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Parameter Assurance Protocol and Efficient Pipeline Design for Accurate Petroleum Product Delivery (CASE STUDY ON SYSTEM 2E/2EX, 0-56 KILOMETER SEGMENTS)

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Abstract— **The objective of this work is to highlight the quality assurance protocol for efficient pipeline delivery discovered while carrying out review study on a pipeline segments. The referenced pipeline systems transport petroleum products from Port Harcourt to Aba for distribution within the South East region of Nigeria and the environs. The main work was on efficient petroleum product delivery through a 56 kilometer length of pipeline. The was to distinguish when pressure drop is due to external impact on the pipeline, low tank level from the supplying point or up-set in any of the associated pumping equipment. This work examined the relationship existing among the pipe inlet/mainline pressure (at pump station), pressure drop (along the pipeline) and the exit or landing pressure at the receiving Depot. The key parameters considered are flow rates, densities of the products, velocity, pressure drop, losses due to elevation change and fittings. Since the products have different specifications, they are introduced into the pipeline in batches, and sometimes in running change-over. Review analysis was carried out using semi-quantitative and semi-empirical techniques, applicable design considerations and assumptions. The outcome was the formula considered as quality assurance protocol for pipeline stability and efficient delivery. The formula expresses the mainline pressure as the product of mass flow rate and velocity divided by the product of the prediction factor and square of the internal diameter for the reference pipe length. The formula was tested with field data and the result showed deviation of less than 0.01% for each product delivery. It also revealed that at optimum flow rate of 240m3/hr, the parameters for the three products are so close and can be used interchangeably for any of the products in a running change-over (continuous) pumping operation.**

Index Terms— **Pumping, products, velocity, pressure, delivery, flow rate.**

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I. INTRODUCTION

The System 2E 56 kilometer pipeline segment is strategic in petroleum product distribution in Nigeria. The pipeline supplies refined petroleum products from the South-South to South-East Region of the country. The pipeline which was installed over 30 years ago transported petroleum products efficiently until challenges associated with multiple vandalism and security concerns led to suspension of pumping of petroleum products through the segment. Some years after the dormancy, the pipeline was rehabilitated and pumping resumed with adequate security safety, environmental and health issues in place. There was successful delivery of products from one segment to the other. The driving force was that the pipeline should remain operational and reduce scarcity of refined petroleum products to all the cities within the receiving region and the environs. The dream was accomplished with all engineering and technical fundamentals in place. Since it is obvious that the same re-commissioning Team may not be there all the years, there was a desire to carry out critical review of the existing design to ensure that whoever is on ground to re-stream and pump through the pipeline should have the basic operational parameter expected for safe pumping. The objective of the work is to develop an equation as rule of thumb for estimating and confirming the pipeline pressure drop during pumping of liquid petroleum products through a 56 kilometer length of pipeline. The equation will aid the Operatives in estimating some critical operation parameters to ensure safe pumping operation parameters.

1.1 Considerations and Assumptions

The basic information used for the research was extracted from the referenced pipeline's field data, reviewed literature and the purchased pipe flow wizard and pipe flow expert software. Table 1 shows designed parameters for the referenced pipeline segment.

Table 1: Designed parameters for the reference pipeline

S/N	Designed Parameters	Dimension
1	Line fill	4100 m^3
2	Minimum designed flow rate	270 m^3/hr
3	Maximum designed flow rate	290 m^3/hr
4	Pipe diameter (D)	0.3048 m (12")
5	Main line pressure: Minimum	25 kg/cm^2
6	Main line pressure: Maximum	35 kg/cm^2

Source: (NNPC, 1980)

The pipeline segment is of steel type. The characteristics for the pipe steel type are found in American National Standards Institute (ANSI) Sch. 40 (Std) Steel. Some of the parameters are shown on Table 2 below.

Table 2: The pipe parameters

S/N	**Parameters**	**Specifications**
1	Nominal Pipe Size (NPS)	300 mm
2	Outside diameter (mm)	323.85 mm
3	Wall thickness (mm)	10.312 mm
4	Internal diameter (mm)	303.225 mm
5	Internal Surface area (m^2/100 m)	101.7405 m^2/100 m
6	Internal volume (m^3/100 m)	7.2214 m^3/100m
7	Weight of pipe (kgs/m)	79.740 kgs/m
8	Roughness	0.046

Source: (MattMilbury and Ratzlaff, 2015).

