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Effect of back pressure on nozzle inner flow in fuel injector

Tao Qiu [a,b,*], Xin Song [a], Yan Lei [a], Hefei Dai [a], Chunlei Cao [c], Hui Xu [a], Xiang Feng [a]

[a] *College of Environmental and Energy Engineering, Beijing University of Technology, Beijing 100124, China*
[b] *Collaborative Innovation Center of Electric Vehicles in Beijing and Beijing University of Technology, Beijing 100081, China*
[c] *School of Mathematics and Statistics, Beijing Institute of Technology, Beijing 100081, China*

HIGHLIGHTS

- As the back pressure drops, the cavitation process is divided into 3 periods.
- During choking period, the back pressure has little effect on the mass flow.
- During choking period, the discharge coefficient declines as the back pressure drops.
- During choking period, the interface between the liquid and mixing section is constant.
- During choking period, the outlet velocity increases as the back pressure drops.

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ABSTRACT

The internal nozzle flow has great influence on fuel injection and spray. This work investigates the impacts of the injection back pressure on the nozzle inner cavitation developing, especially the flow characteristic during choking process. Based on the theoretical analysis, a three-dimension numerical model is developed to investigate the details of the inner nozzle cavitation flow. The numerical model is verified by experiments on a diesel fuel system test rig under different boundary pressures, including varied injection pressure and back pressure. The investigation shows that for a given injection pressure, cavitation occurs with the drop in the back pressure. The incipient bubbles appear just at the upper corner of nozzle inlet hole, and the cavitation area continues to expand until it reaches to the nozzle outlet. The nozzle inner cavitation is divided into three periods: no cavitation period; local cavitation developing period and super cavitation period. Before the super cavitation, as the back pressure drops, bubbles at the entrance of the nozzle hole cover more area, but the average liquid velocity increases and as a result the mass flow increases. Once the liquid velocity reaches to its maximum, the cavitation of the nozzle inlet hole maintains stable, so does the vapor–liquid mixture cross section, and the effective cross section of the liquid phase is minimum; by now the super cavitation forms. Under the condition of the super cavitation, the nozzle inner flow becomes choking and the back pressure has little influence on the mass flow, but the discharge coefficient declines as the back pressure decreases. During the choking flow period, when the back pressure declines, along the nozzle hole central axis from the inlet to the outlet, the effective flow cross section maintains stable in sequence and the liquid velocity also reaches its maximum in order. Moreover, at the outlet of the nozzle hole, super cavitation induces the increase of the turbulence kinetic energy and the outlet velocity. This increased outlet velocity makes up for the loss of the contracting effective flow passage due to super cavitation, thus the total mass flow maintains the same value after choke even the back pressure decreases.

1. Introduction

It is well known that the combustion process and emission characteristics of diesel engines are dominantly governed by fuel injection process and fuel atomization. Some bibliographies have provided evidences on the existence of cavitation in the diesel fuel nozzle and the internal injector cavitation flow has a strong

* Corresponding author at: College of Environmental and Energy Engineering, Beijing University of Technology, Beijing 100124, China. Tel.: +86 18618323651; fax: +86 10 67391985.

E-mail address: qiutao@bjut.edu.cn (T. Qiu).

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influence on the fuel spray and atomization characteristics. Cavitation causes a great deal of noise, damage to components by erosion, vibrations, and a loss of efficiency [1,2]. Gavaises [3] obtained images of diesel injector nozzles and revealed the cavitation phenomenon inside the nozzle, and concluded that the cavitation damage correlates well with areas of bubble collapse as well as increasing engine exhaust emissions. Asi examined and evaluated a failed injector nozzle, and reported that the failure because of cavitation damage in the internal surface of the nozzle was followed by fatigue cracking [4]. On the other hand, it is reported that cavitation occurring inside the nozzle is indeed helpful for fuel atomization [5]. Payri et al. [6,7] investigated the influence of cavitation on fuel injection and spray by combining both experimental and numerical methods, and they reported that cavitation leads to an increment of the spray cone angle as well as the nozzle outlet velocity, which may benefit the atomization for mixture. In addition, cavitation inside the injector nozzle shows a strong influence on the internal nozzle flow in the fuel injection process as well as fuel spray development.

