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Injector Internal Geometry and Sub-Atmospheric Back Pressure Influence on Low Weber Number Liquid Flow

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Abstract

The experimental work presented in this article addresses the question of the influence of the injector internal geometry on the liquid jet characteristics at the nozzle exit. As far as the spray formation is concerned, these characteristics are very much important since they constitute the atomization process initial conditions. High-rate shadowgraph imaging is used. Therefore, in order to have exploitable visualizations of the liquid jet structures, the injection pressure is kept low (not greater than 1 MPa). Furthermore, injections are performed under sub-atmospheric pressure to annihilate the aerodynamic force influence and to concentrate on the nozzle internal geometry effects. According to the literature, working at reduced ambient pressure might trigger internal flow cavitation without increasing the injection pressure. Thus cavitation might be triggered at low injection pressure allowing its effects to be visualized on shadowgraph images. This approach allows also addressing the question of the propensity of internal geometric characteristics to trigger cavitation.

A series of four injectors of the type of gasoline direct injection devices are used. They have three cylindrical orifices of the same diameter and regularly positioned at 23 degrees from the injector axis. One of the injectors is referred as standard and the others present geometrical differences concerning, 1 – the orifice entrance, 2 – the needle roughness and 3 – the sac roughness. The liquid used is Shellsol D40 with physical properties close to those of gasoline. The injection pressure P_i ranges from 0.2 MPa to 1 MPa and the ambient pressure from 0.004 MPa to 0.2 MPa. This corresponds to a gaseous Weber number of the issuing liquid jet ranging from 0.066 to 13.6. The experiments are limited to the fully open stage of the injection only. For each injector, the mass flow rate of this stage is measured as a function of the ambient pressure. Visualizations of the issuing liquid jet are performed with a high-speed camera Phantom V12.1 providing 66,667 frames/s. The snapshot resolution is 256x256 pixels and the spatial resolution is equal to 10.35 µm/pixel. The light source is a continuous 300 W Xenon arc source. The opening time is set to 0.3 µs which is sufficiently to freeze liquid structures.

At an ambient pressure P_a = 0.1 MPa, all injectors report the same mass flow rate (corresponding to a discharge coefficient equal to C_d = 0.59) except for the one with modified orifice entrance (C_d = 0.67). This behavior has been often reported in the literature. As P_a is decreased, the mass flow rate first increases with $\sqrt{P_i - P_a}$ and then decreases or remains constant according to the value of the injection pressure. This behavior is very similar to the one observed by many investigations of the literature and suggests the appearance of cavitation. The images show that the issuing liquid jet structures are affected by a reduction of P_a. The flow shows an intermittent behavior between two stages. The characteristics of this intermittency are quantified by measuring and analyzing the interface length per unit liquid surface area as a function of time. A Fast Fourier Transform of this signal reveals no specific frequency. However, contrary to what is often reported in the literature, it is observed that liquid cavitation does not always enhance atomization.

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