Other pipeline design considerations and assumptions are:

- The petroleum products are transmitted through long distance pipeline.
- The liquid density and viscosity may not be constant along the entire length of the pipeline
- The designed and actual flow rate achieved from 2012 to 2014 is presented on Table 3.

Table 3: As built and field collated actual flow rates

product	**flow rates (m^3/hr)**		
	designed maximum	**designed minimum**	**observed range 2012-2014**
PMS	290	270	170- 240
DPK	290	270	170-240
AGO	290	270	160-240

A. Design temperature 20 °C (68 °F).

B. Liquids being considered are: Premium Motor Spirit (PMS), which is referred to as Gasoline during calculations; Dual Purpose Kerosene (DPK), referred to as Kerosene and Automotive Gas Oil (AGO), also referred to as Diesel. Water which is used for line flushing and product displacement during emergency maintenance or line repair. The emulsion formed due to water presence is received into slop tanks

C. The specific gravities of the Gasoline, Kerosene and Diesel at design temperature of 20°C (68°F) is 0.719, 0.804, and 0.860 respectively.

D. The kinematic viscosity of Gasoline, Kerosene and Diesel at 20.°C (68°F) is taken as 0.406 mm^2/s (cSt-centistokes), 2.4cSt and 5.0cSt respectively.

E. The designed and actual pressure achieve from mainline pump to receiving area is presented on Table 4.

Table 4: As built and Operational determined (actual) Pumping Pressure

Product	Operating Pressure (Bar)			
	Designed Mainline Maximum	Designed Mainline Minimum	Actual Mainline 2012 To 2014	Receiving Area, Actual 2012 To 2014
PMS	35	25	24 - 28	12- 16
DPK	35	25	24 - 28	12-14
AGO	35	25	24 -28	≈ 12

Since refined petroleum products are non-compressible, the Newtonian liquids principles of fluid flow and non-compressible Newtonian liquid laws were considered (Vincent-Genod 1984).

II. METHODOLOGY

This part of the study is very crucial to the entire research work. The challenges of ensuring that the Mainline and reception area gauge pressure readings are within safe operating condition were resolved through the calculations and comparison of previous outflows from the main work. Data for this study was generated from field records and were analyzed using tables, appropriate engineering equations and formulae, graphs. The preliminary calculations were made using equations and formulae extracted from past works on pipeline engineering, fluid hydraulics pumping and transport phenomena (McAllister, 2009; Incropera & Dewitt, 2005; Sinnott & Towler, 2011; Bratland, 2009; Bratland, 2013; Nevers, 2005; Chanson, 2014; Cheng and Mewes, 2009, Rennels and Hudson, 2012, Bansal, 2012 and Ujile, 2014). The results from the preliminary calculations with empirical formulae are attached as Appendices A1 to A-3 and B1 to B3. These results were reconfirmed using the universal pipe-flow wizard and pipe-flow expert software. The inputs to the pipe flow software are pipe type/material, flow rate, internal diameter, specifications of Gasoline, Kerosene and Diesel, elevation change and of course the fittings. With the known parameters collated from the actual operating data, critical operation information like, Reynolds number, pipe roughness, friction factor, pressure and velocity were calculated. Using the 2016 pipe flow expert software further parameters like the mass and volumetric flow rate per second, velocity, mainline pressure, exit pressure, friction loss and loss due to fittings were calculated.

III. RESULTS AND DISCUSSION

The results were generated sequentially, as verification of one finding leads to other verifiable outcome. Some of the results are as presented below.

Performance of the 56 kilometer pipeline segment

3.1.1 The results are tabulated on Tables 5, 6 and 7.

Table 5: **Simulation with Gasoline: "Flow wizard" and "Flow expert" results compared.**

SET FLOW RATE (m^3/hr)	**PRESSURE DROP (bar)**	
	WIZARD	**EXPERT**
207	6.728	6.7671
210	6.9	6.9328
214	7.13	7.1641
218	7.37	7.4211
221	7.551	7.595
225	7.795	7.8377

229	8.044	8.0844
233	8.296	8.3352
236	8.489	8.5434
238	8.618	8.6602
240	8.749	8.8015
242	8.88	8.9201
244	9.013	9.0636
246	9.146	9.1841
248	9.281	9.3298
250	9.416	9.4521
253	9.622	9.6744
257	9.899	9.9497
260	10.11	10.1524

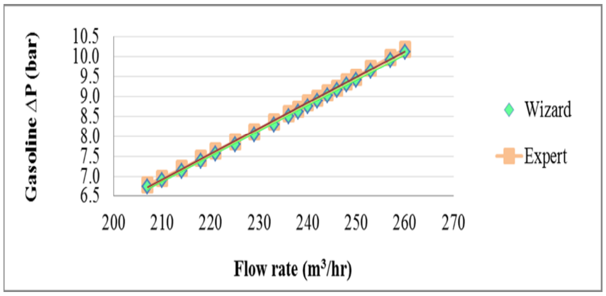

Figure 1: Gasoline: "Flow wizard" and "Flow expert" results compared

Table 6: Simulation with Kerosene: "Flow wizard" and "Flow expert" results compared.

