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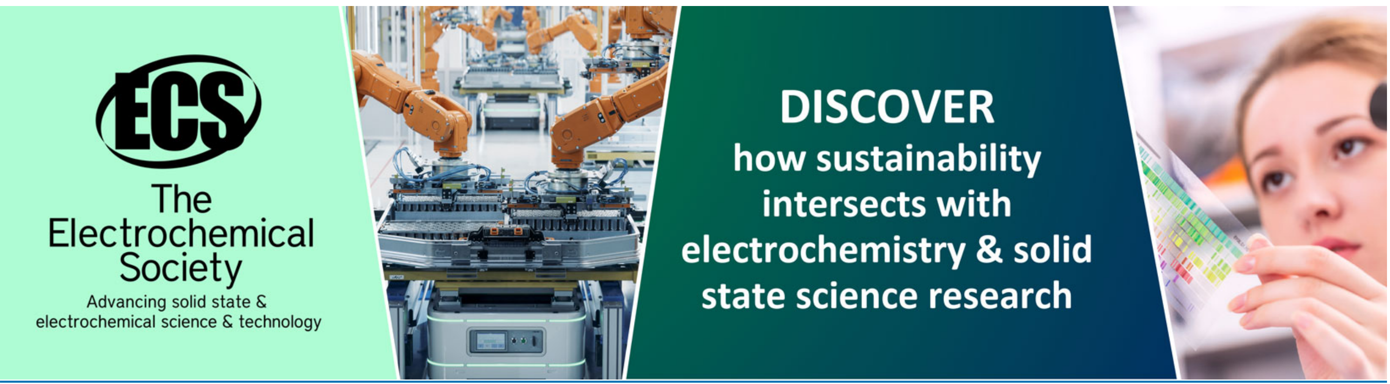

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Experiments on the flow characteristics of hydraulic orifices under high or low temperature conditions

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Abstract. A new test rig with a compact experimental module has been developed in this study to support experiments on fluid mechanics of hydraulic orifices under high or low temperature conditions, by using the test rig, experiments on flow characteristics of a sharp-edged orifice and a thick-wall orifice were conducted in a temperature range of -10℃~+80℃. Experimental results show that in a wide temperature range, the Flow-Pressure characteristics of the sharp-edged orifice are not sensitive to temperature changes, but that of the thick-wall orifice will vary obviously at different temperatures; In the temperature range up to 20℃, the Discharge coefficients and Damping forces of both of the two orifices remain at constants, however, when the fluid temperature is below 20℃, Discharge coefficients of the two orifice will drop linearly, damping forces of the two orifice will increase, but discharge coefficient and damping force of the thick-wall orifice will respectively drop and increase more sharply than that of the sharp-edged orifice, so this indicates that at low temperature conditions the fluid resistance and energy loss when it passes through a thick-wall orifice are larger than that when it passes through a sharp-edged orifice.

1. Introduction

In severe weather conditions, the characteristics of materials [1] and hydraulic components [2] of modern vehicle system might change greatly, so it is significant to research the basic characteristics of hydraulic orifices which have great influences on key component performance, under high or low temperature conditions.

In previous textbooks [3] or research works, the characteristics of hydraulic orifices have been mostly conducted in room temperature conditions. Ding [4] Studied the effects of orifice geometric parameters on damping performance of a landing gear shock absorber and landing dynamics of an aircraft by using Computational Fluid Dynamics (CFD) and experimental approaches, Ramamurthi et al. [5] conducted experimental research on the flow characteristics of sharp-edged orifices when using demineralized water as the working fluids, Naveenji et al. [6] performed simulation works on discharge coefficient during non-Newtonian flows through an orifice meter also by CFD approach, however, the theory and data used are intrinsically based on classical experiments, Liu et al. [7] studied the discharge coefficient of orifice plate flow sensor under specific installation conditions, Yu et al. [8] and Tharakan et al. [9] investigated the effects of back pressure on orifice discharge coefficients.

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In this work, aiming at doing experiments on hydraulic orifices under high or low temperature conditions, a new compact experimental module, which integrates the oil, the oil supply mechanism, the test valve with orifice and several sensors, is firstly developed, the experimental module can be readily placed into a high/low temperature chamber to undertake experiments; By using the compact experimental module, an automatic measurement test rig is further developed. Experiments on flow characteristics of a sharp-edged orifice and a thick-wall orifice were conducted in a temperature range of -10℃~+80℃, the working fluid used is the anti-wear hydraulic oil HM46. The Flow-Pressure characteristics, Discharge coefficient and Damping force of the hydraulic orifices are obtained by curve fitting, the effects of different temperatures on the flow characteristics of the two kinds of orifices are finally investigated.

