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Technical Note

Investigation on effects of upstream flow on submerged jet flow from short cylindrical orifice in common-rail injector

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ABSTRACT

During the fuel injection process of a common rail (CR) fuel system, submerged jet occurs in the injector control valve. Different with the free jet of the nozzle, this submerged jet determines the needle movement and causes great effects on the fuel injection. This work presents an investigation on the submerged jet characteristics of a cylindrical orifice under conditions of varied boundary pressures. An optical test rig is used to examine the submerged jet, and a three-dimension numerical model is built to investigate the details of the submerged jet. The results reveal that for a given inlet pressure, as the back pressure declines, bubbles incept at the orifice inlet, then develop to the orifice outlet, and finally jet into the background liquid. The development process of the impingement force is divided into three periods. This downstream three-period impingent force results from the upstream cavitation flow. The crucial turning points (such as the cavitation inception, choking, cavitation at the orifice outlet) of the downstream impingent force coincide with those of the incoming energy such as the liquid momentum flux, the turbulence kinetic energy. Further, the developing tendency of the downstream impingent force is similar to those of the incoming energy.

1. Introduction

In modern diesel engine, the injector is the key part of the common rail (CR) fuel system, and it directly determines the fuel injection by adjustment of a control valve. When the control valve opens, the high-pressure fuel immediately flows into the low-pressure region through an narrow space, and a submerged jet occurs, different with the free jet of the injector nozzle. Many literatures report the cavitation of the free jet in the nozzle. Salvador et al. [1] find the cavitation in nozzle has great effects on spray and provokes the injection velocity. Payri et al. [2] report that cavitation in nozzle leads to an increment of the spray cone angle and the nozzle outlet velocity. However, there are few literatures about the submerged jet of the injector control valve. Many research studies focus on researching the influence of the jet driven pressure, shape and size of a nozzle, environmental medium on the jet impact capability. Schlender et al. [3] find that the jet from the throttle orifice causes great influence on the local flow field in the chamber. Hutli et al. [4] find that jet cavitation causes many adverse effects that are to be avoided or at least controlled. The cavitation accompanying the jet causes the complicacy of the submerged jet. Many researchers have made efforts to observe the cavitation jet under different pressure boundaries (inlet pressure and back pressure), and investigate the developing process of the cavitation jet. Gavaises et al. [5] use the X-ray micro computed tomography to estimate the temporal-averaged vapor volume fraction within high-speed cavitating flow orifices. Choo et al. [6] report that the geometry of the nozzle has influence of on heat transfer and fluid flow characteristics of a submerged jet.

Those above literatures focus on the nozzle jet and investigate the details of the jet developing process, but don't consider the effects of the nozzle inner flow on the jet. The upstream flow of the submerged jet varies as the pressure boundaries change, and tends to affect the downstream. Our previous published papers [7,8] report that cavitation formation and its characteristics at the nozzle entrance have effects on the cavitation developing and transfer inside the nozzle. Thus, the upstream flow before jet, i.e. the inner inside the nozzle orifice, affects the downstream jet. Further the back pressure has influence different with the inlet pressure. The previous researches [7,8] reveal that both the inlet pressure and the back pressure of the nozzle have respective effects on cavitation flow, which are not equal simply to the differential pressure. Hence the inner nozzle flow process definitely has significant influences on the flow outside the nozzle.

Therefore, the flow characteristic of the submerged jet of a orifice becomes complicated under conditions of varied pressure boundaries, and the downstream jet relates to the upstream flow