SET FLOW RATE (m^3/hr)	PRESSURE DROP (bar)	
	WIZARD RESULT	EXPERT RESULT
207	9.362	9.4668
210	9.594	9.6922
214	9.907	10.0064
218	10.226	10.3549
221	10.469	10.5905
225	10.769	10.9187
229	11.129	11.2519
233	11.469	11.59
236	11.723	11.8703
238	11.896	12.0274
240	12.06	12.2174
242	12.244	12.3767
244	12.421	12.5693
246	12.591	12.7309
248	12.717	12.9262
250	12.957	13.09
253	13.229	13.3875
257	13.597	13.7555
260	13.875	14.0262

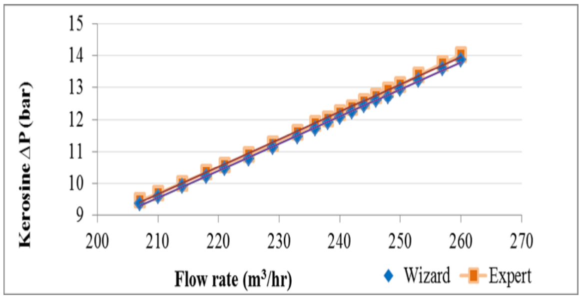

Figure 2: Kerosene: "Flow wizard" and "Flow expert" results compared.

Table 7: Simulation with Diesel: "Flow wizard" and "Flow expert" results compared.

SET FLOW RATE (m^3/hr)	PRESSURE DROP (bar)	
	WIZARD RESULT	EXPERT RESULT
207	11.433	11.5521
210	11.714	11.8252
214	12.094	12.2058
218	12.48	12.6276
221	12.773	12.9126
225	13.169	13.3095
229	13.571	13.7122
233	13.978	14.1206
236	14.288	14.459
238	14.496	14.6486
240	14.706	14.8778
242	14.916	15.07
244	15.128	15.3023
246	15.342	15.4971
248	15.557	15.7325
250	15.774	15.9299
253	16.102	16.2882
257	16.544	16.7313
260	16.879	17.0571

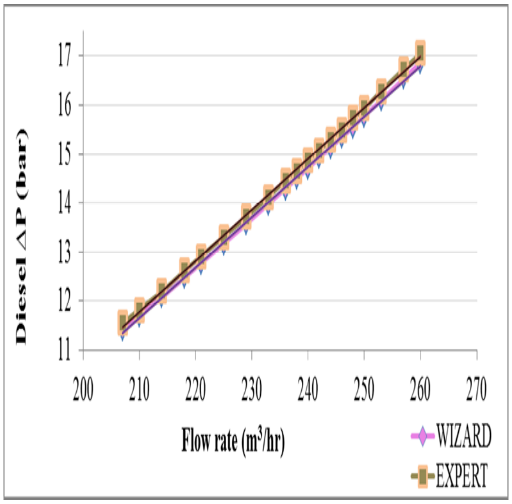

Figure 3: Diesel: "Flow wizard" and "Flow expert" results compared.

3.1.4 Discussion:

The plot of the Table 5 is shown as figure 1 The regression analysis carried shows coefficient of determination which also seen as the degree of accuracy of the data. From the graph, the expert result shows that y = 0.0639x - 6.5186, and the coefficient of determination $R^2 = 0.9992$.

Also the wizard result shows y = 0.0637x - 6.523: $R^2 = 0.9991$.

For Gasoline, the variance between expert calculation and wizard is 0.01%.

The plot of the Table 6 is shown as figure 2. The regression analysis carried shows coefficient of determination which also seen as the degree of accuracy of the data. From the graph, the expert result shows that y = 0.0861x - 8.4497, and the coefficient of determination R² = 0.9993.

Also the wizard result shows y = 0.0849x - 8.2886: R^2 = 0.9991.

