Investigation of the mixture flow rates of oil-water two-phase flow using the turbine flow meter

Dong-hui Li, Fei-fei Feng, Ying-xiang Wu, Jing-yu Xu

Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190 , China

yxwu@imech.ac.cn (Professor Y.-x. Wu)

Abstract. In this work, the mixture flow rate of oil-water flows was studied using the turbine flow-meter. The research emphasis focuses on the effect of oil viscosity and input fluids flow rates on the precision of the meter. Experiments were conducted to measure the in-situ mixture flow rate in a horizontal pipe with 0.05m diameter using seven different viscosities of white oil and tap water as liquid phases. Results showed that both oil viscosity and input oil fraction exert a remarkable effect on measured results, especially when the viscosity of oil phase remained in the area of high value. In addition, for metering mixture flow rate using turbine flow-meter, the results are not sensitive to two-phase flow pattern according to the experimental data.

1. INTRODUCTION

Flows of oil and water two-phase are encountered in a diverse range of processes and equipment. For example, in the oil industry, mixtures of oil and water are transported in pipes over long distances. Accurate oil and water flow rate measurements are essential in order to properly manage both the wells and reservoirs. The problem of how to meter oil/gas/water mixtures has been of interest to the petroleum industry since the early 1980s. Since then considerable research has been conducted into the development of a three-phase flow meter suitable for use in an industrial environment (Falcone, 2002). Ideally such an instrument needs to be reasonably accurate (typically 5% of rate for each phase), nonintrusive, reliable, flow regime independent, and suitable for use over the full component fraction range. Usually, the solution to the problem of metering multiphase flows is to separate the component of the gas phase first, and then measure the flow rate of each using conventional single-phase instruments. In recent publications (Johnson and Farroll, 1995; Luxhùj, 1998; Skea and Hall, 1999; ZHANG et al. 2005), some researcher tried to measure the mixture flow meter using the turbine flow-meter. However, a survey of the past literature shows that no experiment, to the best of the authors' knowledge, has been reported till date to investigate on the effect of oil viscosity on measure results at a fixed system. In this work, the mixture flow rate of oil-water flows was studied using the turbine flow-meter. The research emphasis focuses on the effect of oil viscosity and input oil fraction on the precision of the meter.

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2. EXPERIMENTAL SET-UP AND PROCEDURE

The experiments reported below were carried out on the multiphase flow facilities at Institute of Mechanics, Chinese Academy of Sciences. A schematic diagram of the experimental system was shown in Fig.1. All experiments were conducted using white oils and water at room-temperature and atmospheric outlet pressure. Measurements were made for water flow rates from input oil volume fractions from 5% to 95%. The system consisted of a steel frame supporting a transparent Perspex pipes. Water and oil were pumped from their respective storage tanks, metered, and introduced into pipes via a T-junction. The mixture flowed along a 12 m long horizontal pipe from the entry point, which provided sufficient entrance length to stabilize the flow, to the test section. Different flow structures can be obtained through adjusting the input flow rates of water and oil by the pumps themselves. When the steady state was reached under a flow condition, the input flow fluids rates were measured. The high-speed camera recorded the continuous flow process synchronously when the camera frequency was set at 0.5 kHz, which was high enough to capture the details of the flow process. The holdup measurement was taken after the mixture flowing along a 4.5 m long horizontal pipe from the bend. The rapid closing valves system was operated three times to obtain the averaged water holdup under the flow condition. Seven different viscosities white oil have been used to study the effect of the fluid properties on the measurement. The physical properties of liquids and test matrix have been listed in Table 1.