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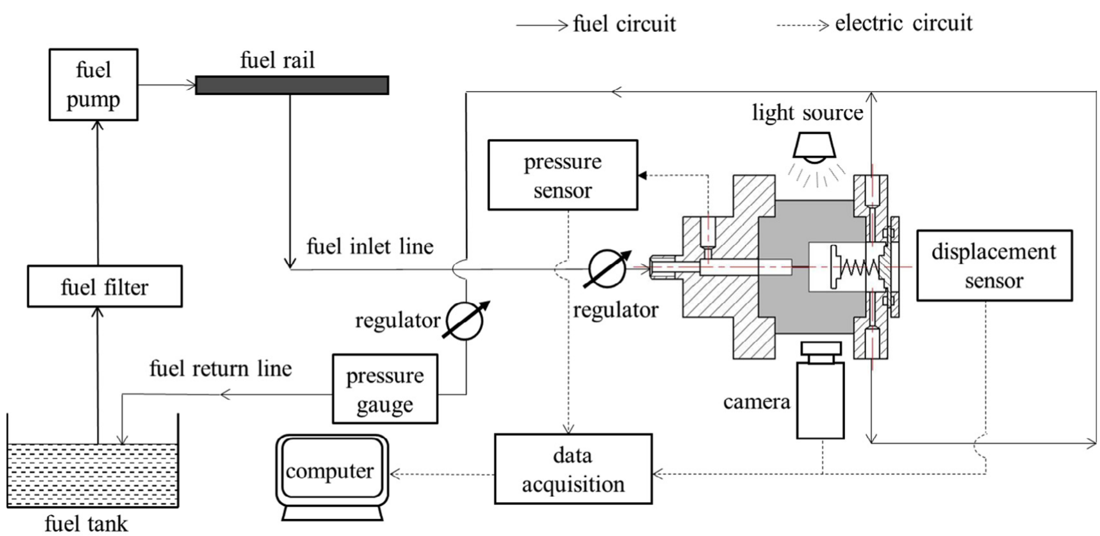
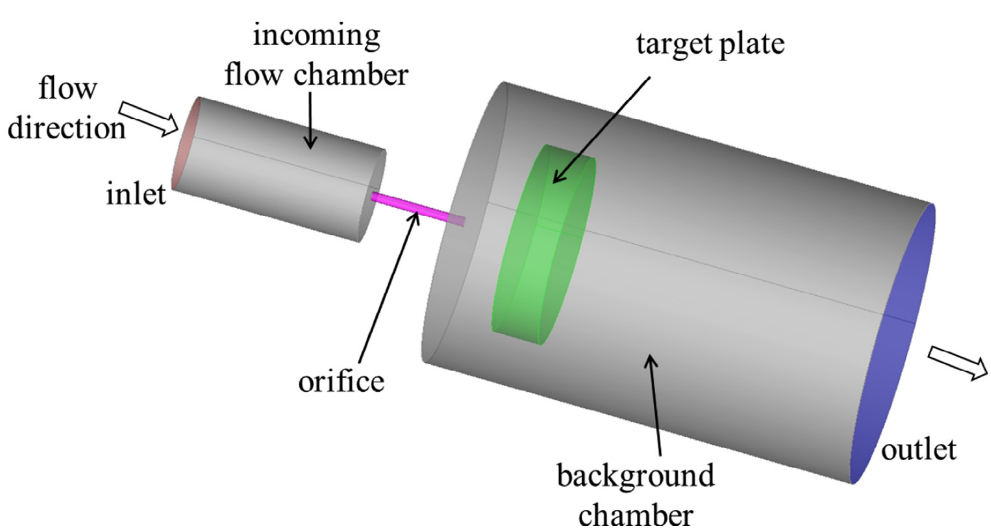
especially. It is essential to understand thoroughly the complex submerged jet and research the influence of the upstream inner orifice flow on the downstream submerged jet. This work aims at investigate the cavitation jet flow inner narrow cylindrical orifice. An optical cylindrical orifice system is designed to realize optical test of the inner jet. In addition, a jet impingent force test system is designed in the test rig. The jet flow performance is tested under conditions of varied inlet/outlet pressures. Moreover, a three-dimension numerical model is built to investigate the details of the submerged jet. Further, the effect of the upstream inner cylindrical office cavitation flow on the downstream submerged jet is discussed based on both the test and simulation results.

2. Experimental investigation

Fig. 1(a) shows a test rig to examine the submerged jet flow. The high-pressure diesel fuel delivered by the pump enters into the cylindrical orifice inlet, then goes out through the outlet. There are regulators to adjust the fuel flow to maintain stable flow rate and pressure. Fig. 1(b) illustrates the optical orifice system assembly. This orifice test system contains the upstream section (an optical orifice made of polymethyl methacrylate, diameter = 1 mm, length = 10 mm) and the downstream section (a large background chamber). A spring set is to detect the jet impingement force. One end of the spring is mounted on a sheet plastic plate while the other end of the spring seat is fixed. The sheet target plate is designed to be much larger than the jet impingement area to support total jet impact force. During the test, both the inlet pressure p_{in} (tested by a Kistler pressure sensor) and the back pressure p_b (tested by a pressure gauge) are stable. For each constant p_{in}, p_b changes from high to low. A LED light illuminates the transparent orifice. For each operation condition of stable pressures, a displacement sensor meters the plate movement, a high-speed digital camera catches the images of cavitation jet, and an electronic scale weighs the fuel mass. A data acquisition system collects all test data and images, and transfers to the computer by for further data post-processing. All the specifications of the test apparatus are in Table 1.



(a) optical orifice test rig



(b) numerical model

Fig. 1. Optical orifice test rig and numerical model.