For Kerosene, the variance between expert calculation and wizard is 0.02%.

The plot of the Table 7 is shown as figure 3. The regression analysis carried shows coefficient of determination which also seen as the degree of accuracy of the data. From the graph, the expert result shows that y = 0.1039x- 10.046, and the coefficient of determination R² = 0.9994.

Also the wizard result shows y = 0.1039x – 10.046: R^2 = 0.9991.

For Diesel, the variance between expert calculation and wizard is 0.01%.

The negligible percentage variance confirms the consistency of the respective software results.

3.2 Comparison of Gasoline, kerosene and Diesel calculated mainline pressure

The results of the initial confirmatory calculation using pipe flow wizard software gave a close range indication of what the ideal figures should be. Using a more elaborate and intricate pipe flow expert package to simulate the flow on the pipe, more observations were made. Further examination and analysis of the results led to the development of the Flow enhancement and pumping efficiency model that will serve as quick rule of thumb in ensuring that optimum pumping Operations is carried on the Port Harcourt - Aba system 2E kilometer pipeline. The inlet pressure from the simulation results were extracted presented on Table 8.

Table 8 Mainline pressure for the products using 56km Pipeline

Table 8: Mainline pressure for the products using 56km Pipeline

SET FLOW RATE (m^3/hr)	Mainline Pressure for Gasoline (bar)	Mainline Pressure for Kerosene (bar)	Mainline Pressure for Diesel (bar)
207	24.7671	24.0509	23.4758
210	24.9328	24.2763	23.7489
214	25.1641	24.5905	24.1295
218	25.4211	24.939	24.5513
221	25.595	25.1746	24.8363
225	25.8377	25.5028	25.2332
229	26.0844	25.836	25.6359
233	26.3352	26.1741	26.0443
236	26.5434	26.4544	26.3827
238	26.6602	26.6115	26.5723
240	26.8015	26.8015	26.8015
242	26.9201	26.9608	26.9937
244	27.0636	27.1534	27.226
246	27.1841	27.315	27.4208
248	27.3298	27.5103	27.6562
250	27.4521	27.6741	27.8536
253	27.6744	27.9716	28.2119
257	27.9497	28.3396	28.655
260	28.1524	28.6103	28.9808

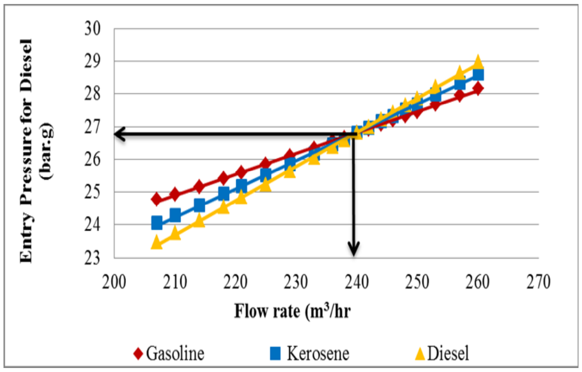

Figure 4: Determination of optimum flow rate and the pressure drop along the pipeline

From figure 4 the optimum pumping flow rate and inlet pressure for Gasoline, kerosene and Diesel 240 m^3/hr and 26.8015bar.

3.3 Determination of rule of thumb (model) for quick assessment of pumping parameters

To determine the rule of thumb, the mainline pressure is seen as a function of other parameters like pipe length, diameter, material, velocity, mass flow rate, losses due to fittings.

$P_{main} = f(D, v, Qm, P_{exit},)$ (1)

From literature and actual calculations, loss due to fittings is negligible (Menon, 2015).

Therefore $P_{main} = f(D, v, Qm, P_{exit},)$. (2)

After the necessary checks for dimensional consistency, the estimated mainline pressure is then expressed as being proportional to the product of mass flow rate, velocity and length of pipe divided by the product of the enhancement factor and the square of the diameter.

Where

$$P_{en} = \text{Pressure drop} = \frac{Qmv}{GD^2}\ (kg/m.\ s^2)$$

For a reference pipeline

1 kg/m.sec^2 is equivalent to 10^{-5} bar = 1Pa = 1N/m^2

Qm = the mass flow rate (kg/sec) of the product.
v = the velocity (m/sec).
G=the efficiency enhanced factor (dimensionless)
D = internal diameter (m).
P_{main} = Inlet pressure to be read from the pressure gauge at the pump house and control room (bar).
P_{exit} = Exit pressure to be read from the pressure gauge at the Product receiving area (bar).