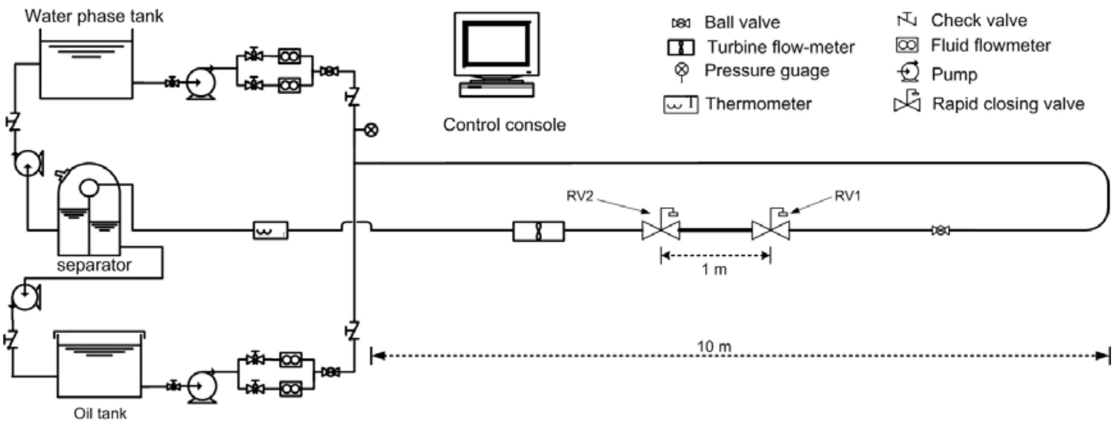

Fig.1 Schematic of experimental setup

Table 1 Experimental matrix

Oil viscosity (mPa·s)	50	160	225	400	700	1100	1450
Water flow rate, Qw (m^3/h)	0~15	0~15	0~15	0~15	0~15	0~15	0~15
Oil flow rate, Qo (m^3/h)	1.7~13	2.5~12	2.9~12	0.8~9.9	0.7~5.7	0.7~1.4	1.4~2.8
Test points	52	41	43	54	40	31	31

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

In this work, input fluids flow rates (Q_W, Q_O) were measured separately under a fixed oil viscosity. Thus, the input oil and water volume fractions can be obtained by:

$$\beta_O = \frac{Q_O}{Q_O + Q_W} = \frac{Q_O}{Q_{M1}} \tag{1}$$

$$\beta_W = \frac{Q_W}{Q_O + Q_W} = \frac{Q_W}{Q_{M1}} = 1 - \beta_O \tag{2}$$

where Q_{M1} is the input mixture flow-rate, Q_{M2} is in-situ mixture flow rate which was measured by turbine flow-meter (shown in figure 1). Compared Q_{M1} with Q_{M2}, the relative error can be cauculated by:

$$Er = \frac{Q_{M2} - Q_{M1}}{Q_{M1}} \times 100\% \tag{3}$$

Figures 2 to 8 show the relative errors using seven different viscosities, respectively. In this work, ±5% relative error is used as the standard to define the work area, and a vertical line is used to distinguish the effective boundary of work area in figures. Relative error vs. input oil volume fraction is shown in figure 2 for water and oil flow with oil viscosity 50mPa·s. It can be found that most of errors are within ±5% during the entire range and turbine flow-meter works well at any given oil fraction. The experimental results with oil viscosity 160mPa·s in figure 3 shows that relative errors are to increase with the increase of input oil fraction. Relative errors can keep within ±5% during a large range of input oil fraction, which is consistent with oil viscosity 50mPa·s for two-phase flow. With oil viscosity increased further to 225mPa·s, similar trend can be observed as shown in figure 4. However, relative errors are within ±5% when βo is less than 70%. Error curves decline with increased βo. When βo reaches 70%, errors can reach to 10%. The failure area appears in the range of 70%~100% for input oil fraction. Relative error vs. input oil volume fraction with oil viscosities 400mPas and 700mPa·s are shown in figures 5 and 6 respectively. It can be seen that, when βo reaches 50~60%, the curves sharply decline and extend ±5%. Work of Turbine flow-meter goes beyond its effective area and the errors turn positive to negative.

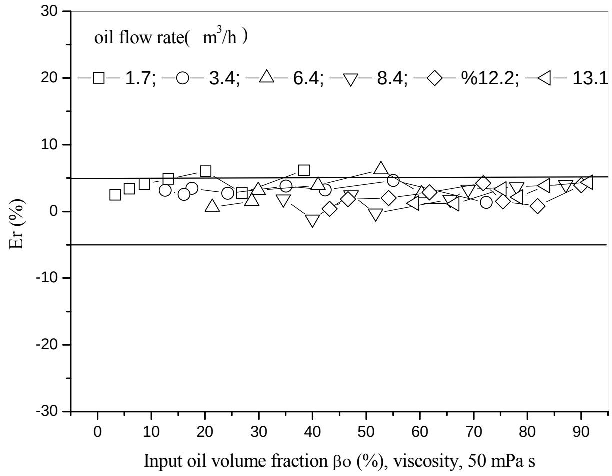

Fig.2 Relative error (Er) vs. input oil volume fraction (βo) with oil viscosity 50mPa·s

