Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 4, Issue 1, 2019, Page 61- 66
ISSN: 2616-1192

(www.ujesr.org)

Validation of Calculated Flow Regime Using Experimental Data with Standard Methods of an Existing Software

Wambua, C.M. *1,2,3**, Joel, O.F.** 1,2**, Ikiensikimama, S.S.** 1,2 **and Oyoo, D.O.** 3
[1]Department of Petroleum & Gas Engineering, University of Port Harcourt, Port Harcourt, Nigeria
[2]World Bank Africa Centre of Excellence for Oilfield Chemicals Research, University of Port Harcourt, Nigeria.
[3]Department of Gas and Petroleum Engineering, Kenyatta University, Kenya.
*Corresponding author's email: eng.chriswambua@gmail.com

Abstract
The aim of this research was to determine the flow regime of a standard steel 14-inch multiproduct pipeline. The study analysed the effects of flow rates, product viscosities, pipe diameter, internal roughness and elevation change on Reynolds number. Reynolds number was calculated using standard empirical method and simulated using pipe-flow wizard (PFW) software package to validate the calculated results. Flow rates used were obtained from the daily operations record of two consecutive years and were in the range of 629 – 765 m^3*/hr. Reynolds number for gasoline ranged 1.7* $x\ 10^6 - 2.1\ x\ 10^6$*, kerosene 2.8* $x\ 10^5 - 3.4\ x\ 10^5$ *and diesel 1.3* $x\ 10^5 - 1.6\ x\ 10^5$*. Based on the results, flow regime was turbulent when pumping all three products. Regression as a standard statistical analysis tool, observed no significant difference between calculated and simulated Reynolds number when pumping gasoline, kerosene and diesel, since the coefficient of determination (*R^2*) equals to one. Simulation results validated the calculated flow regime. Calculated results are recommended for use in further review study of the said pipeline in order to improve product delivery efficiency.*

Keywords: *Pipeline, Gasoline, Kerosene, Diesel, Reynolds number, Flow regime*

Received: 7th December, 2019 *Accepted: 30th December, 2019*

1. Introduction

Oil and gas pipeline networks are the safest, most reliable and efficient mode of transport for petroleum products (Boaz *et al.*, 2014; Xiao *et al.*, 2018). According to Rahman and Nawaz (2017), efficient transportation of petroleum products is a great economy boost to any nation. Standard pipeline operation involves pipes, booster pumping stations, storage facilities and dispatch facilities which are monitored from control room of a pump station (Ross, 2015). In pipeline operations, there are established safety and environmental standards regulated by professional and industrial agencies such as, the American Society of Mechanical Engineers (ASME) and government agencies (Ross, 2015). These standards also take into account the safety of personnel, pipeline infrastructure and environment (Stewart, 2015; Madsen and Madsen, 2016). According to Menon (2014), the standards for design of piping systems, booster stations, storage tanks, pigging facilities, measurement and regulation of stations are coded. Pipeline should be designed and constructed to achieve optimum throughput, reliability and ensure safety during operations (Westhoff, 1999). The selected choice of material used for pipeline construction is influenced by the property of the fluid and the operating environment (Larock *et al.*, 2000). Insufficient pipeline delivery is due to use of obsolete equipment, pipeline age and vandalism incidents on the lines (Schaschke, 1998; Levenspiel, 2012; Barkech, 2015). According to Vincent-Genod (1984), periodic review of the problems associated with pipeline improves product delivery efficiency. The reviewed multiproduct pipeline is a 14-inch standard steel pipe and 450 km long. It has been operational for over 40 years and therefore, there is need for constant review and monitoring of the pipeline parameters. This paper focused on flow regime of the pipeline. Kunes (2012a) describes Reynolds number as a dimensionless value relevant in study of fluid behaviour. According to Brown (2003), Reynolds number (Re) determines the fluid flow transition from laminar to turbulent. Referring to Liu (2003), when Reynolds is low, the pipe's flow is said to be laminar, but if it exceeds critical Reynolds value then it is turbulent. Menon (2014) defined the specific flow regimes range as Re < 2000 laminar, Re 2000 – 4000 critical and Re > 4000 as turbulent. From Ujile (2014), mean velocity and maximum velocity varies according to the fluid flow regime, and therefore, it is important to look into flow regime as it relates to other parameters like velocity, friction factor and pressure drop. Pipe flow wizard is a software package applicable in calculating pipe's flow rate, pressure drop, pipe diameter and length (Pipeflow, 2019). It takes into account the elevation changes and all fittings along the pipeline. Pipe flow wizard can be used for results comparison and verification of calculated pipeline parameters (Akujobi-Emetuche *et al*., 2016). Regression analysis is a statistical tool used to investigate the interrelation between variables. It can also be used to develop or improve theoretical models (Golberg and Cho, 2004). This paper aimed at determining the flow regime for the pipeline under review and validating the calculated results.

