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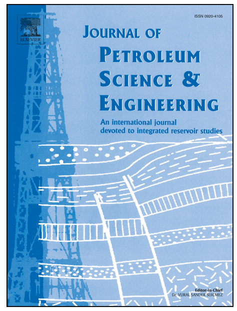

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Scale-up and turbulence modelling in pipes

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Abstract

Large diameter pipes are commonly used for oil and gas transportation. Experimental and numerical results, including turbulence properties, are often obtained for small diameter pipes. Only little information is available for pipes larger or equal to 200 mm. Results obtained with Reynolds Averaged Navier-Stokes (RANS) turbulence models for single phase flow in pipes of different sizes are presented and discussed. The use of non-dimensional data is usually assumed sufficient to present general information and is assumed valid for any size of pipe. The validity of such assumptions has been checked and the flow behaviour in small, medium and large pipes obtained with several of the most common RANS turbulence models, has been established under specific conditions via Computational Fluid Dynamics (CFD) techniques. Although difficulties were sometimes encountered to reproduce correctly the turbulence properties described in the literature with the turbulence models implemented in open source CFD codes, it is shown that a scaling-up approach is valid as the general flow pattern can be predicted by a non-dimensional strategy.

Keywords: CFD model, pipe, turbulence, simulation, scale-up, non-dimensional

1. Introduction

Results obtained with different turbulence models and compared with experimental data are legion in the literature for small diameter pipes, see for instance Hrenya *et al.* (1995); Spalart (2000); Pope (2001); Karvinen & Ahlstedt (2008); Vijiapurapu & Cui (2010); Escue & Cui (2010). Some numerical work has been performed for large diameter pipes (Brown *et al.*, 2009; Verdin *et al.*, 2014; Guan *et al.*, 2015), however, published studies of the behaviour of turbulence models in pipes larger or equal to 200 mm, such as from Shawkat *et al.* (2008), are rare.

The flow can be laminar or turbulent. Between these two regimes, there is a transition region, which has been found experimentally to be a function of the Reynolds (Reynolds, 1883) number $Re = \rho U L/\mu$, ρ being the fluid density, U its velocity, μ its dynamic viscosity and L a characteristic length, equal to the hydraulic diameter of the pipe D_h when a pipe flow is considered. For such geometries, the flow is assumed turbulent when the Reynolds number is higher than 4,000 and a transition from laminar to turbulent is present when $2,300 < Re < 4,000$.

Experiments being restricted to small diameter pipes, numerical approaches are usually used for studies of the flow in medium and large diameter pipes. Although Large Eddy Simulations (LES) and Direct Numerical Simulations (DNS) solve the spatially averaged and the full Navier-Stokes equations respectively, they also require more time and computing resources compared to Reynolds Averaged Navier-Stokes (RANS) based simulations. Their use is therefore often restricted to simple geometries and relatively low Reynolds numbers flows, as pointed out by Ahn *et al.* (2015).

The aim of the work presented here is to palliate the lack of information for medium and large pipes and to provide a set of RANS based results for single phase flow in pipes of different sizes. This will be achieved through the use of Computational Fluid Dynamics (CFD) which is used extensively to study macroscopic hydraulics phenomena in industrial systems. Near the walls (where the non-dimensional distance to the wall is $y^+ = u^* y/\nu < 100$, with u^*

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