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Roughness analysis within flexible water injection pipes in petroleum production projects

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ABSTRACT

In petroleum production projects it is important to consider injection wells in order to promote the mass balance of the porous environment and increase the recovery factor of petroleum. Some of the injection wells are utilized to inject water, especially in the Brazilian scenario of petroleum production. There are some uncertainties regarding the flow modeling, mainly associated with the inner wall roughness determination of flexible pipes whose manufacturing process can originate a corrugated surface or surfaces that are not informed by the manufacturer or are hard to determine. This study takes an approach to water injection well modeling in petroleum production systems and how, through the flow data measured in the field, the pipe inner wall roughness is determined. These results are analyzed with other values of roughness that are normally utilized at wells of water injection in flexible flowlines and numerical–experimental results recently observed in Brazil. The results show that an accurate consideration of the roughness value can bring significant benefits to reducing the costs of injection well projects.

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1. Introduction

In flow projects there are usually some uncertainties that must be estimated in pipeline projects. In the case of water flow, the fluid is Newtonian, with low viscosity, and practically incompressible. Therefore, water flow problems are well known and uncertainties are low, though there might be uncertainties related, mainly to roughness in water injection wells in the petroleum industry according to Stel et al. (2010).

Isothermal flow can be adopted for many single-phase flow problems, even when there is some temperature variation. Particularly for water flow in injection wells there is a Newtonian fluid with low viscosity. In this scenario, although the flow may not usually be isothermal, such hypothesis can be adopted because the flow is commonly quite turbulent. With a very turbulent flow the pressure drop does not depend on viscosity, consequently, a variation of viscosity with temperature, by and large, can be disregarded when calculating the pressure drop (Andreolli et al., 2015; Bobokk et al., 1996).

Besides viscosity, the density is also important for water flow, which also depends on pressure and temperature. This is a low dependency, and the hypothesis of incompressible flow is usually taken into consideration, which incurs minor errors and leads to considerable simplification in simulations. In more precise studies pressure and temperature corrections can be considered, as proposed by Spivey et al. (2004) and Fine and Millero (1973).

The Moody (1944) diagram is used to determine the pressure drop through friction, as it depends on several parameters, roughness being one of them. In cases of a turbulent flow, uncertainties regarding fluid properties that can change the Reynolds number have little relevance on the pressure drop (Andreolli et al., 2015), whereas uncertainties regarding the roughness value have a direct impact on the friction factor (Farshad et al., 2001; Moody, 1944; Samadianfard, 2012). In several water injection pipelines, the internal surface is made of polyethylene, designated by API 17B (2014) as smooth bore. For water injection pipelines and petroleum production, internal stainless steel carcass layer pipes – called rough bore or corrugated tube, as specified in API 17B (2014) – are used. Flexible pipes with internal steel carcass layers are used for submarine flowlines, in which internal pressure may become lower than the external one, so the carcass layer is made to withstand the sea water hydrostatic pressure and avoid the pipelines from collapsing (API, 2014). However, the flow inside corrugated pipelines is generally subjected to an increase in pressure drop and turbulence when compared to a normal flow observed in

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non-corrugated tubes. There are also some uncertainties regarding the effective roughness to be considered in these pipeline projects.

Pioneer studies that observed the influence of roughness on the pressure drop of pipelines were presented by Nikuradse (1933), and showed the importance of roughness in flowlines with a high Reynolds number of turbulence. An increase in the Reynolds number makes the friction factor also increase if compared with a smooth bore, and then the friction factor becomes a function of the Reynolds number and roughness. For even higher Reynolds numbers, the flow becomes "completely rough" since the friction factor becomes dependent solely on the surface roughness scale, and consequently does not depend on the Reynolds number. This conclusion was synthesized later by Moody (1944).

For corrugated pipelines in particular, with the further improvements of turbulence models associated with the development of computers, several numerical and experimental studies have been performed on corrugated surfaces, including flexible lines. Due to their manufacturing process, macroscopic elements are incorporated into the surface of flexible lines and become exposed to the flow. Such macroscopic elements are not a natural roughness of the material but an artificial roughness, macroscopic and evenly distributed, called discreet roughness. This type of surface makes it even more complex to understand and estimate the absolute roughness value according to Djenidi et al. (1994), who noted that these macroscopic elements cause a significant global increase in turbulence levels, transversal velocity components and turbulence stress on the surface, which leads to momentum exchanges. Later, Chang et al. (2006) made a numerical study of turbulence flow on corrugated plain plates similar to the flexible pipe structures and observed that the turbulence tension had a gain when in contact with the rough surface due to its concavity. Other flow studies on corrugated surfaces can be found in Jiménez (2004) and Vijiapurapu and Cui (2007) with similar conclusions.

