

Performance of turbine flowmeter in horizontal oil-water flow

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Abstract

The response of turbine flowmeter in horizontal oil-water two-phase flow is experimentally investigated. The flow patterns in pipe as well as the turbine behavior are captured via high speed videography. Varied incoming flow rates up to $30\text{m}^3\text{d}^{-1}$ are tested. It is found that the turbine response in oil-water flow deflects from that in pure water. The deflection direction and extent depend on respective flow rates rather than flow pattern. Considerable deflection is only observed in stratified flow. In addition, a theoretical modeling of the response of turbine meter in steady stratified flow is realized. Preliminary tests indicate that the established model may predict some important features of meter response in reality.

Key words: Turbine flowmeter; oil-water flow; flow pattern; performance model

1. Introduction

Horizontal oil-water two-phase flow is constantly seen in the oil industry, especially in the process of secondary exploration of low-yielding oil fields where water injection and horizontal welling are two major techniques to raise the production [1]. The logging of such wells demands an effective measurement of the two-phase flow. And turbine flowmeter presents one of the applicable and most experienced instruments. However, a turbine flowmeter is normally designed for and calibrated in pure fluid and the use of it in multiphase flow usually leads to measuring deviation and uncertainties. The study of the influence of two-phase flow on

the meter response is therefore a necessary preparation towards an accurate measurement of the flow.

The response of turbine flowmeter in oil-water two-phase flow has been widely addressed. Skea and Hall [2] carried out a series of experiments to investigate the effect of two-phase flow on the performance of a range of flowmeters. They found when the total flow is small the meter factor in oil-water is lower than that in pure water. Instead, Xu [3] indicated that the multiphase effect in low flow is rather complicated and appears no bold regularity, and, as the flow exceeds $30\text{m}^3/\text{day}$, the meter response rises slightly with the oil content. Also by experiment, Feng and Li [4] revealed the remarkable influence of oil viscosity on the response of turbine flowmeter. Jin [5] and Sun [6] studied the oil-water flow patterns in the measuring channel as well as their dependence on incoming flows. Turbine performance was out of their main interest, though.

The current paper presents an experimental investigation on the performance of turbine flowmeter in horizontal oil-water flow. As a deepening and extension to the work of Xu [3], this work dedicates to establish the detailed relationship among the phasic flow rates, the flow pattern and the meter response (K factor). Furthermore, a theoretical model is developed for description of turbine response in stratified flow. The model is then tested, preliminarily.

2. Experimental setup

The experiments are conducted upon a horizontal multiphase platform as shown in Fig. 1. Oil and water are pumped to circulate in the

pipelines. Flow rates of respective phases are monitored before they join at the junction. The blend of oil and water coming out of the test section is collected by a tank and rested for separation.

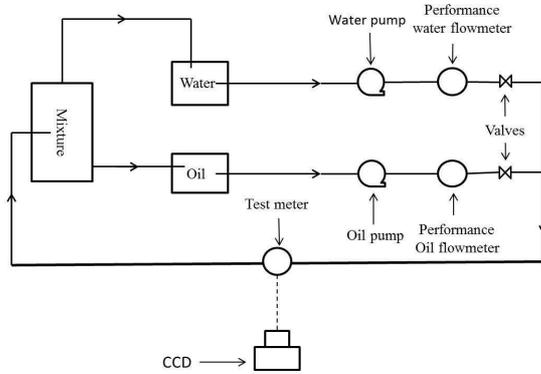


Fig. 1 Schematic of experiment pipelines

A transparent turbine flowmeter is fabricated and installed in middle of the test section. Direct videography is applied to record the flow pattern and to pick up the turbine rotation. Shooting speed of the video camera is 600 frames per second, which is sufficient for the test.

The density and viscosity of the two testing liquids – water and oil -- are exhibited in Table 1 for clarity.

Table1 Properties of oil and water

Liquid	Oil	Water
Density (kg/m ³)	795	988
Viscosity (mPa*s)	2.9	1.0

3. Experimental results

3.1 Flow patterns

The flow pattern in the pipe changes with the flow rates. According to the classification of Trallero [7], we observe four typical flow patterns, i.e. stratified flow (ST), stratified flow with mixing at the interface (ST&MI), dispersion of oil in water and water (Do/w&w), and dispersion of oil in water (Do/w). Fig. 2 shows the distribution of the four flow patterns in a plane of two phasic flow rates.