2. New test rig development

The existing experimental equipment testing the fluid mechanics of orifices usually employs a full and bulky hydraulic system [10] including the pump, valves and even an accumulator to supply pressure oil to the orifices, and the experiments are also conducted under room temperature conditions.

To perform experiment on fluid mechanics of orifices in a high or low temperature conditions, a new compact experimental module which borrows the idea of a railway hydraulic damper was proposed [11]. The module integrates the oil, the oil supply mechanism, the testing damping valve with orifices and several sensors. Based on the proposed compact experimental module, an automatic measurement test rig was developed, as shown in Figure 1.

Figure 1. A new test rig for experiments on fluid mechanics of hydraulic orifices under high or low temperature conditions.

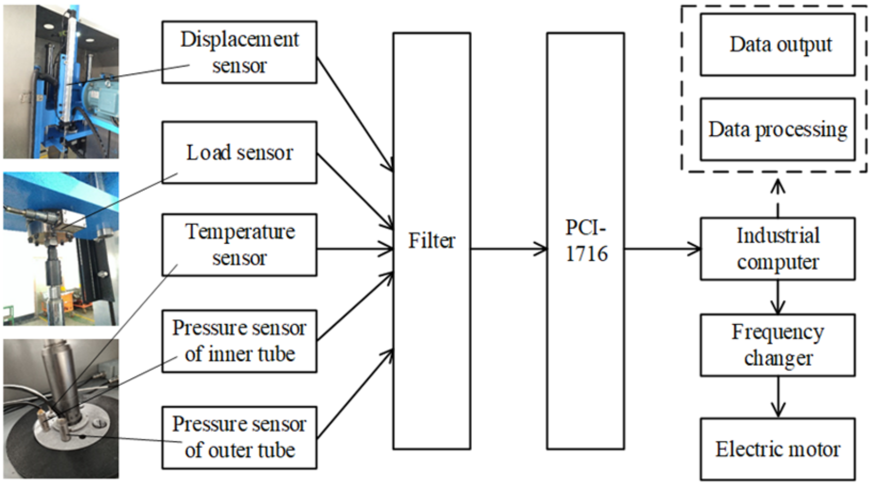


Figure 2. Principle of the automatic measurement system of the fluid mechanics test rig.

Figure 2 illustrates the principle and configuration of the automatic measurement system of the fluid mechanics test rig. The displacement sensor and the load sensor are attached with the actuator, so the driving velocity and force of the actuator will be obtained; A temperature sensor, a pressure sensor of inner tube and a pressure sensor of outer tube are integrated into the compact testing module, so the fluid temperature and the differential pressure of the orifice will be obtained in real-time, the differential pressure of the orifice is the pressure difference between the inner tube and the outer tube.

The sensor signals are filtered and collected by outside circuits and then sent to the industrial computer, the computer controls the actuator by controlling the electric motor via the frequency changer, and in the same time, processes the signals and outputs experimental results. The stochastic datum acquired can be processed by curve-fitting, and basically the Flow-Pressure characteristics and Discharge coefficient of the orifices can be obtained.

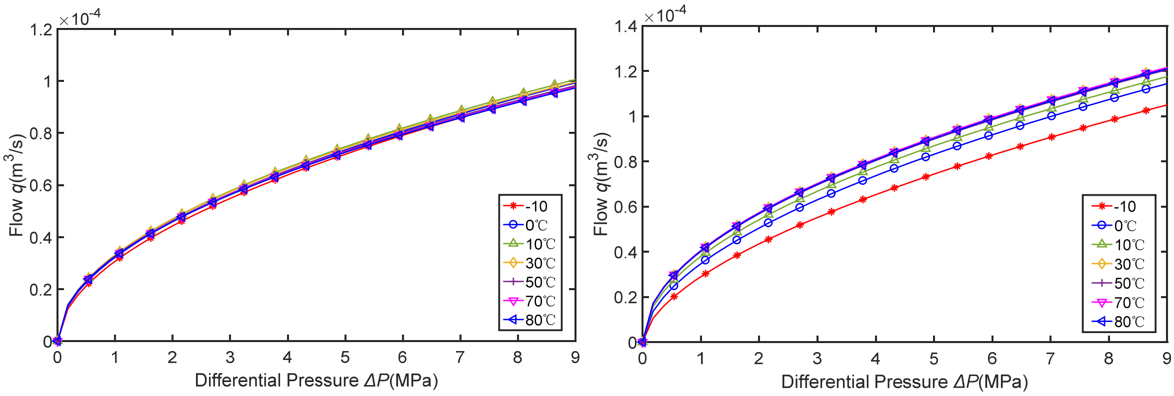
3. Experiment and analysis on flow characteristics