2. Materials and methods

Actual daily flow rates on gasoline, kerosene and diesel were collated for two consecutive years. After arranging and trimming the data, average monthly flow rates were calculated. The calculated monthly flow rates were used as part of variables in the study. Reynolds number as the specific operating parameter for this study, was calculated using standard empirical method and simulated using pipe-flow wizard (PFW) software package to validate the calculated values. The reviewed pipeline is a 14-inch standard steel pipe with the following specifications shown in Table 1.

Table 1: Pipeline specifications

Parameters	**Specifications**
Nominal Pipe Size (NPS)	350 mm
Internal diameter (mm)	333.35 mm
Wall thickness (mm)	11.125 mm
Outside diameter (mm)	355.600 mm
Pipe weight (kgs/m)	94.513 kgs/m
Internal volume (m^3/100 m)	8.7275 m^3/100 m
Internal Surface area (m^2/100m)	111.7150 m^2/100m
Internal Roughness	0.04572 mm

Source: (Matt-Milbury and Ratzlaff, 2015)

According to Schaschke (1998) and Kunes (2012b), the expressed Equation (1) was used to calculate Reynolds number for gasoline, kerosene and diesel.

$$Re = \frac{DV\rho}{\mu} = \frac{DV}{V} = \frac{4Q}{\pi D\eta} \qquad (1)$$

The actual average flow rates for two consecutive years were used. The following parameter values were used in calculation of Reynolds number.

- Minimum flow rate (Q_{min}) = 629 m^3/hr
- Maximum flow rate (Q_{max}) = 765 m^3/hr
- Internal pipe diameter (D) = 0.33335 m
- Kinematic viscosity of gasoline ($\boldsymbol{\eta}_{gasoline}$) = 0.0014616 m^2/hr
- Kinematic viscosity of kerosene ($\boldsymbol{\eta}_{kerosene}$) = 0.00864 m^2/hr
- Kinematic viscosity of kerosene ($\boldsymbol{\eta}_{Diesel}$) = 0.018 m^2/hr
- π = 3.142

Pipe-flow wizard was used to compare and validate calculated Reynolds number results (Akujobi-Emetuche *et al*., 2016). Inputs for pipe-flow wizard software were pipe diameter, pipe length, internal roughness, pipe fittings, flow rates and elevation change.

3. Results and discussion

3.1 Comparison of calculated flow regime

Comparison of calculated Reynolds number when pumping gasoline, kerosene and diesel is shown in Fig. 1. The minimum and maximum flow rates were 629 and 765 m^3/hr, respectively. In order to determine the flow regime when pumping gasoline, kerosene and diesel, Reynolds number was calculated for the respective products. The following ranges were observed: $1.7 \times 10^6 – 2.1 \times 10^6$ (gasoline), $2.8 \times 10^5 – 3.4 \times 10^5$ (kerosene) and $1.3 \times 10^5 – 1.6 \times 10^5$ (diesel). Gasoline had the highest range of Reynolds number while diesel had the least range. This relates to density difference of the three pumped products i.e. gasoline – 740 kg/m^3, kerosene – 780 kg/m^3, diesel – 840 kg/m^3. According to Menon (2014), the observed flow regime (gasoline, kerosene and diesel) was turbulent since their calculated Reynolds number is above 4000. The difference in flow regime could advise on order of batching when packing the line.