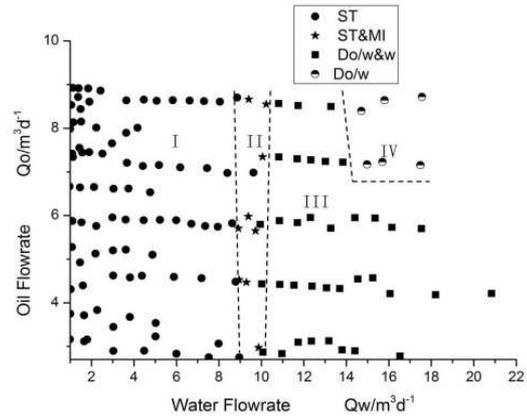


Fig. 2 A map of flow patterns

From Fig. 2 we can find that when the water flow is less than 9m³d⁻¹, the interface of oil and water remains integrated and clear (ST). But when the water flow goes higher than 9m³d⁻¹, there will be small oil drops formed in water. As the total flow exceeds about 24m³d⁻¹, oil drops are scattered all over the pipe (Do/w).

3.2 Response of turbine flowmeter

The meter factor K of the turbine flowmeter can be derived from the measured rotor frequency. Data of K corresponding to all the cases in Fig.2 versus the total flow rate are summarized in Fig. 3.

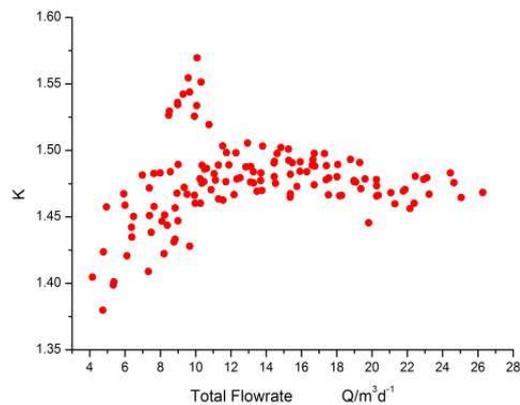


Fig. 3 K factors under different flow rates

It is evident that the dispersion of K is relatively large when the total flow rate is below 11m³d⁻¹, which indicates the turbine response has a strong dependence on the phase cut in this region. The dispersion reduces notably as the total flow goes higher. Thus the multiphase effect is fading away with the increase of total flow.

To reveal the correspondence between flow patterns and turbine response, the relative offset of K factor with respect to that in pure water is computed, and a contour map of it is created and superimposed upon the diagram of flow pattern (Fig. 2). The outcome delivers Fig 4.

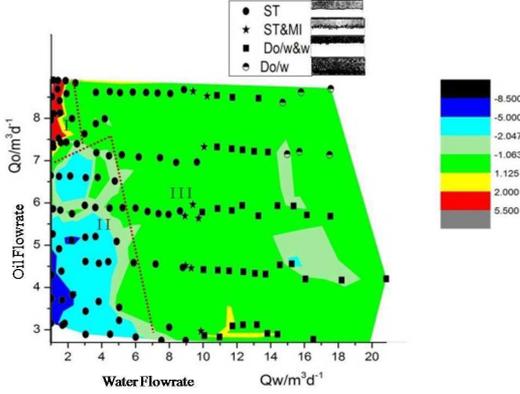


Fig. 4 Relative offset of meter factor and flow patterns under different flow conditions

The green color in contour map represents a minor offset less than 1.0%, red represents a positive one of 2.0~5.5%, and azure blue a negative one of -5.0~-8.5%.

Obviously, large deviations occur only in stratified flow. When both water flow and oil flow are less than $7.0\text{m}^3\text{d}^{-1}$, the response of turbine flowmeter is lower than that in pure water. Whereas, when the oil flow goes larger than $7.0\text{m}^3\text{d}^{-1}$ and the water flow drops under $2.0\text{m}^3\text{d}^{-1}$, the meter response becomes higher than that in pure water.

The deficit part is explainable because when both flows are low, the viscosity which serves to resist the rotation has a more significant existence, and the replacement of water with the more sticky oil (see Table 1) causes a slowing down of the rotor. The reason of the surplus is not quite clear, however. A speculation is that, as the water flow is low and the oil flow is large, the water layer at the bottom of pipe seems to have a lubrication effect which relieves the clearance drag acting on blade tips.

4. Theoretical modeling

In order to clarify the reason of the changes of turbine response in oil-water two-phase flow, we propose a theoretical model for calculations of turbine response in stratified flow.

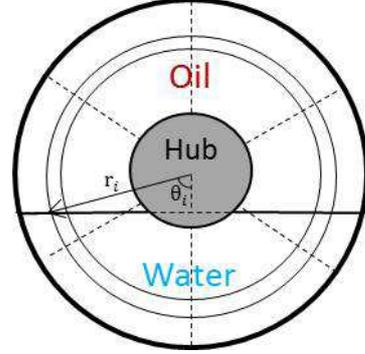


Fig. 5 Sketch of cross-sectional layout of turbine flowmeter for theoretical modeling

The general consideration is to construct a stable and flat interface as sketched in Fig. 5. For a given size of pipe, as long as the two incoming flow rates are known and the slip velocity is given, the location of the interface is solely determined. In present study, uniform flow velocity is applied for each phase, and the slip velocity between phases adopts the experimental data of Xu [3].