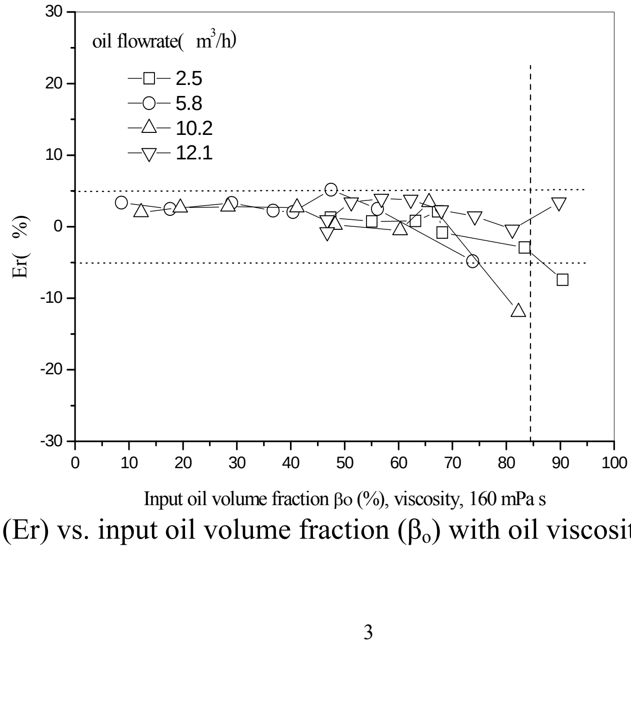

Fig.3 Relative error (Er) vs. input oil volume fraction (β_o) with oil viscosity 160mPa·s.

In order to further investigate of the effects high-viscosity oil on measurement precision, we observed the characteristics of turbine flow-meter when oil viscosities are 1100 mPa·s and 1450mPa·s respectively. The results are shown in figure 7 and 8 respectively. It can be seen that errors sharply increase when βo remains in the range of 30%~40%. Thus, the effective area of turbine flow meter is very narrow for super heavy oil.

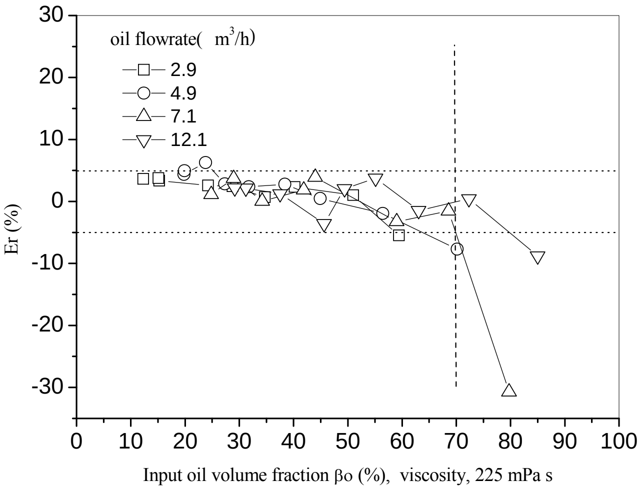

Fig.4 Relative error (Er) vs. input oil volume fraction (β_o) with oil viscosity 225mPa·s

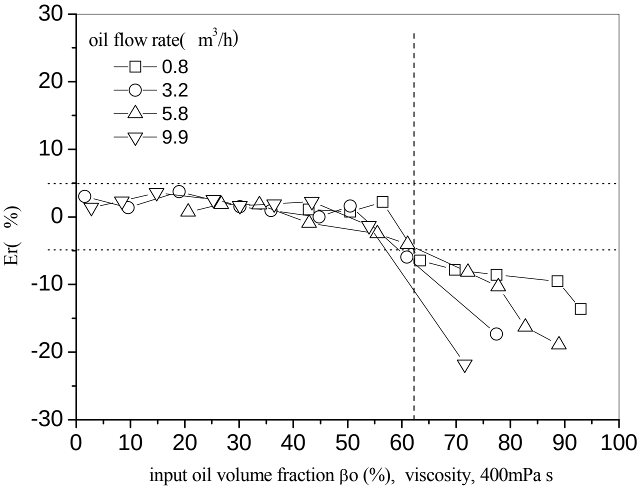

Fig.5 Relative error (Er) vs. input oil volume fraction (β_o) with oil viscosity 400mPa·s.

