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Studies on water carrying of diesel oil in upward inclined pipes with different inclination angle

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ABSTRACT

The characteristics of oil-water two phase flow in the case of water initially accumulated at low position in upward inclined pipelines were researched. A large scale experiment loop was conducted to analyse the flow characteristics by using a series of 50 mm transparent acrylic bends with different inclination angle (10° ~ 45° at the interval of 5°). Five flow patterns were identified and a corresponding flow pattern map was established. The same situation was also simulated by using computational fluid dynamics (CFD) techniques, and the results of simulation were validated by comparing with the experimental results. The impact of oil superficial velocity, inclination angle and initial water volume on flow characteristics was further investigated. The results indicate that the backflow effect in water phase is the major factor that causes water accumulation at the bottom of the pipe. The initial residual water volume has no influence on the oil-water flow pattern and the water-carrying capacity of oil. The lower flow rate and the higher inclination angle cause the decrease of water-carrying capacity of oil, resulting in the water accumulation at the low position and internal corrosion of product oil pipelines.

1. Introduction

Product oil pipelines are frequently subjected to severe internal corrosion, which may cause significant economic losses. The internal corrosion occurs when water drops out of the hydrocarbon phase and wets the pipe steel (Pouraria et al., 2016). The accumulated water also causes microbiologically influenced corrosion (MIC) in the pipeline (Song et al., 2016).

The water frequently accumulates at the low position of product oil pipelines due to its higher density compared with oil. The water accumulation is caused by the hydrostatic test and the oil flow which carries minute amounts of water (Chen et al., 2011). Even with low water content in the oil, accumulation occurs at the lower spots of the pipe, in particular during production shut-down. In oil-water two phase flow in pipelines, determination of the locations where water-wetting occurs is critical to predict the location for internal corrosion to occur (Hu and Cheng, 2016). Therefore, flushing out of the accumulated water by flowing oil is an effective and simple method to avoid internal corrosion and other associated problems.

The situation of accumulated water is affected by many factors such as fluid hydrodynamics, fluid physical properties, inclination angle and flow pattern (Silva et al., 2006). This is a typical transient oil-water two-phase flow problem which can be analysed by experiment (Ismail et al., 2015a) and computational fluid dynamics (CFD) methods (Walvekar et al., 2009). The existence of various flow patterns and diverse governing mechanisms cause liquid–liquid flow to be a complex system and highly problematical (Shi, 2001). In oil-water flow studies, different researchers have analysed the flow patterns (Al-Wahaibi et al., 2012; Hanafizadeh et al., 2015; Ismail et al., 2015b), pressure drop (Rodriguez and Oliemans, 2006), inclination angle (Xu et al., 2016) and liquid holdup (Pan et al., 2016; Soleimani et al., 2000). However, most of these works concentrate on the oil and water mixing flow in pipes. There are few investigations about the situation that accumulated water displace by oil flow in upward inclined pipes.

In this study, the characteristics of oil-water two phase flow in the case of water initially accumulated at low position in upward inclined pipelines were researched. A large scale experiment loop was conducted to analyse the flow characteristics by using a series of transparent acrylic pipes with different inclination angle. The flow pattern was observed and a corresponding flow pattern map was established. CFD simulations were performed and the results of which were compared with the experimental results. The impact of fluid velocity, inclination angle and initial