3.2 Comparison of calculated and simulated flow regime

Simulated flow regime results when pumping gasoline, kerosene and diesel are shown in Tables 3, 4 and 5, respectively. It was observed that the simulated Reynolds number ranged as follows: 1.7 x 10^6 – 2.1 x 10^6 (gasoline), 2.8 x 10^5 – 3.4 x 10^5 (kerosene) and 1.3 x 10^5 – 1.6 x 10^5 (diesel). Comparison of calculated and simulated results was done at flow rates range of 629 to 765 m^3/hr in order to validate the calculated results. It was seen that percentage deviation between calculated and simulated Reynolds number when pumping gasoline, kerosene and diesel was 0.013% as shown in Tables 3, 4 and 5. Also, from regression analysis the coefficient of determination (R^2) was 1 and therefore, no significant difference was observed between calculated and simulated Reynolds number when pumping all three products. Calculated Reynolds number results when pumping all three products (gasoline, kerosene and diesel) were validated.

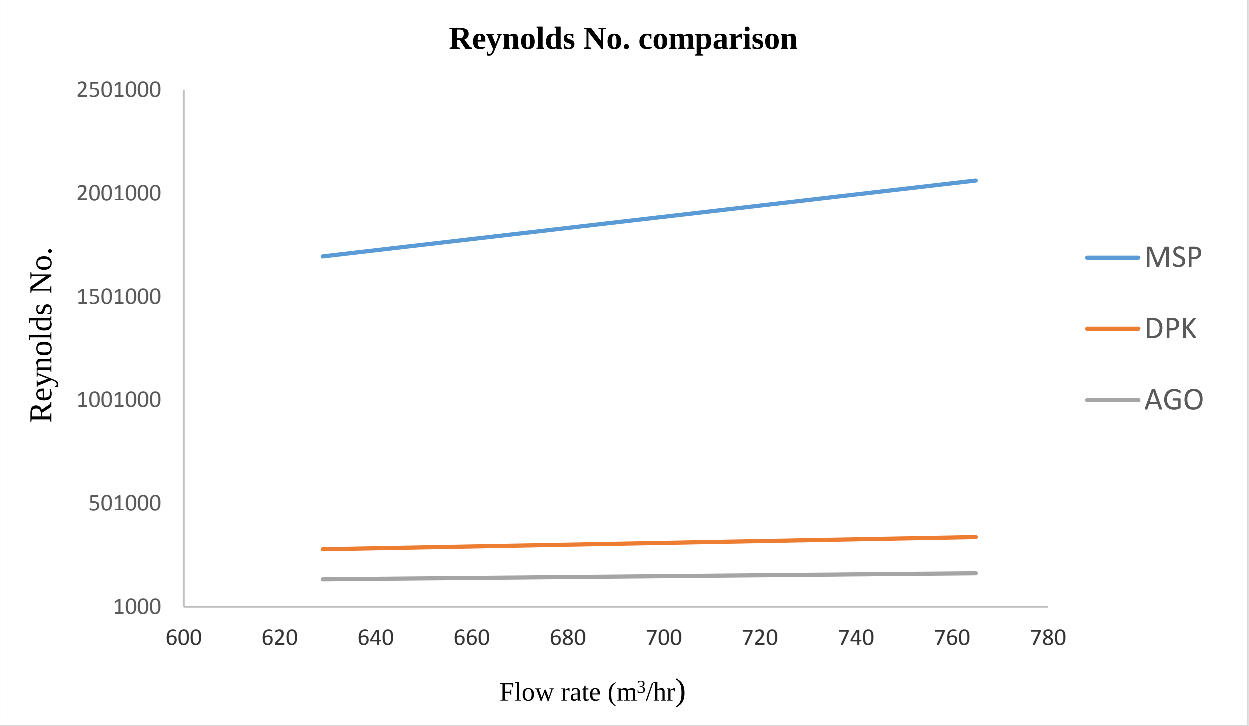

Fig. 1: Comparison of calculated Reynolds number when pumping gasoline (MSP), kerosene (DPK) and diesel (AGO).