The factor was calculated using iteration, interpolation and extrapolation processes to arrive at an optimal value. The flow enhancement model developed for Gasoline, kerosene and diesel Pumping are as presented as formula 1, 2 and 3 respectively.

The Gasoline Pumping Model,

$$P_{main} = \frac{Qmv}{GD^2} + P_{exit} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3)$$

∴ Gasoline inlet pressure is calculated with

$$P_{main} = \frac{Qmv}{32.097582D^2} + P_{exit}$$

The G factor is 8.10689 using the expert software to the power 1.656551.

The Kerosene pumping Model is therefore $P_{main} = \frac{Qmv}{24.586735D^2} + P_{exit}\ldots\ldots(4)$

For kerosene, G factor is the average of pressure drop (11.83415 bar) calculated using the expert software to the power 1.295921.

The Diesel Pumping Model is therefore $P_{main} = \frac{Qmv}{21.592921D^2} + P_{exit}\ldots\ldots\ldots(5)$

For Diesel, average pressure drop (14.41365bar) calculated using the expert software to the power 1.51482.

The formulae can also be rearranged to calculate other operating parameters like volumetric flow rate, density of the products, the pressure drop, internal diameter, frictional head loss and even the confirmation pipe length. The formula is applicable to pumping of petroleum product in a fully developed flow.

Tables 9, 10 and 11 show some of the calculations that can be done with the developed efficiency enhancement model which will serve as rule of thumb for the operatives and further academic research studies.

Table 9: Calculations based on Gasoline pumping model formula

Mass Flow, Q_m(kg/s)	**Velocity v(m/s)**	**Referenced pipe Length L(m**	**Internal Diameter ID^2 (m)**	**calculated Efficiency Enhanced factor, G**	**Calculated Enhanced Pressure P_{en} = a**		**Calculated Exit gauge pressure**	**Estimated Mainline gauge pressure**
					(kg/ms^2)	**bar**	**$P_{exit\,(bar)} = b$**	**a+ b=P_{main} (bar)**
41.3425	0.796	56000	0.0919454	32.097582	624,447	6.2445	18.3931	24.6376
41.9177	0.807	56000	0.0919454	32.097582	641,884	6.4188	18.3931	24.8119
42.7086	0.823	56000	0.0919454	32.097582	666,962	6.6696	18.3931	25.0627
43.5714	0.839	56000	0.0919454	32.097582	693,664	6.9366	18.3931	25.3297
44.1466	0.85	56000	0.0919454	32.097582	712,036	7.1204	18.3931	25.5135
44.9375	0.865	56000	0.0919454	32.097582	737,583	7.3758	18.3931	25.7689
45.7284	0.881	56000	0.0919454	32.097582	764,447	7.6445	18.3931	26.0376
46.5193	0.896	56000	0.0919454	32.097582	790,910	7.9091	18.3931	26.3022
47.1664	0.908	56000	0.0919454	32.097582	812,651	8.1265	18.3931	26.5196
47.5259	0.915	56000	0.0919454	32.097582	825,158	8.2516	18.3931	26.6447
47.9573	0.924	56000	0.0919454	32.097582	840,838	8.4084	18.3931	26.8015
48.3168	0.931	56000	0.0919454	32.097582	853,559	8.5356	18.3931	26.9287
48.7482	0.939	56000	0.0919454	32.097582	868,580	8.6858	18.3931	27.0789
49.1077	0.946	56000	0.0919454	32.097582	881,508	8.8151	18.3931	27.2082
49.5391	0.954	56000	0.0919454	32.097582	896,772	8.9677	18.3931	27.3608
49.8986	0.961	56000	0.0919454	32.097582	909,908	9.0991	18.3931	27.4922
50.5457	0.973	56000	0.0919454	32.097582	933,217	9.3322	18.3931	27.7253
51.3366	0.989	56000	0.0919454	32.097582	963,405	9.6341	18.3931	28.0272
51.9118	1	56000	0.0919454	32.097582	985,035	9.8504	18.3931	28.2435

Table 10: Calculations based on kerosene pumping model equation

Mass Flow, Q_m(kg/s)	**Velocity, v(m/s)**	**Referenced pipe Length, L(m)**	**Internal Diameter, ID^2 (m^2)**	**calculated Efficiency Enhanced factor, G**	**Calculated Enhanced Pressure P_{en} =a**		**Calculated Exit gauge pressure**	**Estimated Mainline gauge pressure**
					(kg/ms^2)	**bar**	**$P_{exit\,(bar)} = b$**	**a+ b=P_{main}**

