270 m^3/hr respectively. The result led to the established confidence and commitment to run the aged pumps again in order to sustain product delivery through the pipeline.

The objective of this work was to establish the relationship between data used for the formula and current field data irrespective of the pump and product type being moved.

METHODOLOGY

This present review considered 2017 field figures as there was no tangible operation from 2015 to 2016. The 2017 available field data was for AGO only. The data was reviewed and compared with the result from the previous work. The operational field data was from Automotive Gas Oil which is the dominated product pumped in 2017.The collated hourly flow rate was averaged to daily and then compressed to weekly. The observed minimum and maximum flow rates were noted. The main line pressure was extracted from the daily log book and control room activity charts. The exit pressure was not certain due to the observed inconsistency in the data. For the observed inconsistent, quality assurance procedure was deployed to ascertain the exit/receiving pressure. The data was evaluated

using relevant empirical and statistical formulae, equations and correlations. Other analysis models used were linear, power, exponential logarithmic and polynomial functions. Linear function was used when the data appear to fall within a straight line. This was done to choose the best possible fit for the data. Power function is used by engineers and scientist in areas that require basic qualitative evaluations. Exponential function relates to the understanding of mechanisms and working of nature. Logarithmic function is a mathematical inverse of exponential and it was used as an instrument which governs growth processes. Polynomial is a quadratic equation which appears as consequences of laws of physics and other classical phenomena in certain range of parameter, (Shestopaloff, 2100; Richards, 2014; Barkech, 2015; Kalman, 1997).
The current review was compared with the results of the previous work. Additional input to this work was the rehabilitation and performance of an Allen Engine pump abandoned for over 20 years due to vandalism. The results from the previous work was compared with the recent.

FINDINGS AND DISCUSSIONS

Observed Flow rate and Mainline Pressure using different functions and the same Diesel Pump for previous research:

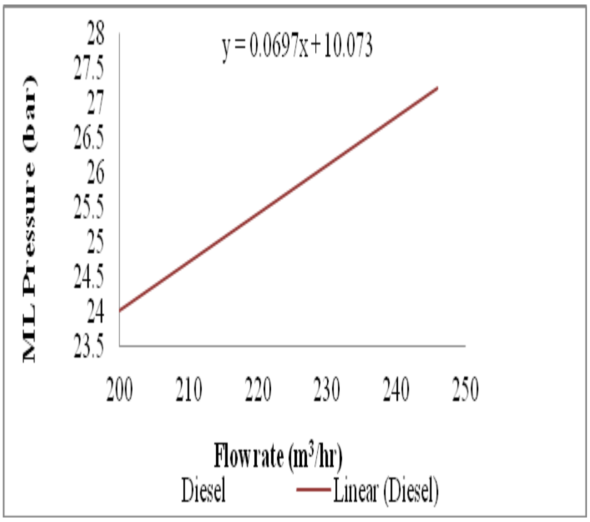

Fig 1: Linear function

At optimum flow rate of 240m^3/hr., the main line pressure was calculated as 26.973 bar

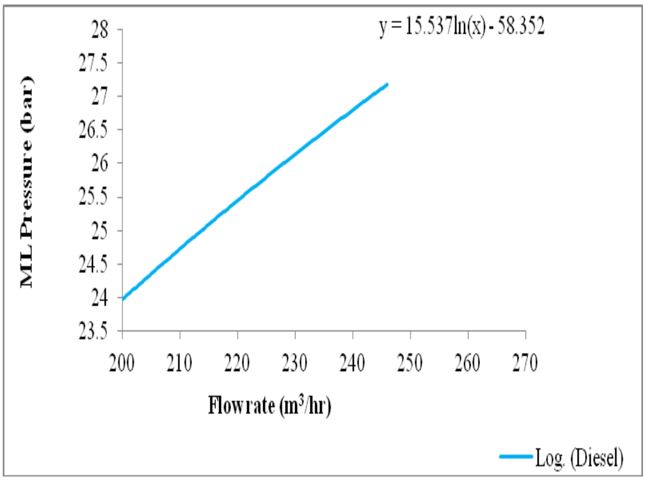

Fig 2: Logarithmic function

At optimum flow rate of 240 m^3/hr, the main line pressure is calculated as 26.801bar.