On the basis of equal opportunity for all blades, the average torque acting on any radial position r can be derived.

$$dT_d = N\Gamma\rho_r v_r r dr \quad (1)$$

where,

$$\rho_r = \frac{\theta}{\pi}\rho_o + \frac{\pi-\theta}{\pi}\rho_w \quad (2)$$

$$v_r = \frac{\theta}{\pi}v_o + \frac{\pi-\theta}{\pi}v_w \quad (3)$$

The torque T_d is then integrated along radial direction, which in total yields the total torque exerted on the blades

$$T_d = \int_{R_h}^{R_i} N\Gamma\rho_r v_r r dr \quad (4)$$

The model is applied to examine the test cases discussed above. Fig.6, 7 and 8 are the calculation results.

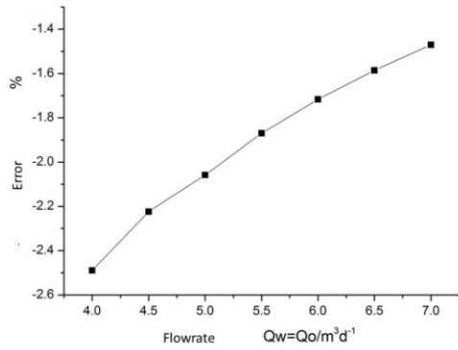


Fig.6 Calculated relative offset of the meter factor in flow with the same water and oil rates,

$$Q_w=Q_o$$

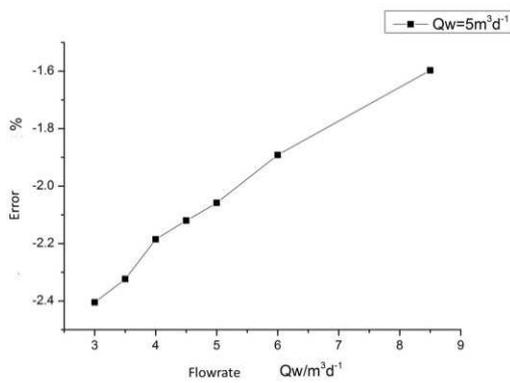


Fig.7 Calculated relative offset of the meter factor in flow with water flow rate $Q_w=5m^3d^{-1}$

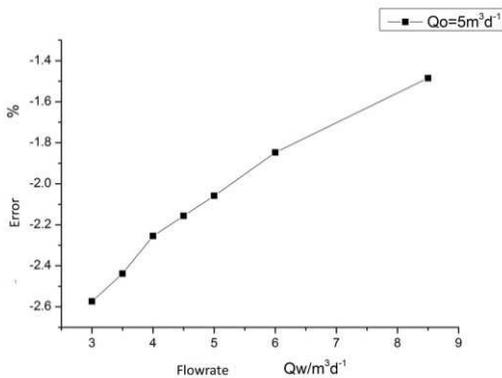


Fig.8 Calculated relative offset of the meter factor in flow with oil flow rate $Q_o=5m^3d^{-1}$

From the figures, we can see that the tendency of the calculation results is in good agreement with the experimental observation. A quantitative comparison of selected data is given in Table 2. It turns out not only the tendency but also the exact values are well predicted by the theoretical model.

Table 2 A comparison between calculation and experiment about the relative offset of meter factor (with respect to pure water)

Q_o m^3d^{-1}	Q_w m^3d^{-1}	Calculated offset %	Measured offset %
2.75	7.52	-1.84	-1.81
2.83	6.00	-2.17	-2.23
3.23	5.01	-2.37	-2.69
4.62	4.37	-2.24	-2.86
4.53	8.94	-1.45	-0.93
4.88	3.82	-2.34	-3.19
5.21	3.61	-2.34	-3.81
5.99	4.87	-2.15	-1.85
6.53	4.76	-1.85	-1.49
7.13	4.42	-1.84	-1.53
7.16	5.18	-1.71	-0.39
7.20	3.67	-1.97	-1.06

5, Conclusion

1. The turbine response in oil-water flow deflects from that in pure water, and the deflection direction and extent vary with respective flow rates. The deflection is relatively significant in stratified flow while negligible in dispersed flow.

2. A theoretical modeling of the response of turbine flowmeter in steady stratified flow is realized preliminarily. The model has succeeded in predicting some of the regularities revealed by experiments.

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