

# Numerical Analysis of Initial Shape of Nozzle Inject Flow

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## ABSTRACT

At the initial stage of injection, the inject flow has not yet broken up and in a range of small atmosphere pressure (16~500KPa), the tip of the inject flow always forms a shape of mushroom. And the umbrella of the mushroom is always very big and the root of it is always very thin, especially when the atmosphere pressure is relatively low (88KPa, or 100mmHg)<sup>(1) (2)</sup>. These phenomena are not known popularly and the reason of mushroom formation is not clear. In this paper, with MARS (Multi-interfaces Advection and Reconstruction Solver) method<sup>(3) (4) (5)</sup> for simulating free surface, analysis of inject flow is practiced. The phenomena are reproduced and the reason is cleared that the formation of the mushroom is induced by the momentum exchange between the very high speed fuel flow and the very complex air flow.

## INTRODUCTION

In combustion chamber of self-ignition engines, the characteristics of injected fuel flow will dominantly affect the process of ignition, the process of combustion and the emission amount of pollution. Considering the necessary time to form mixture in a practical engine, the detail analysis of the spray developing process and the mechanism of the atomization in the initial stage just after the injection from the nozzle will be most significant. However, in experiments, measurement is more than extremely difficult for the transient spray with rather high pressure and rather high speed, in numerical analysis, how to define the computational domain and fix the suitable boundary conditions for the domain are always not clear, a few analyses of time-oriented particulars have been reported about the developing process of the inject flow right from the beginning when the flow is injected from the nozzle. In spite of that the injection process of the nozzle flow of the compressed fuel by high pressure into atmosphere gas with also high pressure has been reported ever so much, the mechanism of the break up of the inject flow has not yet been explained clearly and did not become a distinct guideline. Investigating the characteristics of the inject

flow with both continuous shooting and single shot, authors performed a bunch of observation experiments focusing on magnification technique of inject flow. At the first step of the injection, the inject flow does not break up at once. Especially in a range of small atmosphere pressure (16~500kPa), the tip of the inject flow always shapes mushroom. And the umbrella of the mushroom is always relatively big and the root of it is always relatively thin, when the atmosphere pressure is relatively low (88KPa, or 100mmHg). These phenomena are not known widely and there is no simulation of the mushroom formation. In this paper, with MARS, which is a method for simulating free surface, analysis of inject flow are practiced. The complex phenomena are represented and the reason to understand these phenomena is cleared. It is explained that the complex momentum exchange between the very high speed fuel flow and the very complex air flow shaped the mushroom.

## INJECT FLOW SIMULATION COMPARED WITH EXPERIMENTS

Inject flow in diesel engines is a multiple phase flow (liquid fuel and gaseous air) and the effect of air to fuel can not be neglected. Using normal VOF (Volume of Fluid) method, authors could not get reasonable results, in which the behaviors of flow do not agree with the experiments. In this paper, MARS method is adopted. Showing initial conditions, boundary conditions and related theory, the simulation is described, and the simulated results are compared with experiments<sup>(1) (2)</sup>. The simulation agrees with experiment very well. At last why the mushroom shape in the inject flow is shaped is explained with the detail data of the simulation.

## MARS METHOD

In the paper, an accurate algorithm for interface advection and reconstruction, called MARS method, which is one of the useful methods for simulating free surface, has been used. That is to say, MARS method is one of the methods, which can simulate multiple phases

flow with free surfaces. Although MARS method is basically the same as VOF (Volume of Fluid Method) method, MARS has the following 3 points, which can feature the method. The method 1) introduces CSF surface tension model, 2) considers the gradient of the boundary surface between fuel and gas, 3) and uses an algorithm on the boundary surface, which considers the continuousness of the value of VOF on the boundary surface. Please refer the detail of all these in related paper <sup>(3) (4) (5)</sup>.

### CALCULATION CONDITIONS

The domain is shown in Figure 1 and it is 5mm in radius direction and 20mm in axial direction. The left and bottom boundaries of the domain are no-slip walls and the right boundary of the domain is symmetrical axis. The upper boundary of the domain is outlet where natural in-out boundary condition (zero gradient of pressure) is defined. The domain is divided into 360,000 grids (300 grids in radius direction and 1200 in axial direction). One case takes about 18-24hours with 8CPU on a CRAY XD1 cluster platform (OPTERON 2.4GHz, 4.8GFlops), which has totally 72 CPU.