Under the condition of cavitation inside the nozzle, the mass flow chokes and the inner flow will become saturated. Desantes et al. [8] completed near-nozzle visualization experiment and observed the mass flow choking phenomenon. Payri et al. [9,10] reported that cavitating nozzles experience a decrease in the discharge coefficient due to mass flow choking. This choking

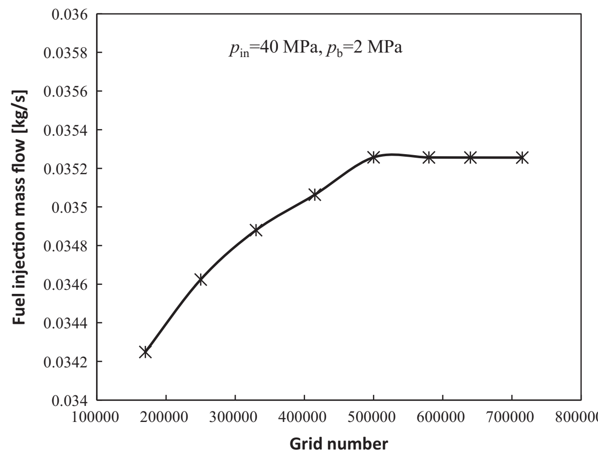
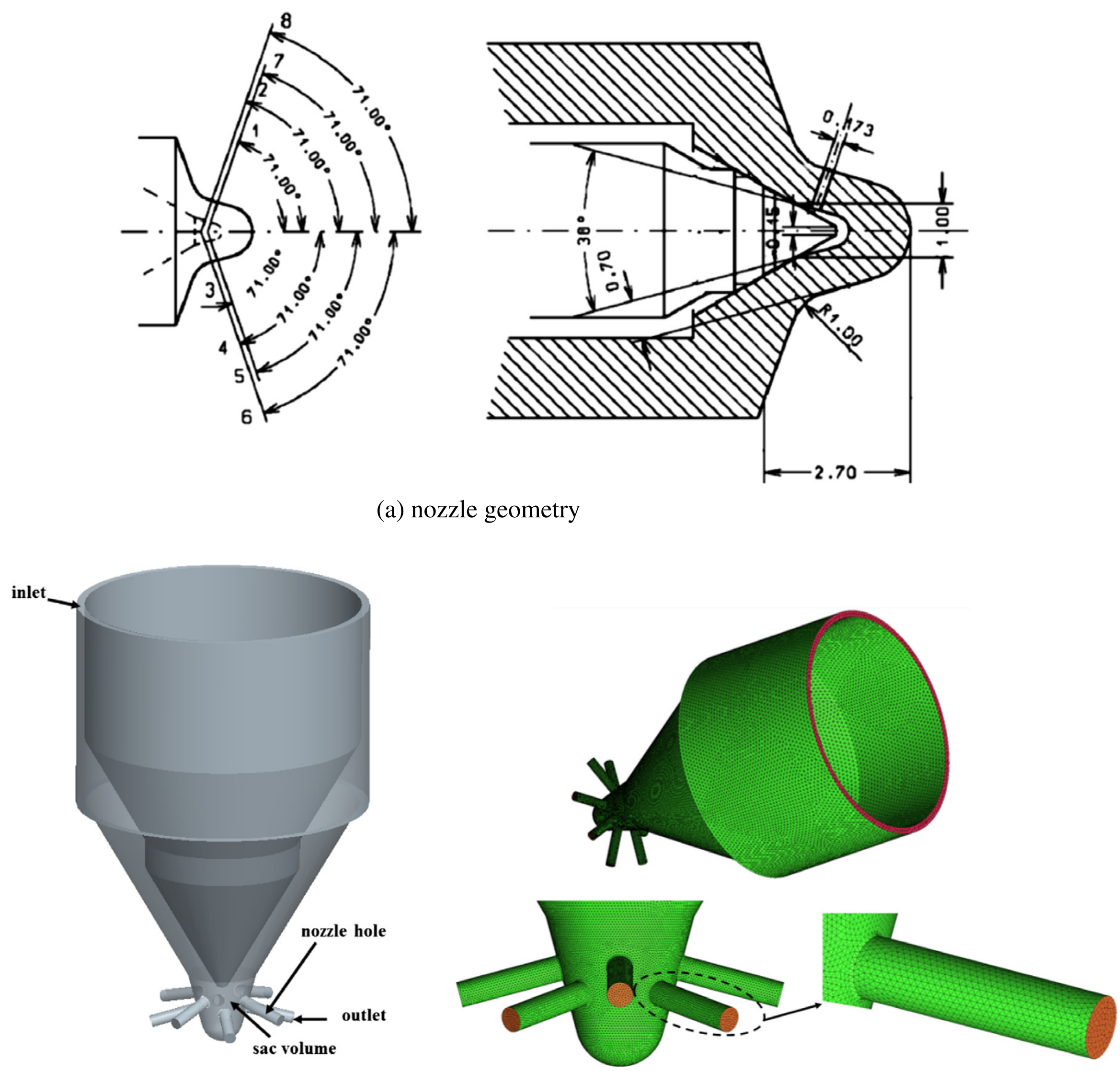


Fig. 2. Grid independency result.



(a) nozzle geometry

(b) geometry model

(c) meshes

Fig. 1. Nozzle CFD model.