								(bar)
46.23	0.796	56000	0.0919454	24.586735	911,579	9.1158	14.5268	23.6426
46.8732	0.807	56000	0.0919454	24.586735	937,034	9.3703	14.5268	23.8971
47.7576	0.823	56000	0.0919454	24.586735	973,642	9.7364	14.5268	24.2632
48.7224	0.839	56000	0.0919454	24.586735	1,012,623	10.1262	14.5268	24.6530
49.3656	0.85	56000	0.0919454	24.586735	1,039,443	10.3944	14.5268	24.9212
50.25	0.865	56000	0.0919454	24.586735	1,076,736	10.7674	14.5268	25.2942
51.1344	0.881	56000	0.0919454	24.586735	1,115,954	11.1595	14.5268	25.6863
52.0188	0.896	56000	0.0919454	24.586735	1,154,584	11.5458	14.5268	26.0726
52.7424	0.908	56000	0.0919454	24.586735	1,186,323	11.8632	14.5268	26.3900
53.1444	0.915	56000	0.0919454	24.586735	1,204,580	12.0458	14.5268	26.5726
53.6268	0.924	56000	0.0919454	24.586735	1,227,470	12.2747	14.5268	26.8015
54.0288	0.931	56000	0.0919454	24.586735	1,246,040	12.4604	14.5268	26.9872
54.5112	0.939	56000	0.0919454	24.586735	1,267,969	12.6797	14.5268	27.2065
54.9132	0.946	56000	0.0919454	24.586735	1,286,841	12.8684	14.5268	27.3952
55.3956	0.954	56000	0.0919454	24.586735	1,309,124	13.0912	14.5268	27.6180
55.7976	0.961	56000	0.0919454	24.586735	1,328,300	13.2830	14.5268	27.8098
56.5212	0.973	56000	0.0919454	24.586735	1,362,327	13.6233	14.5268	28.1501
57.4056	0.989	56000	0.0919454	24.586735	1,406,396	14.0640	14.5268	28.5908
58.0488	1	56000	0.0919454	24.586735	1,437,972	14.3797	14.5268	28.9065

Table 11: Calculations based on Diesel pumping model formula

Mass Flow, Q_m(kg/s)	**Velocity, v(m/s)**	**Length, L(m)**	**Internal Diameter, ID^2 (m^2)**	**calculated Efficiency Enhanced factor, G**	**Calculated Enhanced Pressure $P_{en} = a$**		**Calculated Exit gauge pressure**	**Estimated Mainline gauge pressure**
					(kg/ms^2)	**bar**	**$P_{exit\ (bar)} = b$**	**a+ b=P_{main} (bar)**
49.45	0.796	56000	0.0919454	21.592721	1,110,274	11.1027	11.8513	22.9540
50.138	0.807	56000	0.0919454	21.592721	1,141,277	11.4128	11.8513	23.2641
51.084	0.823	56000	0.0919454	21.592721	1,185,865	11.8587	11.8513	23.7100
52.116	0.839	56000	0.0919454	21.592721	1,233,342	12.3334	11.8513	24.1847
52.804	0.85	56000	0.0919454	21.592721	1,266,008	12.6601	11.8513	24.5114
53.75	0.865	56000	0.0919454	21.592721	1,311,430	13.1143	11.8513	24.9656
54.696	0.881	56000	0.0919454	21.592721	1,359,196	13.5920	11.8513	25.4433
55.642	0.896	56000	0.0919454	21.592721	1,406,246	14.0625	11.8513	25.9138
56.416	0.908	56000	0.0919454	21.592721	1,444,903	14.4490	11.8513	26.3003
56.846	0.915	56000	0.0919454	21.592721	1,467,140	14.6714	11.8513	26.5227
57.362	0.924	56000	0.0919454	21.592721	1,495,020	14.9502	11.8513	26.8015
57.792	0.931	56000	0.0919454	21.592721	1,517,638	15.1764	11.8513	27.0277
58.308	0.939	56000	0.0919454	21.592721	1,544,345	15.4435	11.8513	27.2948
58.738	0.946	56000	0.0919454	21.592721	1,567,332	15.6733	11.8513	27.5246
59.254	0.954	56000	0.0919454	21.592721	1,594,471	15.9447	11.8513	27.7960
59.684	0.961	56000	0.0919454	21.592721	1,617,827	16.1783	11.8513	28.0296
60.458	0.973	56000	0.0919454	21.592721	1,659,271	16.5927	11.8513	28.4440
61.404	0.989	56000	0.0919454	21.592721	1,712,946	17.1295	11.8513	28.9808
62.092	1	56000	0.0919454	21.592721	1,751,404	17.5140	11.8513	29.3653