The fact that turbulence fluctuations and momentum exchanges exist and are caused by corrugated surfaces represents a flow disturbance mechanism that causes a raise in the global friction factor on these surfaces when compared to plain surfaces. More recently (Stel et al., 2010) used a classic turbulence model and an experimental mechanism to develop a parametric study for the friction factor on the Colebrook equation (Colebrook, 1939), based on four corrugated structures, among them a petroleum flexible line structure. Analysis of the flow patterns, the fluctuations of velocity levels, and the Reynolds tensor showed that the geometry of these elements favor the momentum exchange mechanism, the result of which can be seen as a great turbulent contribution adding to global friction on the surface. The results obtained converge to the other conclusions mentioned before by other authors in the text where they studied similar problems.

For flowline projects with flexible pipes, API 17B (2014) indicates, for rough bore pipes, the use of the practical formula ID/250 (where ID is the inside diameter of the pipe) and for smooth bore pipes, the roughness value equal to 0.005 mm. These values are considered conservative by the API 17B and there might be significant deviations due to several factors that affect the effective roughness of the pipe, as mentioned above, as well as small grooves resulting from the manufacturing process. Due to the uncertainties in determining the actual roughness of flexible pipes, it is common to consider for both smooth bore and rough bore pipes the practical formula ID/250, though recent studies have shown that this methodology is inadequate, including corrugated lines (Stel et al., 2010). Uncertainty to determine the roughness of flexible lines that inject water can lead to significant errors with the flow, as well as bringing about uncertainties at the project stage, and higher costs. For example, overestimating the pressure drop might point to the need of more injector wells in the production field and end up increasing the cost of the project.

This study aims at assessing the roughness of flexible pipes used in water injector wells that incorporate both rough bore and smooth bore pipes. The methodology indicated in API 17B (2014) will be confronted with other equations in order to estimate the absolute roughness as well as that calculated on the basis of the pressure data measured in the flowline. These are important results in developing petroleum production and can bring significant gains to the project, in so far as the results of simulations are more reliable.

2. Methodology and data

This study consists of evaluating the roughness of flexible pipes utilizing real pressure data measured in the field and a classic modeling of pressure drop. Although the turbulence theory presented by Komolgorov (1941), and addressed later by many authors such as Tennekes and Lumley (1972), Pope (2000), and Jiménez (2004), has been incorporated in several studies of flow on rough surfaces, like the one addressed by Stel et al. (2010), this study considers only the classic equation for momentum in a permanent regime. This equation incorporates terms like: pressure, gravitational, acceleration and friction. In general, acceleration is disregarded; leaving only the other three terms, but turbulence is incorporated into the friction term. Fig. 1a presents the system's geometry that exists within a flexible pipe connecting the Wet Christmas Tree (WCT) to the platform. The stretch between the WCT and the petroleum reservoir, where the water injection occurs, is not presented in this system. This stretch is hidden because the roughness analysis is made only at the line connecting WCT to the platform. Fig. 1b presents the force decomposition on a

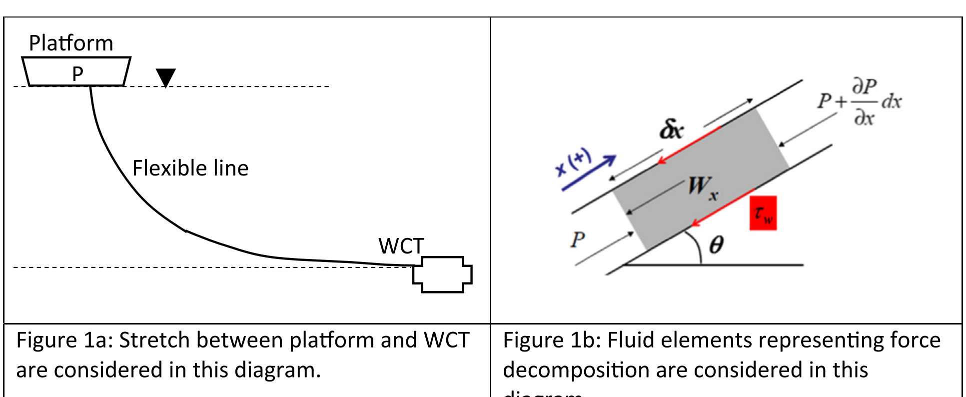

Fig. 1. a: Stretch between platform and WCT are considered in this diagram. b: Fluid elements representing force decomposition are considered in this diagram.

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