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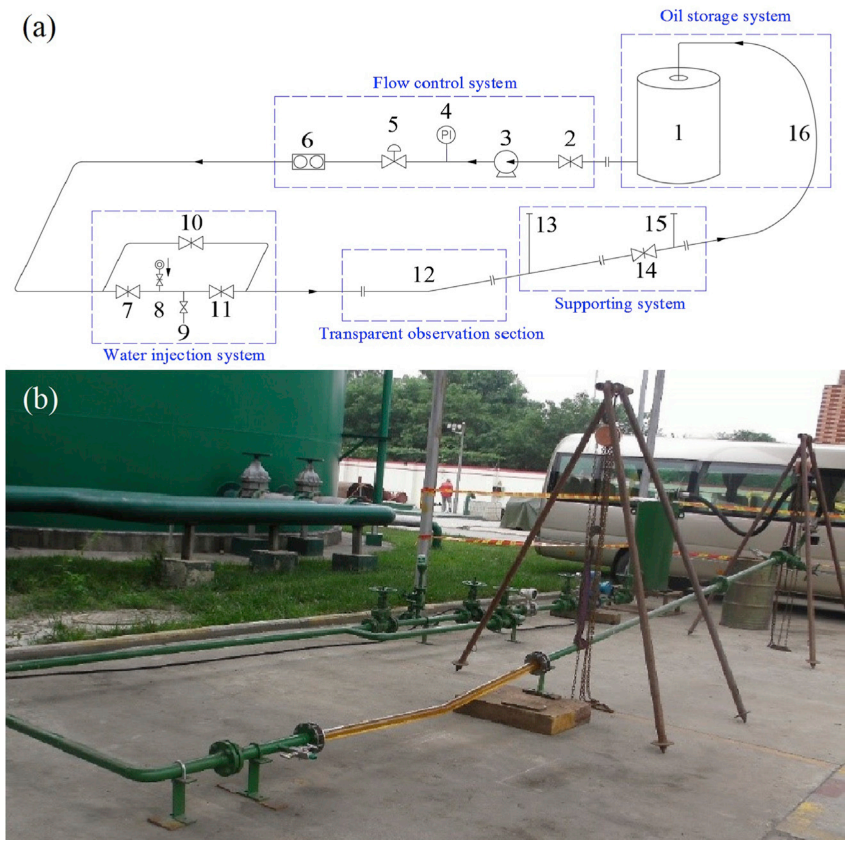

Fig. 1. The experimental setup. (a) Schematic description; (b) Picture.

Table 1
Properties of the liquid at 20 °C and 1 atm.

Liquid	Diesel oil	Water
Density (kg/m^3)	$\rho_o = 833.5$	$\rho_w = 998.205$
Viscosity (mPa·s)	$\mu_o = 3.575$	$\mu_w = 1.03$
Interfacial tension (mN/m)	17.95	

Table 2
The relationship between U_{so} and *Re*.

Oil superficial velocity (U_{so})	Reynolds numbers of the oil phase (*Re*)
0.1	1165.7
0.15	1748.6
0.2	2331.5
0.25	2914.3
0.3	3497.2
0.35	4080.0

water volume on the water accumulation was further analysed.

2. Experimental setup

The experiments on flow characteristics of the accumulated water flushed by flowing oil were performed in the large scale flow loop. The overall length and width of the experimental setup are 10 m and 3 m, respectively.

The experimental setup consists of oil tank (1), gate valve (2, 7, 10, 11, 14), centrifugal pump (3), pressure indicator (4), globe valve (5), turbine flowmeter (6), injection valve (8), drain valve (9), acrylic bend (12), chain hoist (13, 15) and rubber hose (16), shown in Fig. 1. Diesel oil and water were used as test fluids. The physical properties are shown in Table 1. Water was dyed in order to obviously distinguish it from diesel oil. The experimental setup consists of 5 parts, the detail of which is as follows:

Table 3
Solution method of simulation.

Pressure-Velocity Coupling		PISO
Transient Formulation		First Order Implicit
Time Step Size		0.005s
Number of Time Steps		40,000
Max Iterations		50
Spatial Discretization	Gradient	Least Square Cell Based
	Pressure	Body Force Weighted
	Momentum	Second Order Upwind
	Volume fraction	Geo-Reconstruct
	Turbulent Kinetic Energy	Second Order Upwind
	Turbulent Dissipation Rate	Second Order Upwind

(a) Oil storage system

Oil storage system is an oil tank (1) with 323.9 mm diameter and 1200 mm height. The bottom of the tank shapes as an inverted cone connecting with a drain valve in order to discharge the sediment. The tank with a 70 mm diameter hole on the top connects the rubber hose (16) in order to circulate test fluids.

(b) Flow control system

The pipe is sequentially connected with gate valve (2), centrifugal pump (3), pressure indicator (4), globe valve (5), and turbine flowmeter (6), and those equipment forms the flow control system. Gate valve (2) is used to control liquid level in the tank and prevent spilling of diesel oil. Centrifugal pump (3) is used to supply energy to the fluid. Pressure indicator (4) is utilized to measure pressure in the pipeline. The oil flow