Table 3: Comparative analysis of calculated and simulated Reynolds number when pumping gasoline

Flow rate Q (m^3/hr)	Reynolds number, Re (Calculated)	Reynolds number, Re (PF Wizard)	% Deviation
629	1696329	1696554	0.0133
640	1725994	1726223	0.0133
643	1734085	1734315	0.0133
645	1739479	1739709	0.0132
665	1793416	1793654	0.0133
668	1801507	1801745	0.0132
676	1823082	1823323	0.0132
688	1855444	1855690	0.0133
690	1860838	1861084	0.0132
696	1877019	1877268	0.0133
699	1885110	1885359	0.0132
707	1906685	1906937	0.0132

708	1909381	1909634	0.0132
713	1922866	1923120	0.0132
716	1930956	1931212	0.0133
726	1957925	1958184	0.0132
728	1963319	1963579	0.0132
729	1966016	1966276	0.0132
736	1984894	1985157	0.0132
741	1998378	1998643	0.0133
744	2006469	2006734	0.0132
751	2025347	2025615	0.0132
765	2063103	2063376	0.0132

Table 4: Comparative analysis of calculated and simulated Reynolds number when pumping kerosene

Flow rate Q (m^3/hr)	Reynolds number, Re (Calculated)	Reynolds number, Re (PF Wizard)	% Deviation
629	278029	278065	0.0129
640	282891	282928	0.0131
643	284217	284254	0.0130
645	285101	285138	0.0130
665	293942	293980	0.0129
668	295268	295306	0.0129
676	298804	298843	0.0131
688	304108	304148	0.0132
690	304992	305032	0.0131
696	307644	307684	0.0130
699	308970	309010	0.0129
707	312506	312547	0.0131
708	312948	312989	0.0131
713	315159	315199	0.0127
716	316485	316526	0.0130
726	320905	320946	0.0128
728	321789	321831	0.0131
729	322231	322273	0.0130
736	325325	325367	0.0129
741	327535	327578	0.0131
744	328861	328904	0.0131
751	331955	331998	0.0130
765	338144	338187	0.0127

Table 5: Comparative analysis of calculated and simulated Reynolds number when pumping diesel

Flow rate Q (m^3/hr)	Reynolds number, Re (Calculated)	Reynolds number, Re (PF Wizard)	% Deviation
629	133454	133471	0.0127
640	135788	135805	0.0125
643	136424	136442	0.0132
645	136849	136866	0.0124
665	141092	141110	0.0128
668	141729	141747	0.0127
676	143426	143444	0.0125

688	145972	145991	0.0130
690	146396	146415	0.0130
696	147669	147688	0.0129
699	148306	148325	0.0128
707	150003	150023	0.0133
708	150215	150235	0.0133
713	151276	151296	0.0132
716	151913	151932	0.0125
726	154034	154054	0.0130
728	154459	154479	0.0129
729	154671	154691	0.0129
736	156156	156176	0.0128
741	157217	157237	0.0127
744	157853	157874	0.0133
751	159339	159359	0.0126
765	162309	162330	0.0129

4. Conclusions

A multiproduct pipeline of 14-inch diameter and 450km long that has been operational for over 40 years has been studied. The results obtained shows the following:

- Flow regime for the pipeline when pumping gasoline, kerosene and diesel was concluded to be turbulent.
- Calculated Reynolds number results, when pumping gasoline, kerosene and diesel, were validated through software simulations and therefore, the results are relevant for further review of the pipeline for flow enhancement purposes.
- When packing the pipeline with all three products, it would be recommended to have the spirit (gasoline) as the middle batch and pushed by the distillates (kerosene or diesel) to reduce contamination width at the interface.

