PERFORMANCE OF LIQUID TURBINE FLOMETER UNDER LOW FLOW RATE CONDITION

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Abstract An experimental system was set up to study the performance of turbine flowmeter under low flow rate condition. The behaviours of the turbine in a transparent shell were recorded with a high-speed video camera. The response of turbine flowmeter in single-phase fluids with different viscosities and oil-water two-phase flow in a vertical pipe was investigated. It was found that under low flow condition the rotational speed of the turbine changes periodically. For single-phase flow, the K-factor of the turbine flowmeter (ratio of the turbine speed to the flow rate) increases exponentially with the local Reynolds number, and the start-up flow rate as well as the instability of the turbine speed decrease with the flow viscosity. For oil-water flow, the flow pattern appears to have a significant influence on the K-factor under low flow condition.

INTRODUCTION

Turbine flowmeters are widely used for the measurements of flow rate in liquid and gas, such as the water industry, well logging, fuel measurement, and so on. A turbine flowmeter has a linear range within which it performs in good precision. Generally, the smaller the turbine size is the lower the low bound of the linear zone can be. However, it is not always appropriate to employ a small flowmeter, as it may be easily stuck due to impurity of the fluid or cause high pressure loss. Thus under certain situation, turbine flowmeter has to work below the linear range. Such situations are common in field of oil exploitation, especially the logging of low-yielding wells. Therefore it is important to understand the performance of turbine flowmeter under low flow rate conditions.
Since the first turbine flowmeter was invented in 1938[1], the performance of the turbine flowmeter has been widely investigated [2-3]. Several theoretical models have been proposed, among which the airfoil theory of Thompson [4] has been approved by many later researchers, although most investigations are focused on the linear response and very few have considered the low flow rate condition beyond the linear zone where the response of the turbine may be totally different.
This paper investigates experimentally the performance of liquid turbine under low flow rate condition. Two sets of test are carried out in a vertical pipe, one with single-phase fluids of different viscosity and the other with oil-water two-phase flow. The response of the turbine to the low flow rate under those conditions is analyzed and discussed.

EXPERIMENT SETUP

The experimental system consists of a 3.5-meter-high pipe with an inner diameter of 20mm, a turbine flowmeter for the test, and relative operation system such as pumps, throttles, tanks and monitoring flowmeters. The water tank at the top of the vertical pipe has an overflow weir inside to keep the water level constant and therefore maintains a steady pressure and constant flow rate in lower pipes (lower than $10m^3$/day). The oil pump drives a steady flow rate ranging from $0.3m^3$/day to 4 m^3/day. The test section, namely the turbine flowmeter is located downstream of the mixing junction of water and oil. With a graduated cylinder and a stopwatch, we can measure and calculate the flow rate, water content in the pipe. For low flow rate, this measuring method is quite accurate with an error less than 1.5%. A digital camera, Casio EX-F1, with a speed of 600fps, is employed to record the movement of the turbine through its transparent shell, which is high enough to make clear observation for all the conditions in the tests. With this method, not only the slow rotation of the turbine is measurable but also the unsteady features can be characterized.
In single-phase experiment, water solutions of Polyacrylamide (PAM) are used to achieve different flow viscosity. The density of PAM solution is similar to that of water and the kinematic viscosity varies from 8cst to 87cst. In the two-phase experiment, the oil phase is 0# diesel oil whose density is 865 kg/m^3 and kinematic viscosity is 1.8cst in general.

RESULTS AND DISCUSSION

Response of flowmeter in single phase Flow

With the increase of flow rate, the response of turbine flowmeter goes through three typical stages. First, when the flow rate is lower than the start-up rate of current turbine flowmeter (less than 0.5 m^3/day), the rotor keeps still. Second, if the flow rate exceeds the start-up rate but is still less than 2 m^3/day, the rotor begins to rotate although the rotation is not steady. At this stage, the response is strongly nonlinear and the flowmeter can hardly give an accurate measurement. The rotational speed of the turbine changes periodically during each turn. Finally, with the further increasing of flow rate, the movement of the rotor enters a stable rotating period and the response curve becomes linear. At this stage, the turbine flowmeter works normally and gives elegant measuring results. Fig.1 shows the fluctuation range of rotational speed and K-factor versus flow rate in pure water.