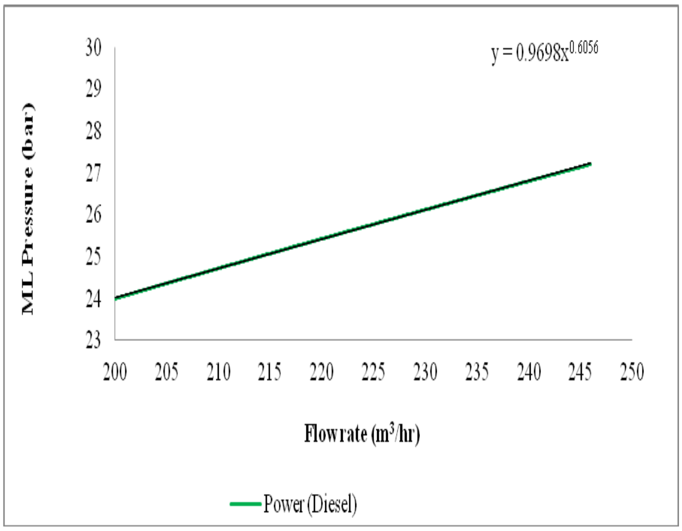

Fig 3: Power function

At optimum flow rate of 240 m^3/hr, the main line pressure was calculated as 26.80 bar

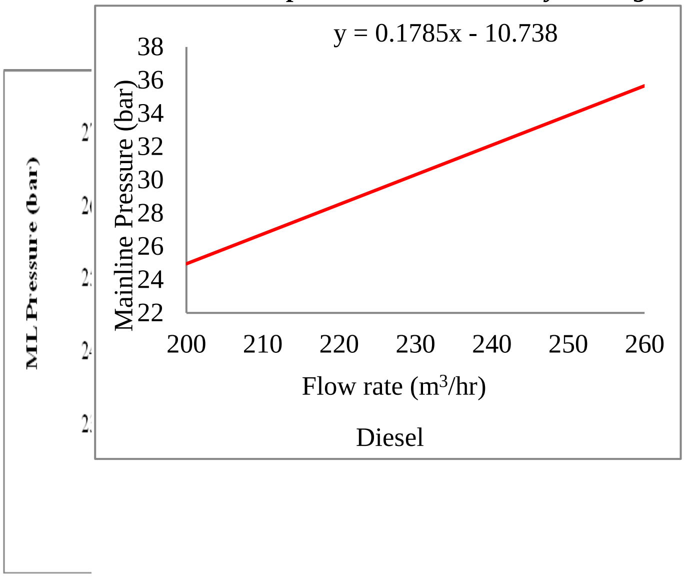

Fig 4: Exponential function

At optimum flow rate of 240m^3/hr, the main line pressure was calculated as 26.701 bar

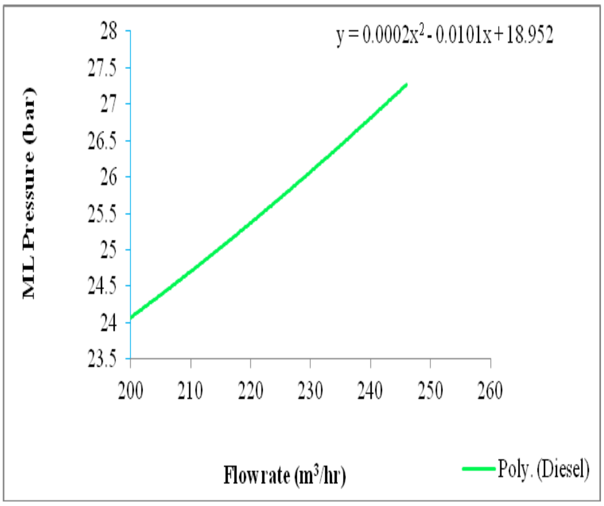

Fig 5: Polynomial function

Considering the optimum flow rate of 240 m^3/hr, main line pressure was calculated as 28.048 bar.

