Generation of Empirical Correlation for Predicting Drag Reduction of Oil-Water Flows with Natural Polymers

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ABSTRACT: There is an increasing need to accurately predict the behaviour of fluid in the different flow geometry as applicable in the industries. The prediction of drag reduction phenomenon observed during the two-phase oil-water flow with drag reducing polymers in horizontal pipes was investigated. The Power law model was adopted in this study to empirically correlate the data acquired from our earlier experimental works in a 12-mm ID and 20-mm ID pipes. The model accurately predicts the drag reduction across the horizontal pipes. The agreement between the predicted and experimental drag reductions was better in the 12-mm ID pipe than in the 20-mm ID pipe. More work and data is needed to enhance the predictive accuracy of applicable models.

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Liquid-liquid flow through pipeline has many different industrial applications, such as petrochemicals and crude oil pipelines. The liquid-liquid flow become very complex in nature and the two important hydrodynamic parameters in the design of directional wells or pipelines are the pressure gradient and holdup (Abubakar, 2016; Edomwonyi-Otu et al., 2015). Mechanistic and empirical models can unfailingly predict these parameters, especially pressure gradients. Empirical models are used to predict pressure gradients from available experimental data. Mechanistic models classified as two-fluid and homogeneous models are used to predict the pressure gradients of separated oil-water flow and dispersed oil-water flow respectively (Abubakar, 2016). However, despite numerous experimental, theoretical and simulation approaches in this field, the exact mechanism of drag reduction is still a subject of research and debate (Jiri and Jacqyes, 1997; Kulmatova, 2013; Edomwonyi-Otu, 2015; Edomwonyi-Otu and Angeli, 2019). The two major classical explanations of the drag reduction (DR) phenomena focus on the viscous effects (Lumley, 1969) and the elastic effects (Tabor and De-Gennes, 1986). Accurate determination of the frictional pressure losses of dilute drag reducing polymer solutions has remained a challenge in many practical applications. Virk (1975) carried out a comprehensive study on drag reduction for aqueous flow and proposed relationships for fanning friction factor which assist other researchers to analyze their results. The performance of his investigation of different polymer solutions showed a trend of maximum drag reduction asymptote in all cases.

Mowla and Naderi (2004) used the experimental data obtained from different operating conditions to propose a mechanistic model for predicting the DR by polymer in two-phase flow. Their model was used for calculating friction and maximum drag reduction as a function of drag reducing agent (DRA) concentration. Sher and Hetsoni (2008) in accordance with the elastic properties of polymer, proposed a mechanistic model for the turbulent drag reduction by additives, and compared their results with Virk’s experiment. Chakrabartiet al., (2005) used the ordinary two-fluid model to confirm the interfacial shape in segregated flow. They confirmed that the interface separating the two phases of the separated flow which was assumed to be planar is usually not flat. Liu et al., (2008) reported their experimental studies on the two-phase oil-water in curved pipes with turbulence promoters and analysed their pressure gradient and holdup data using modified Chakrabarti et al., (2005) correlation to account for the curved interface of the oil-water flow. Their result showed acceptable agreement with the experimental pressure gradients of their study and
those of Angeli and Hewitt (1998). Sharma et al., (2011) also used the mechanistic models coupled with the total energy of the oil-water system to predict the pressure gradients of separated and dispersed oil-water flow in a smooth pipe. The performance of their developed model was tested against several experimental data and existing models, and found that the model predicted the pressure gradients quite well. Rodriguez and Baldani (2012) developed two additional models for the interfacial friction factor in the two-fluid model with the aim of improving the prediction of the pressure gradients. Their developed models were validated against experimental data with some published experimental data. Also, the prediction of the correlation was validated against the two-fluid model and it was found to give a better performance in predicting the pressure gradients in most of the existing works. Edomwonyi-Otu and Angeli (2015) also developed an expression between the interfacial heights of oil-water flow at the pipe centre and those close to the pipe wall that was used in the two-fluid model. Their results showed that the addition of both the interfacial curvature and the equivalent roughness in the two-fluid model improved its predictions of pressure gradients. Abubakar (2016) extended his study to develop an empirical model to predict the pressure gradient for oil-water flow with drag reducing polymer (DRP). The prediction was done using 350 experimental pressure drop data points obtained at maximum drag reductions from the two uPVC pipes (12 mm and 20 mm ID) against their corresponding Reynolds number for each polymer sample (xanthan gum and guar gum). The performance of the developed correlation was checked using statistical analysis. This was achieved by calculating the Mean Percent Error (MPE), Mean Absolute Percent Error (MAPE) and Root Mean Square Percent Error also known as Percent Standard Deviation (PSD) using data from each pipe diameter and combined experimental data. Equations (1) – (3) were used to determine the MPE, MAPE and PSD respectively (Yusuf, 2011; Abubakar, 2016).