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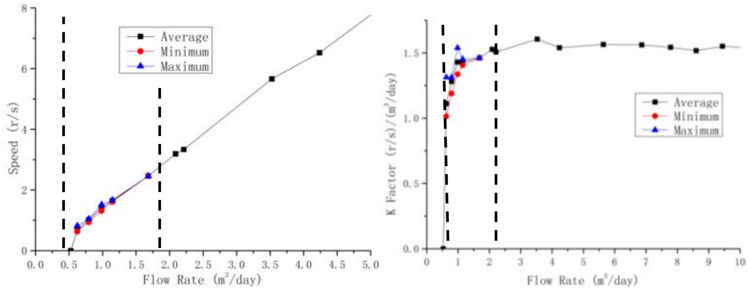
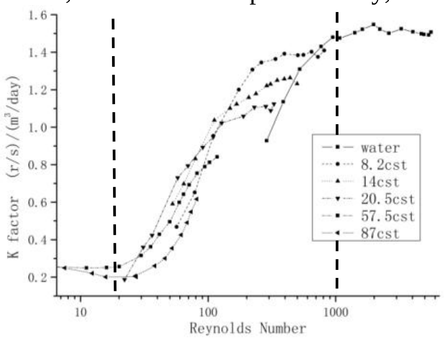


Fig.1 Response curve of flowmeter under low flow in water

Effects of Viscosity

The responses of the flowmeter in six different PAM-water solutions have been tested in the present study. It is found that, along with the increase of viscosity, the K factor of the flowmeter decreases and the linearity becomes worse, while the start-up flow rate goes lower. The dependence of the K factor to the Reynolds number (Re) is shown in Fig.2, from which we can see that it can be also divided into three stages. When Re is lower than 20, the K factor stays low and nearly constant. When Re is higher than 20 and lower than 1000, the K factor increases exponentially with Re. As Re goes higher than 1000, the K factor keeps stationary, which means it enters the linear response zone.



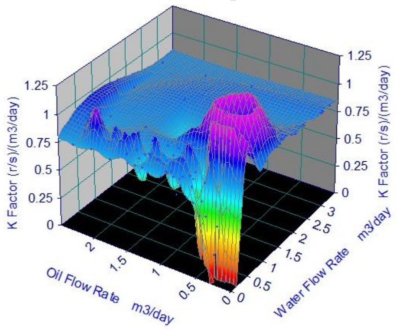


Fig. 2 Correlation of viscosity effects using Reynolds number

Fig.3 Effect of oil-water flow

Response of flowmeter in Oil-Water two-phase Flow

The response of turbine in oil-water two-phase flow under low-flow-rate condition is investigated. Five different flow patterns are experimentally revealed with various oil/water input conditions, i.e. D o/w, o/w CF, w/o CF, w/o CF and slug flow. Special attentions have been paid to the starting rule and the response of turbine under different flow patterns. It is found that the turbine easily starts under D o/w pattern, while it needs higher flow rates to get into linear response zone under o/w CF and slug flow patterns. An interesting phenomenon is that the response of the turbine can be stronger within the nonlinear response stage, depending on certain flow patterns. The K factor fluctuates violently under low flow condition as shown in Fig.3.

CONCLUSIONS

This paper studied experimentally the performance of turbine flowmeter under low flow condition. Main conclusions are summarized as follows.

● When the turbine begins to rotate but it is still not in the linear range, the rotational speed changes periodically in single phase flow.

● The characteristic factor of meter has a relationship to inlet Reynolds number under low flow condition. The response of flowmeter with different flow viscosity can be ascribed to a single relationship with the tube-diameter based Reynolds number under low flow condition.

● The flow pattern of oil-water flow has a significant influence on the performance of turbine flowmeter when the flow rate is lower than minimum linear threshold. But in the linear range, K factor is not sensitive to the flow pattern.

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