3.4 Findings

The referenced petroleum product pipeline is over 30 years old and the research findings are:

- i. The actual mainline pressure achieved since 2011 is 28bar. The figure is 20% below the maximum designed figure and 12% above the minimum.
- ii. The referenced pipeline was dormant for seven years before its rehabilitation in 2011. The maximum flow rate achieved since 2011 is 15% below the minimum designed value. However, this pipeline has been safely operated at the current mainline pressure and flow rate.to deliver product to the reception point node.
- iii. The expression for the rule of thumb is $P_{main} = \frac{Qmv}{GD^2} + P_{exit}$.
- iv. G is the efficiency enhancement factor.
- v. The efficiency enhancement factor during Gasoline pumping is 32.097582.
- vi. The efficiency enhancement factor during Kerosene pumping is 24.586735.
- vii. The efficiency enhancement factor during Diesel pumping is 21.592921.
- viii. Using 'G' as 32.097582, the mainline pressure range calculated during Gasoline pumping is 24.6376bar to 28.2435bar.
- ix. Using 'G' as 24.586735, the mainline pressure range calculated during Kerosene pumping is 23.6426bar to 28.9065bar.
- x. Using 'G' as 21.592921, the mainline pressure range calculated during Diesel pumping is 22.954bar to 29.3653bar.
- xi. Using the developed model or rule of thumb, the optimum flow rate and mainline pressure when pumping Gasoline, Kerosene or Diesel through the 56km pipeline is about 240m^3/hr and 26.8015bar.

CONCLUSION

From the research results and findings, it is concluded that the developed equation or rule of thumb is a quick tool to guide the Operatives in estimating some critical operational parameters and also ensure safe pumping operation. The equation can be rearranged to calculate other operating parameters. The optimum operating pressure and flow rate at which Gasoline, Kerosene and Diesel can be pumped on the referenced 56 kilometer, 12 inch over 30 years pipeline is 26.8015bar and 240m^3/hr.

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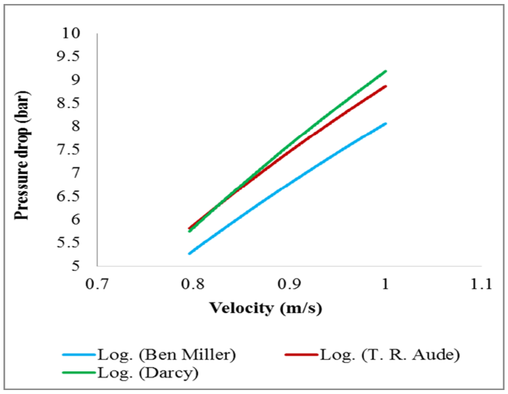
Appendix A-1: Comparison of pressure drop calculated assuming Gasoline was being pumped

Flow rate (m^3/hr)	**Pressure Drop (Calculated for Gasoline Pumping)**		
	Benjamin Miller	**T. R. Aude**	**Darcy**
207	5.37	5.92	5.89
210	5.52	6.08	6.06
211	5.56	6.13	6.12
214	5.71	6.29	6.29
215	5.76	6.34	6.35
218	5.9	6.51	6.53
219	5.97	6.56	6.59
221	6.07	6.67	6.71
223	6.16	6.78	6.83
225	6.26	6.89	6.96
227	6.36	7	7.08
229	6.45	7.11	7.21
231	6.55	7.23	7.33
233	6.64	7.34	7.46
235	6.74	7.45	7.59
236	6.83	7.51	7.65
238	6.91	7.63	7.78
240	7.05	7.74	7.92
242	7.15	7.86	8.05
244	7.27	7.98	8.18
245	7.31	8.04	8.25
247	7.39	8.16	8.38
249	7.53	8.28	8.52
251	7.63	8.4	8.66
252	7.7	8.46	8.73
254	7.82	8.58	8.87
256	7.91	8.7	9.01
258	8.03	8.83	9.15
259	8.08	8.89	9.22
260	8.15	8.95	9.29