\[
MPE = \frac{1}{n} \sum_{k=1}^{n} \frac{DR_{Pred} - DR_{Exp}}{DR_{Exp}} \times 100 
\]

\[
MAPE = \frac{1}{n} \sum_{k=1}^{n} \left| \frac{DR_{Pred} - DR_{Exp}}{DR_{Exp}} \right| \times 100 
\]

\[
PSD = \left[ \frac{1}{n-1} \sum_{k=1}^{n} \left( \frac{DR_{Pred} - DR_{Exp}}{DR_{Exp}} \right)^2 \right] \times 100 
\]

The MPE indicates the nature of prediction by the correlation which can either be over prediction if it is a positive value or under prediction if it is a negative value. The MAPE shows the prediction capability of the correlation while the PSD indicates the measure of the spread of the predicted values about the experimental values.

RESULTS AND DISCUSSION

MATERIALS AND METHODS

EDOMWONYI-OTU, LC; DOSUMU, AI; YUSUF, N; ABUBAKAR, A
Empirical Correlation for Predicting Drag Reduction with DRP: Figures 1 show the variation of maximum drag reduction values with their corresponding Reynolds number by addition of guar gum and xanthan gum. It can be seen from the figure that the correlation coefficient for predicting maximum drag reductions was generated for the natural gums and expressed by Equation (4).

\[ \%DR = 4 \times 10^{-7} Re^{1.72} \]  

(4)

Comparison of predicted drag reductions with experimental data: Figures 2 – 5 show the comparisons of the predicted pressure gradients obtained from the developed correlations with the experimental pressure gradients for different DRP and pipe diameters while Table 1 presents the performance of the developed correlation. The MPE and MAPE of the correlation in the 12-mm ID pipe by guar gum (Figure 2) were 8.01 and 23.46 % respectively while the PSD of the predicted drag reductions from the experimental values was estimated to be 28.49 % of the experimental values (Table 1).

| Data Source | MPE  | MAPE  | PSD  |
|-------------|------|-------|------|
| GG 12 mm ID | 8.01 | 23.46 | 28.49|
| 20 mm ID    | -13.01 | 28.62 | 33.16|
| XG 12 mm ID | -10.45 | 19.51 | 22.47|
| 20 mm ID    | -21.82 | 27.31 | 30.71|
| Overall     | GG 2.50 | 26.04 | 30.37|
|             | XG -8.48 | 11.71 | 18.53|

Meanwhile, in the 20-mm ID pipe (Figure 3), the MPE, MAPE and PSD of the correlation were -13.01, 28.62 and 33.16 % respectively as presented in Table 1. It can be seen from the error values that the best agreement in the predicted drag reductions by using guar gum as the DRP was better in 12-mm ID pipe than in 20-mm ID pipe.

For the combined prediction, the MPE, MAPE and PSD of the predicted drag reductions from the experimental values was estimated to be -4.87, 11.71 and 18.53 % of the experimental values respectively (Table 1). The agreement of the predicted drag reductions with all the experimental drag reductions was also better in the 12-mm ID pipe than in the 20-mm ID pipe.

This result shows that the model can be used to predict data accurately in different systems.
**Conclusion:** Empirical models were developed for the prediction of drag reduction for oil-water flow with DRPs in horizontal pipes. The models accurately predict the drag reduction across the horizontal pipes. The best agreement between the predicted and experimental drag reductions was better in the 12-mm ID pipe than in the 20-mm ID pipe.

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