Fuel is injected from a nozzle. The diameter of the nozzle is 0.3mm and the length of the nozzle is 3mm. The axis of the nozzle is arranged along the symmetrical axis and the initial surface of the fuel is defined at a plane that is 2mm from the inlet of the nozzle. That is to say the fuel flow will be injected out after flowing 1mm in the nozzle. It is of great significance in this simulation to consider the effects of the fuel flow behavior in the nozzle to the flow patterns out of the nozzle.

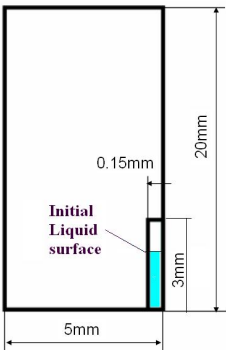


Figure 1 Calculation domain and nozzle position

SI unit is used in the paper. The temperature of atmosphere is 293K. Because the effect of pressure is little, the properties of light fuel at 293K are defined as constants, which do not vary with pressure changes. They are density  $\rho_0=840\text{kg/m}^3$ , viscosity  $\mu_0=2.0\times10^{-3}\text{Ns/m}^2$ , surface tension  $\sigma_0=20\times10^{-3}\text{N/m}$ . The properties of air are viscosity  $\mu_{\text{air}}=17.98\times10^{-6}\text{Ns/m}^2$ , surface tension  $\sigma_{\text{air}}=0\text{N/m}$ . They are also constants, which do not vary with pressure. And the density of air  $\rho_{\text{air}}$  is calculated by formula 1, which varies with pressure changes. The atmosphere pressure and density in various cases are

listed in Table 1. Where p (Pa) is pressure and T is temperature (K).

$$\rho = \frac{1}{0.287 \times 10^3} \frac{p}{T} \tag{1}$$

All calculations are transient ones with constant time steps of  $1.25\times10^{-8}\text{s}$ . The end of calculation time is  $75\mu\text{s}$  for all cases. The injection pressure is fixed as a constant as shown in Table 1. When fuel mass fraction in one cell (grid) of the domain is less than  $1\times10^{-5}$ , the program will consider fuel liquid mass fraction as zero in the cell.

Table 1 Calculation Conditions of Cases

| Case | Atmosphere Pressure (Pa) | Air Density (kg/m³) |
|------|--------------------------|---------------------|
| A    | 16000                    | 0.19027             |
| A2   | 48000                    | 0.57081             |
| A3   | 61000                    | 0.72540             |
| A4   | 75000                    | 0.89189             |
| B    | 88000                    | 1.06450             |
| C    | 101300                   | 1.20500             |
| D    | 500000                   | 5.00700             |

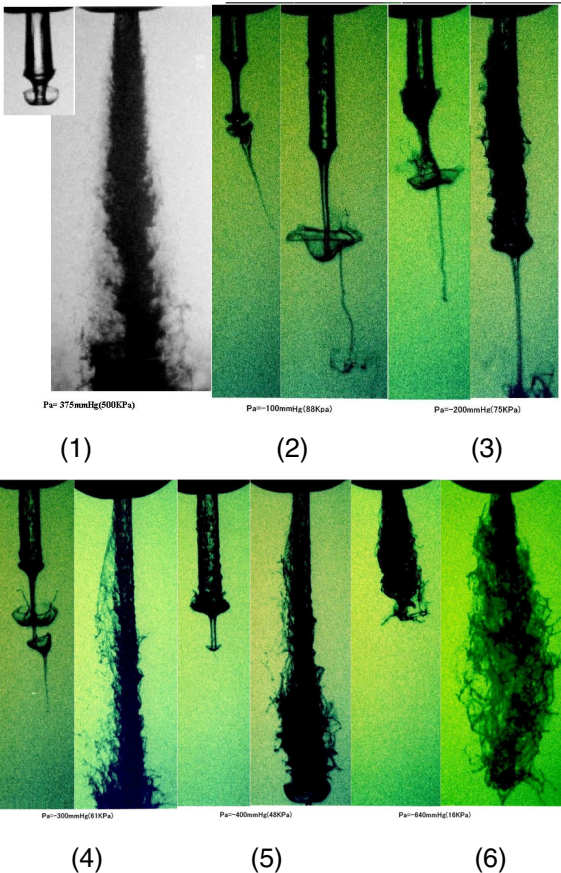


Figure 2 Inject flow shape of experiments in atmosphere at ambient pressure of 500, 88, 75, 61, 48 and 16KPa <sup>(1)</sup>, and in above case (1) of 500KPa, the injection pressure is 32MPa, other cases are 1 MPa