DEVELOPMENT WITH ALLEN ENGINEMAINLINE PRESSURE AND FLOW RATE

For the Allen Engine pump, the maximum and minimum designed pressure and flow rate is 50 bar to 35 bars and 290 m^3/hr to 270 m^3/hr respectively. The result obtained after the analysis of the field data revealed the following:

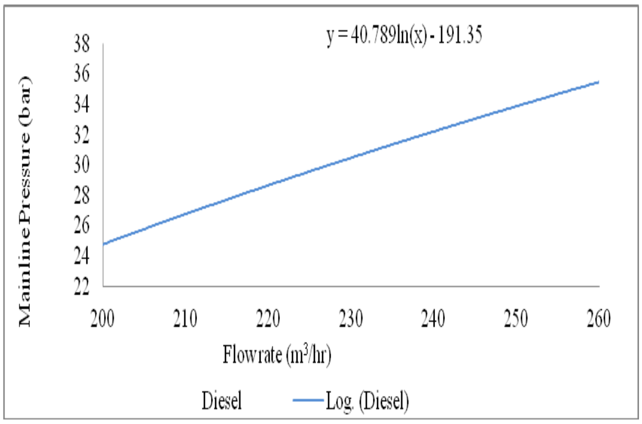

Fig. 6: Logarithmic function

With the Allen engine, the optimum mainline pressure at 240m^3/hr was calculated as 32.2 bar.

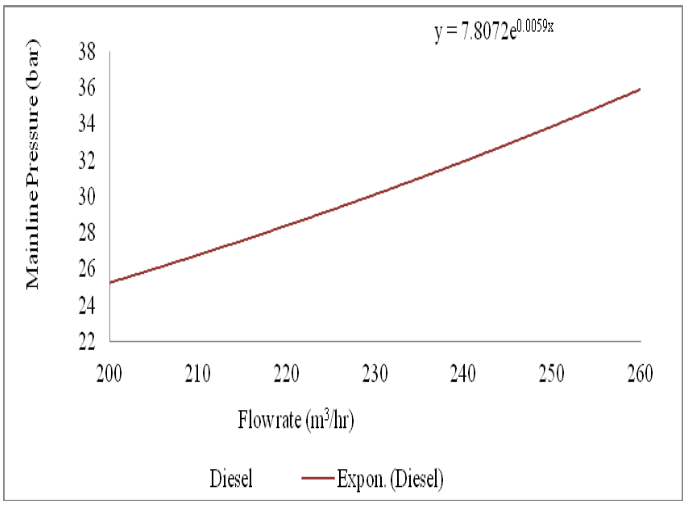

Fig. 7: Exponential function

Using optimum flow rate 240m^3/hr, the main line pressure was calculated 32.17 bar.

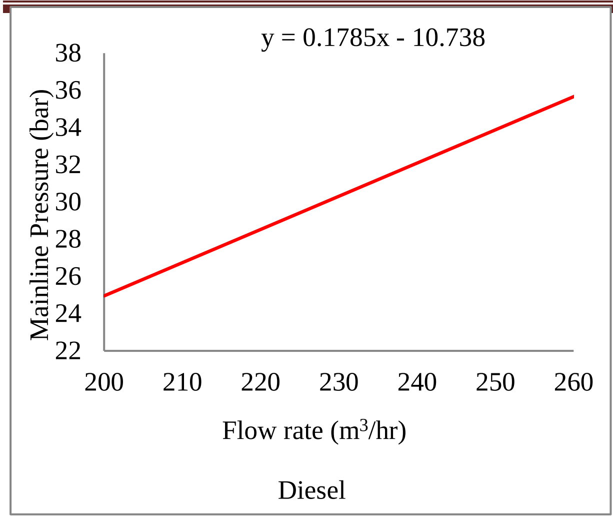

Fig. 8: Linear function

With the Allen engine, the optimum mainline pressure at 240 m^3/hr was calculated as 32.102 bar.

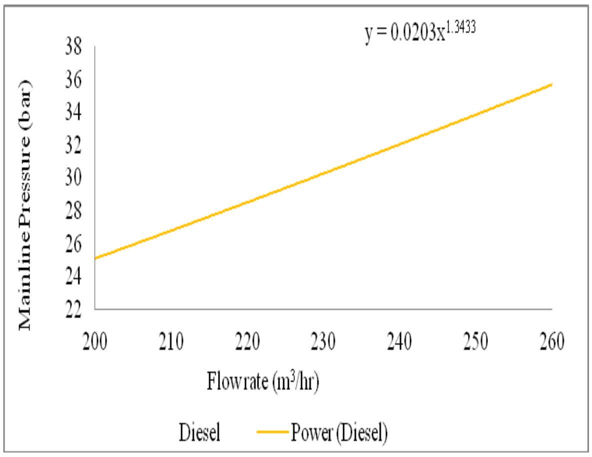

Fig 9: Power function

With Allen engine, the optimum mainline pressure at 240m^3/hr was 31.977 bar.