By using the above developed new test rig, fluid mechanics experiments on a sharp-edged orifice with length/diameter ratio l/d=0.36 and a thick-wall orifice with l/d=1.63 are conducted in a wide temperature range of -10℃~+80℃.

Before any experiment, the compact testing module is prepared with the right orifice and wholly put into the high/low temperature chamber for at least 24 hours after the experimental temperature is reached, and then the experiment can be performed.

3.1. Flow-Pressure Characteristics

Figure 3 demonstrates the obtained Flow-Pressure characteristics versus temperatures. Figure 3(a) shows that Flow-Pressure characteristics of the sharp-edged orifice vary slightly at different temperatures, that is to say the sharp-edged orifice is not sensitive to fluid temperature changes; However, the Flow-Pressure characteristics of the thick-wall orifice, as shown in Figure 3(b), vary obviously at different temperatures, thus, the thick-wall orifice is sensitive to fluid temperature changes when using the HM46 oil as the working fluid.



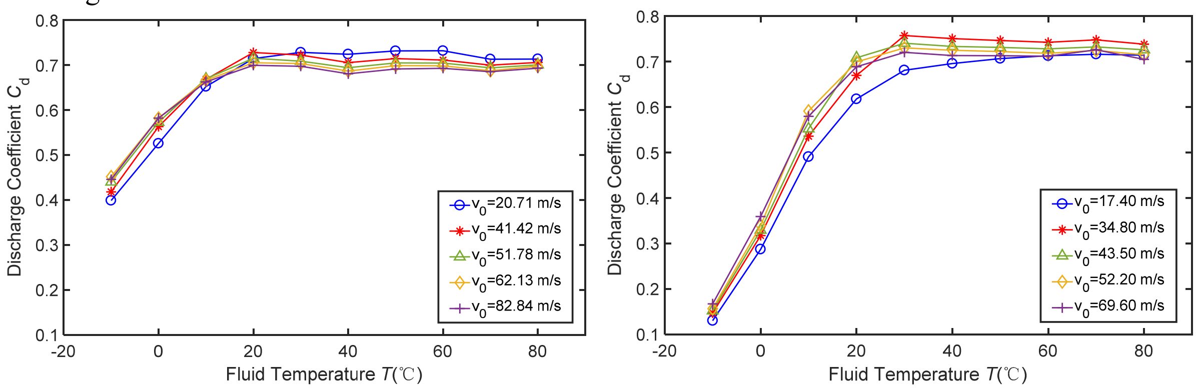
(a) (b)

Figure 3. Flow-Pressure characteristics at different fluid temperatures: (a) sharp-edged orifice with l/d=0.36 and (b) Thick-wall orifice with l/d=1.63. (Fluid: HM46).

3.2. Discharge coefficient

Figure 4 gives the Discharge coefficients of the two orifices in the range with high Reynolds Numbers. Figure 4(a) shows that Discharge coefficients of the sharp-edged orifice vary between 0.4~0.72 in the temperature range of -10℃~+80℃, when the temperature is above temperature 20℃, the Discharge coefficients almost remain at a constant mean value of 0.7, however, when the fluid temperature is below room temperatures, the Discharge coefficient drops linearly from 0.72 to 0.4. Thus, the phenomenon indicates that with the temperature decreasing, viscosity of the fluid is increasing, so the energy losses of the fluid will also increase when it flows through the orifice.

Figure 4(b) shows that Discharge coefficients of the thick-wall orifice vary between 0.12~0.75 in the temperature range of -10℃~+80℃, when the temperature is above temperature 20℃, the Discharge



(a) (b)

Figure 4. Discharge coefficient at different fluid temperatures: (a) sharp-edged orifice with l/d=0.36 and (b) Thick-wall orifice with l/d=1.63. (Fluid: HM46).

coefficients also remain at a constant mean value of 0.7, however, when the fluid temperature is below room temperatures, the Discharge coefficient drops linearly but more sharply from 0.75 to 0.12. Thus, the thick-wall orifice is more sensitive to fluid temperature changes than that of the sharp-edged orifice in the low-temperature range, and this indicates that, when the temperature is low, energy losses of the fluid when it passes through a thick-wall orifice is larger than that when it passes through a sharp-edged orifice.