Acknowledgement

The authors acknowledge the World Bank Africa Centre of Excellence for Oilfield Chemicals Research, University of Port Harcourt, Nigeria for their support in carrying out this research. The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) are acknowledged for financial support during research. Insights by Dr. (Mrs) Grace C. Akujobi-Emetuche as a pipeline expert at the Pipeline Product and Marketing Company (PPMC), Port Harcourt, Nigeria are appreciated.

References

Akujobi-Emetuche, G.C., Joel, O.F., Chukwuma, F.O. and Wami, E.N. (2016) Parameter Assurance Protocol and Efficient Pipeline Design for Accurate Petroleum Product Delivery (Case Study on System 2e/2ex, 0-56 Kilometer Segments). International Journal of Engineering Research and Management, 3(9): 91-99.

Barkech, K. (2015) Studies in Systems, Decisions and Control: Modelling and Analysis of Linear Hyperbolic Systems of Balanced Laws, Springer. Pp 15.

Boaz, L., Kaijage, S. and Sinde, R. (2014) An overview of pipeline leak detection and location systems. In Proceedings of the 2nd Pan African International Conference on Science, Computing and Telecommunications (PACT 2014) (pp. 133-137). IEEE.

Brown, G.O. (2003) The history of the Darcy-Weisbach equation for pipe flow resistance. In Environmental and Water Resources History (pp. 34-43).

Golberg, M.A. and Cho, H.A. (2004) Introduction to regression analysis. WIT Press.

Kunes, J. (2012a) Similarity and modeling in science and engineering. Cambridge International Science Publishing. Springer. Pp 390.

Kunes, J. (2012b) Dimensionless physical quantities in science and engineering. Elsevier.

Larock, B.E., Jeppson, R.W. and Watters, G.Z. (2000) Hydraulics of pipeline systems. CRC Press. Pp 7-18.

Levenspiel, O. (2012) Fluid mechanics and its application: tracer technology modelling the flow of fluids. Springer, 96.

Liu, H. (2003) Pipeline engineering. CRC Press.

Madsen, D.A. and Madsen, D.P. (2016) Engineering drawing and design. Nelson Education.

Matt-Millbury, P.E. and Ratzlaff, J. (2015) Piping designer, LLC: Data Sheet, Pipe-CS, and ANSI Sch 40 (in). 68.

Menon, E.S. (2004) Liquid pipeline hydraulics. CRC press.

Menon, E.S. (2014) Transmission pipeline calculations and simulations manual. Gulf Professional Publishing.

Pipeflow (2019) Pipe Flow Wizard Software: Flow Rate and Pipe Pressure Drop Calculator. Retrieved from https://www.pipeflow.com/pipe-flow-wizard-software. Accessed 6 September 2019.

Rehman, K. and Nawaz, F. (2017) Remote pipeline monitoring using wireless sensor networks. In 2017 International Conference on Communication, Computing and Digital Systems (C-CODE) (pp. 32-37). IEEE.

Ross, D.F. (2015) Distribution Planning and control: managing in the era of supply chain management. Springer.

Schaschke, C. (1998) Fluid mechanics: Worked examples for engineers. Institution of Chemical Engineers. UK. (1998)108.

Stewart, M. (2015) Surface Production Operations: Volume III: Facility Piping and Pipeline Systems. Gulf Professional Publishing.

Ujile, A.A. (2014) Chemical engineering unit operations, synthesis and basic design calculations. Vol 1. BOMN prints Nigeria. Pp 21.

Vincent-Genod, J. (1984) Fundamentals of pipeline engineering. Technip Publishing Company, France. Pp 16-19.

Westhoff, M.A. (1999) Using operating data at natural gas pipelines. In Proceedings: International Symposium on Transportation Recorders. Pipeline materials and property

Xiao, Q., Li, J., Sun, J., Feng, H. and Jin, S. (2018) Natural-gas pipeline leak location using variational mode decomposition analysis and cross-time–frequency spectrum. Measurement, 124, 163-172.