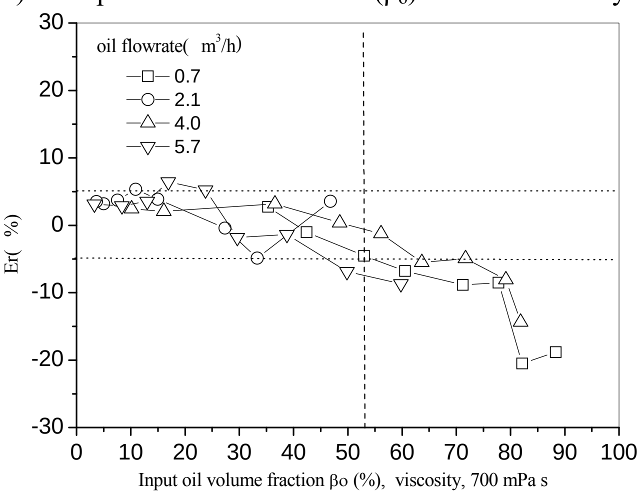

Fig.6 Relative error (Er) vs. input oil volume fraction (β_o) with oil viscosity 700mPa·s.

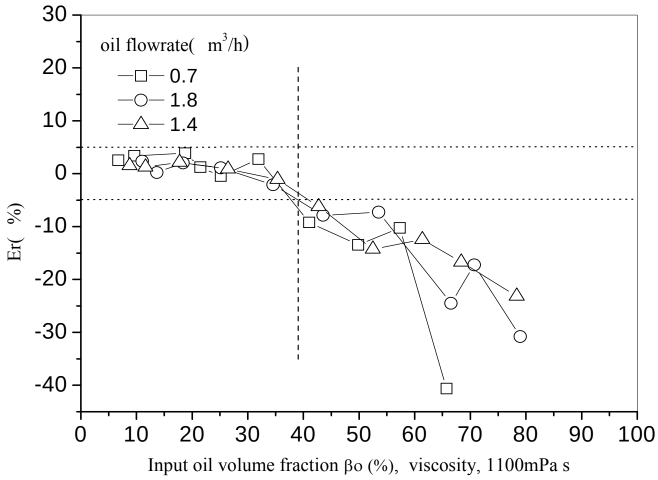

Fig.7 Relative error (Er) vs. input oil volume fraction (β_o) with oil viscosity 1100mPa·s.

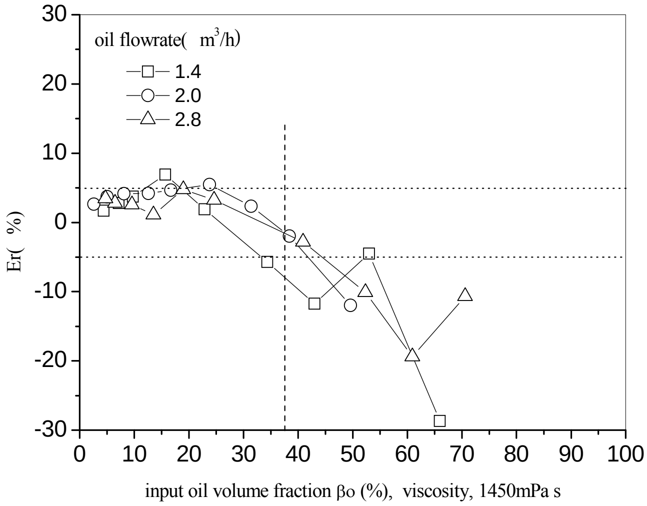

Fig.8 Relative error (Er) vs. input oil volume fraction (βo) with oil viscosity 1450mPa s.