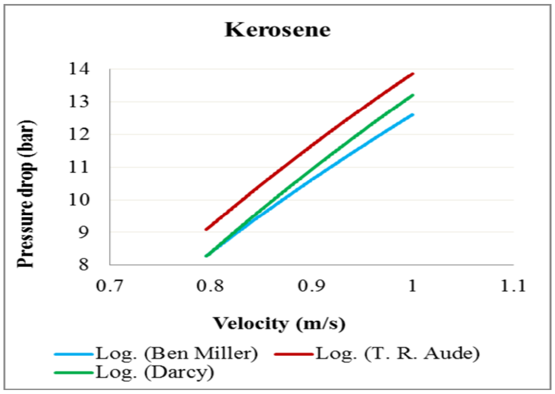
Appendix B-1: Comparison of pressure drop calculated assuming Gasoline was being pumped



Appendix A-2: Comparison of pressure drop calculated assuming Kerosene was being pumped

Flow rate (m^3/hr)	Pressure Drop (Calculated for Kerosene Pumping)		
	Benjamin Miller	T. R. Aude	Darcy
207	8.47	9.26	8.47
210	8.71	9.5	8.71
211	8.75	9.58	8.8
214	8.95	9.83	9.05
215	9.07	9.92	9.13
218	9.22	10.17	9.39
219	9.36	10.25	9.48
221	9.5	10.42	9.65
223	9.65	10.6	9.83
225	9.79	10.77	10
227	9.94	10.94	10.18
229	10.1	11.12	10.36
231	10.26	11.29	10.54
233	10.43	11.47	10.73
235	10.58	11.65	10.91
236	10.66	11.74	11
238	10.89	11.92	11.19
240	10.98	12.1	11.38
242	11.15	12.29	11.57
244	11.39	12.47	11.76
245	11.44	12.56	11.86
247	11.63	12.75	12.05
249	11.77	12.94	12.25
251	11.92	13.13	12.45
252	12.06	13.22	12.55
254	12.23	13.41	12.75
256	12.26	13.61	12.95
258	12.59	13.8	13.15
259	12.66	13.9	13.25
260	12.76	13.99	13.36

Appendix B-2: Comparison of pressure drop calculated assuming Kerosene was being pumped



Appendix A-3: Comparison of pressure drop calculated assuming Diesel was being pumped

Flow rate (m^3/hr)	Pressure Drop (Calculated for Diesel Pumping)		
	Benjamin Miller	T. R. Aude	Darcy
207	10.62	11.37	10.56
210	10.91	11.67	10.87
211	10.96	11.77	10.98
214	11.27	12.08	11.29
215	11.37	12.18	11.4
218	11.63	12.49	11.72
219	11.75	12.59	11.83
221	11.92	12.8	12.04
223	12.13	13.01	12.26
225	12.33	13.23	12.48
227	12.47	13.44	12.7
229	12.65	13.66	12.93
231	12.83	13.87	13.16
233	13.12	14.09	13.39
235	13.26	14.31	13.62
236	13.38	14.42	13.73
238	13.57	14.64	13.97
240	13.79	14.87	14.2
242	13.98	15.09	14.44
244	14.15	15.32	14.68
245	14.34	15.43	14.8
247	14.56	15.66	15.04
249	14.75	15.89	15.29
251	14.96	16.12	15.53
252	15.08	16.24	15.66
254	15.3	16.48	15.91
256	15.47	16.71	16.16
258	15.73	16.95	16.41
259	15.83	17.07	16.54
260	15.95	17.19	16.67

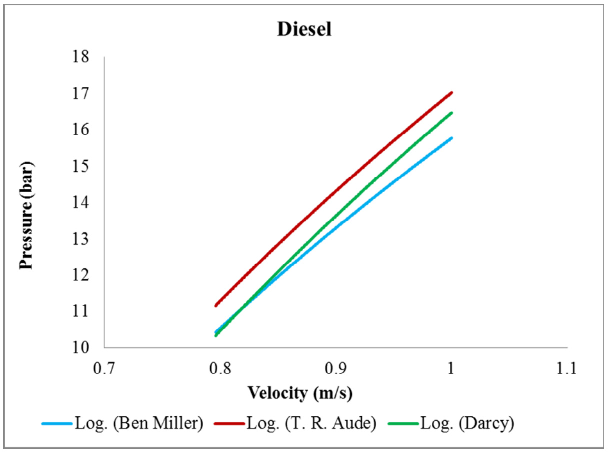


Figure 4.14: Comparison of pressure drop calculated assuming Diesel pumping