3.3. Damping force

Figure 5 demonstrates the Damping forces produced by the orifices when the compact testing modules are actuated at different speeds and in different fluid temperature conditions. Figure 4(a) shows that Damping forces of the sharp-edged orifice are not sensitive to fluid temperature changes in the temperature range of 20℃~80℃, but in the temperature range of -10℃~20℃, the Damping forces increase slightly with the decreasing of temperatures, this indicates that with the temperature decreasing, viscosity of the fluid is increasing, so the resistance of the fluid will also increase when it flows through the orifice, which will cause damping force to increase.

Figure 4(b) shows the same trend of Damping force changes when HM46 oil passes through the thick-wall orifice at different temperature conditions, the difference is that in the temperature range of -10℃~20℃, Damping forces of the thick-wall orifice increase more sharply than that of the sharp-edged orifice, it means that at low temperature conditions the fluid resistance when it passes through a thick-wall orifice is larger than that when it passes through a sharp-edged orifice.

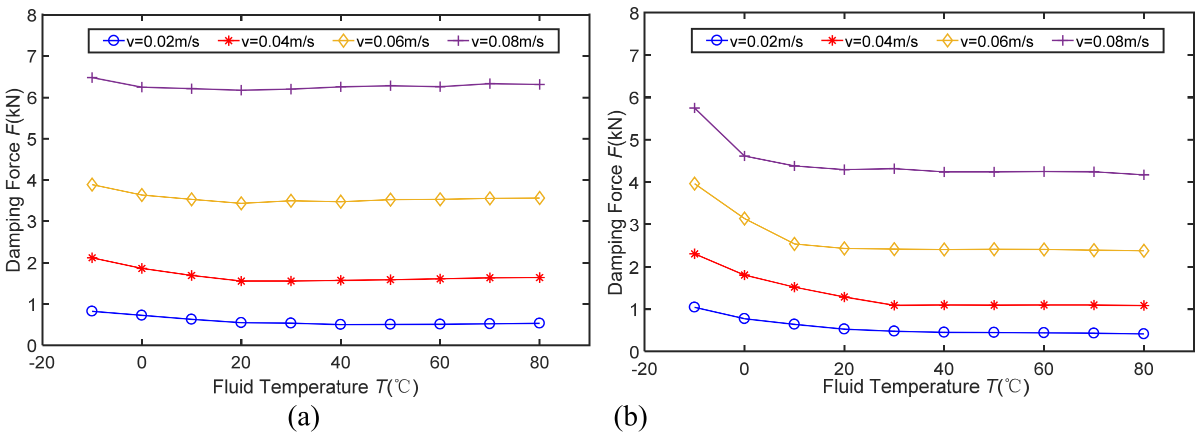


Figure 5. Damping forces at different fluid temperatures: (a) sharp-edged orifice with l/d=0.36 and (b) Thick-wall orifice with l/d=1.63. (Fluid: HM46).

4. Conclusions

(1) The developed new test rig with the compact experimental module can support fluid mechanics of hydraulic orifices in a wide temperature range, it has avoided the traditional bulky and energy-consuming method of using a full hydraulic system for oil supply, so it is a versatile and powerful platform for fluid mechanics research.

(2) In a wide temperature range of -10℃~80℃, the Flow-Pressure characteristics of the sharp-edged orifice are not sensitive to temperature changes, but that of the thick-wall orifice will vary obviously at different temperatures.

(3) In the temperature range up to 20℃, the Discharge coefficients and Damping forces of both of the sharp-edged orifice and the thick-wall orifice remain at constants, however, when the fluid temperature is below room temperatures, Discharge coefficients of the two orifice will drop linearly, damping forces of the two orifice will increase, but the discharge coefficient of the thick-wall orifice will drop more sharply than that of the sharp-edged orifice, and damping force of the thick-wall orifice will increase more sharply than that of the sharp-edged orifice. So this indicates that at low temperature conditions the fluid resistance and energy losses when it passes through a thick-wall orifice are larger than that when it passes through a sharp-edged orifice.

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