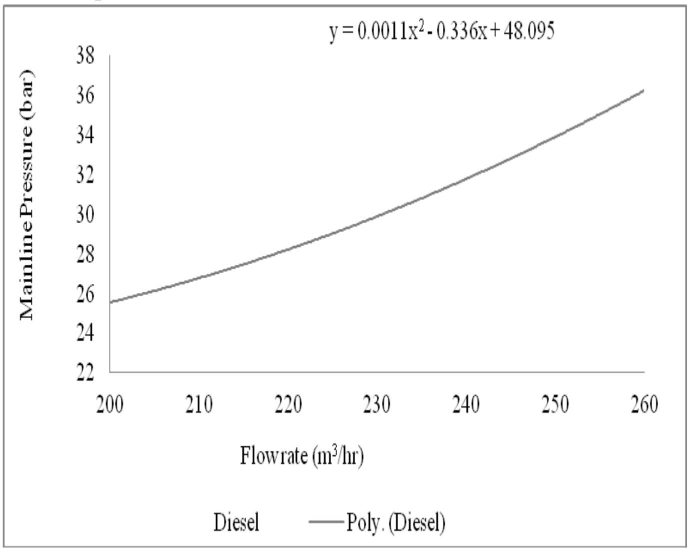

Fig 10: Polynomial function

With the Allen engine, the optimum mainline pressure at 240m^3/hr was 30.85 bar.

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COMPARISON OF 2E AND 2EX DIESEL PUMP FIELD DATA

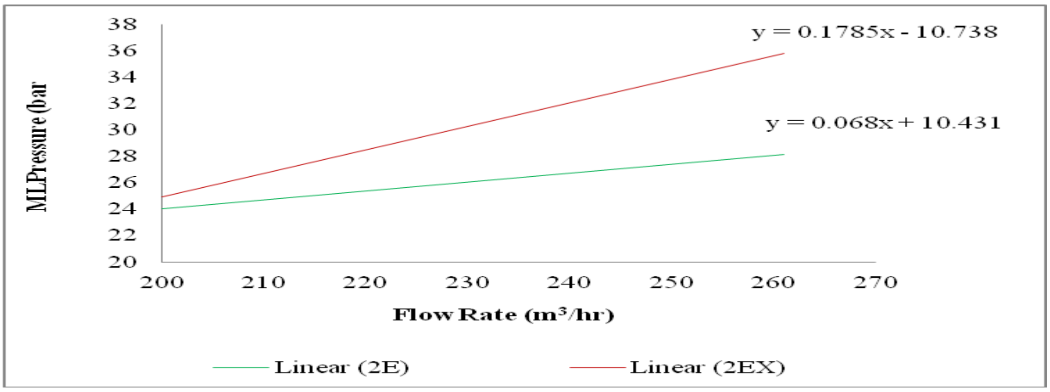

Fig 11: 2E and 2EX field data compared.

Table 1: AGO PUMPING USING 2E MAINLINE PUMP

P_{ML} (bar)	A = P_{ML} (kg/ms^2)	B = Qm (kg/s)	C = V (m/s)	D = Enhancement factor	E = d^2 (m^2)	F = (BxC) ÷ (DxE)	G = Fx56,000m in respect of the segment	P (EXIT) = A-G (kg/ms^2)	P(EXIT) (bar)
24	2,400,000	47.78	0.781	21.592721	0.0919454	18.795756	1,052,184	1,347,816	13.5
24.2	2,420,000	48.73	0.796	21.592721	0.0919454	19.53764	1,094,440	1,325,560	13.3
24.3	2,430,000	49.21	0.804	21.592721	0.0919454	19.928382	1,116,107	1,313,893	13.1
24.7	2,470,000	49.69	0.812	21.592721	0.0919454	20.322992	1,137,987	1,332,013	13.3
25	2,500,000	50.17	0.820	21.592721	0.0919454	20.721471	1,160,079	1,339,921	13.4
25.2	2,520,000	51.6	0.843	21.592721	0.0919454	21.909875	1,227,153	1,292,847	12.9
25.3	2,530,000	52.56	0.859	21.592721	0.0919454	22.741083	1,273,239	1,256,761	12.6
25.7	2,570,000	53.51	0.874	21.592721	0.0919454	23.556405	1,319,681	1,250,319	12.5
26	2,600,000	54.47	0.890	21.592721	0.0919454	24.417995	1,367,458	1,232,542	12.3
26.2	2,620,000	56.38	0.921	21.592721	0.0919454	26.154554	1,465,040	1,154,960	11.5
26.4	2,640,000	56.86	0.929	21.592721	0.0919454	26.606343	1,490,091	1,149,909	11.5
26.8	2,680,000	57.33	0.937	21.592721	0.0919454	27.057281	1,514,827	1,165,173	11.7
27.1	2,710,000	57.81	0.945	21.592721	0.0919454	27.516766	1,540,299	1,169,701	11.7
27.2	2,720,000	58.29	0.952	21.592721	0.0919454	27.95076	1,565,984	1,154,016	11.5
27.4	2,740,000	58.77	0.960	21.592721	0.0919454	28.41774	1,591,881	1,148,119	11.5