Form above results, it can be concluded that measured errors tend to increase with the increase of input oil fraction (βo) and the effective area of turbine flow meter becomes narrow. For oil-water flow with high oil viscosity, the viscosity of fluid has great impact on measure precision. When oil viscosity goes beyond a certain value, the measure errors will be enlarged. In order to explain this, we study the effective viscosity of oil-water flow: regarding water-oil mixture as homogeneous flow, the mixture viscosity can be defined as:

Water as continuous phase: $$\mu_1 = \frac{\rho_o(1-\beta_w)+\rho_w\beta_w}{\dfrac{\rho_o(1-\beta_w)}{\mu_o}+\dfrac{\rho_w\beta_w}{\beta_w}} \tag{4}$$

Oil as continuous phase: $$\mu_2 = \frac{\mu_o}{1+\mu_w}\left(1+\frac{1.5\mu_w\beta_w}{\mu_o+\mu_w}\right) \tag{5}$$

In the present work, when water phase is continuous, the calculated effective viscosity is between 1.02 mPa ·s and 2.35mPa ·s and measured errors are within ±5%. When oil phase is continuous, calculated effective viscosity is between 283 and 370 mPa ·s and measured errors go beyond 10% and even reach to 21%. During the effective area of turbine flow meter, most of relative errors are positive with low oil viscosity, which means measured values are larger than real values. However, most of absolute errors are negative with high oil viscosity, which means measured values are smaller than real values.

In order to investigate the relationship between measure precision and flow pattern, flow pattern with oil viscosity 50mPa·s are presented and compared with the flow pattern map obtained by Lovick and Angeli (2004). The flow patterns have been observed visually as well as by photographic techniques. In the present work the flow structures of oil-water two-phase flow are distinguished, in general, as six basic flow structures according to the definition of Trallero et al (1997). They are: stratified flow (*ST*), stratified flow with mixing at the interface (*ST&MI*), dispersion of oil in water and water (*Do/w&w*), oil in water emulsion (*o/w*), dispersions of water in oil and oil in water (*Dw/o&Do/w*) and water in oil emulsion (*w/o*). Flow pattern map of Lovick and Angeli with corresponding superficial velocity (solid lines), showing oil-water two-phase flowing in horizontal pipes for the experiments reported in the present work, is presented in Figure 10. From boundary of different flow pattern we can find that flow pattern obtained in this experiment accord well with flow pattern obtained by Lovick and Angeli. According to the figure 3, we can see that errors between different patterns have no obvious difference, so we conclude that the characteristics of turbine flow meter is not sensitive to flow pattern for low viscosity oil and water flow.

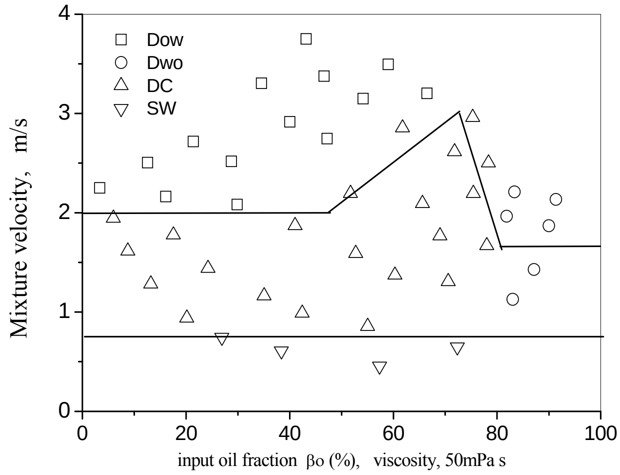

Fig.9 Oil/water flow pattern map in horizontal pipe

4. CONCLUSIONS

An experimental study of the mixture flow rate of oil-water flows using the turbine flow-meter has been conducted. The research emphasis focuses on the effect of oil viscosity and input fluids flow rates on the precision of the meter. Results showed that oil viscosity and input oil fraction exert a remarkable effect on measured errors, especially when the viscosity of oil phase remained in the area of high value. In addition, for metering mixture flow rate using turbine flow-meter, the results are not sensitive to flow-pattern for low viscosity oil and water flow according to the experimental data..

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