Note that the density of AGO used is 860 kg/m^3

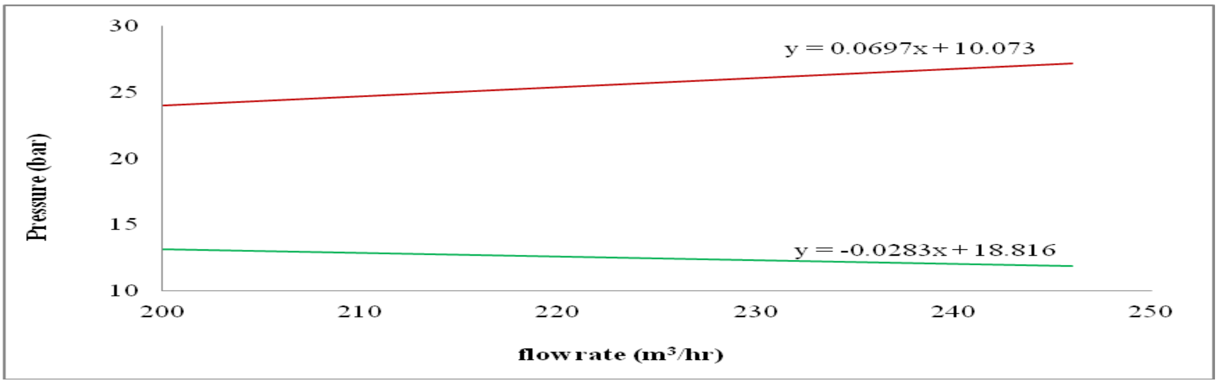

Fig 12: Comparison of 2E mainline and and stabilized reception pressure.

Table 2: AGO PUMPING USING 2EX ALLEN PUMP

P_{ML} (bar)	A = P_{ML} (kg/ms^2)	B = Qm (kg/s)	C = V (m/s)	D = Enhancement factor	E = d^2 (m^2)	F = (BxC) ÷ (DxE)	G = Fx56,000m in respect of the segment	P (EXIT) = A-G (kg/ms^2)	P(EXIT) (bar)
26	2,600,000	48.733	0.785	21.592721	0.0919454	19.268834	1,078,712	1,521,288	15.2
26.4	2,640,000	49.211	0.792	21.592721	0.0919454	19.631342	1,099,977	1,540,023	15.4
27	2,700,000	49.689	0.800	21.592721	0.0919454	20.022249	1,121,449	1,578,551	15.8
27.2	2,720,000	50.167	0.808	21.592721	0.0919454	20.417009	1,143,129	1,576,871	15.8
27.6	2,760,000	51.6	0.831	21.592721	0.0919454	21.59799	1,209,368	1,550,632	15.5
28	2,800,000	52.556	0.846	21.592721	0.0919454	22.395218	1,254,595	1,545,405	15.5
28.6	2,860,000	53.272	0.858	21.592721	0.0919454	23.022311	1,289,012	1,570,988	15.7
30	3,000,000	54.944	0.885	21.592721	0.0919454	24.492108	1,371,196	1,628,804	16.3
30.6	3,060,000	56.378	0.908	21.592721	0.0919454	25.784466	1,443,705	1,616,295	16.2
31.4	3,140,000	56.856	0.916	21.592721	0.0919454	26.232181	1,468,289	1,671,711	16.7
31.7	3,170,000	57.333	0.923	21.592721	0.0919454	26.654405	1,493,029	1,676,971	16.8
32	3,200,000	57.811	0.931	21.592721	0.0919454	27.10958	1,518,029	1,681,971	16.8
32.8	3,280,000	58.767	0.946	21.592721	0.0919454	28.001886	1,568,650	1,711,350	17.1
33	3,300,000	59.244	0.954	21.592721	0.0919454	28.467896	1,594,218	1,705,782	17.1
34	3,400,000	59.722	0.962	21.592721	0.0919454	28.938235	1,620,047	1,779,953	17.8
35	3,500,000	60.2	0.969	21.592721	0.0919454	29.382104	1,646,084	1,853,916	18.5
35	3,500,000	60.439	0.973	21.592721	0.0919454	29.620524	1,659,180	1,840,820	18.4

Note that the density of AGO used is 860 kg/m^3

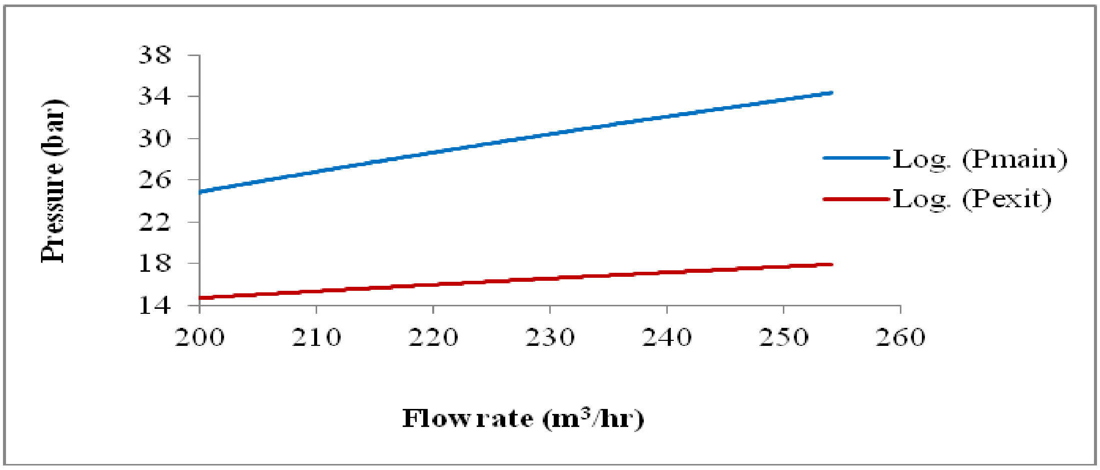

Fig 13: Comparison of 2EX main line and stabilized reception pressure.

Table 3: Summary of calculations using the 2E Main line pump

S/N	PROCEDURE	PRESSURE (bar)	PREVIOUS RESEARCH	DEVIATION	% DEVIATION
1	Linear	26.801	26.8015	0.001	0.004
2	Logarithmic	26.801		0.001	0.004
3	Power	26.8		0.002	0.007
4	Exponential	26.701		0.101	0.378
5	Polynomial	28.048		-1.246	-4.442

Table 4: Summary of calculations using 2EX Allen Engine Pump

S/N	PROCEDURE	MAINLINE PRESSURE (bar)	REMARKS
1	Linear	32.2	All results are within the range of 30.5 to 32.5
2	Logarithmic	32.1	
3	Power	31.98	
4	Polynomial	30.85	
5	Exponential	32.17	

CONCLUSION

Comparison of the respective plots shows that the current individual and average flow rate are still below the designed value, but the previous optimum mainline pressure and flow rate are still valid. The deviation from the optimal flowrate on the 2E main was below 0.01% using linear, logarithmic and power functions. The objective of this work and the relationship between data used for the formula and current field data was a success, However, the values for exponential and polynomials functions are still within operational range.

Using the quality assurance parameters, the uncertain field data for exit pressure was ascertained both for 2E and 2EX. Meanwhile the calculation with the Allen has the optimal flow rate and the mainline pressure as 240 m^3/hr and 32 bar. Using the quality assurance parameters, the uncertain field data for exit pressure was established both for 2E and 2EX. The newly restored Allen engine pump that has been dormant for over 20 years is established to be delivering at optimal flow rate and mainline pressure of 240 m^3/hr and 32 bar respectively. The pump is transporting products optimally and smoothly to the designated Depot

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