

Study of Adhesion Fuel Behavior Formed by Spray-Wall Impingement in PFI Engine

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ABSTRACT

In this study, a new method is proposed to evaluate the amount of adhered fuel when fuel spray impinges on a wall surface, by considering the normal and tangential droplet impact velocities. To verify this method, how the amount of fuel adhering to a flat plate varies with the spray's angle of incidence is examined. Our experimental results show that less fuel adheres to the wall when spray is oriented obliquely. To verify our method, the concentration of the air-fuel mixture and the fuel film thickness formed in an engine intake port model are also examined. By comparing these experimental results with our calculated results, it is shown that the proposed method can evaluate the behavior of adhered fuel, which conventional methods cannot evaluate.

INTRODUCTION

In recent years, there has been a growing demand for vehicles with better fuel consumption and lower emissions in order to protect the global environment. In port fuel injection (PFI) engines, the behavior of the fuel spray injected into the intake port is complex, that is, part of the fuel spray impacts and adheres to the wall surface, and evaporates while flowing. The adhesion of fuel to the wall surface has a large effect on the fuel consumption and exhaust gas characteristics, so it is essential to understand this behavior.

Fuel adhesion behavior that occurs when a fuel spray impinges on a wall surface has already been studied in detail in basic experiments, and it has been shown that different conditions such as the spray droplet size and wall impact velocity lead to different behaviors such as adhesion, reflection and splashing [1,2,3]. However, few of these studies have examined the proportion of adhered fuel and redispersed fuel during splash behavior, and most of them only considered droplets impinging on the wall surface

vertically. In real engines, most of the fuel droplets impinge on the wall surface at an oblique angle.

On the other hand, in numerical simulations on the behavior of fuel spray impinging on wall surfaces [4,5,6,7,8,9,10,11,12,13,14], many assumptions and empirical formulae based on basic experiments were used to model the wall impact behavior, which changes in complex ways depending on the impact conditions. In nearly all of these simulations, the models used to calculate the amount of fuel adhering to the wall surface were based on the results of a few basic experiments in which droplets impinged on the wall surface vertically. In these simulations, the validity of the simulation was demonstrated by comparing the experimental results with regard to the shape of the fuel adhering to the wall surface and the distribution of fuel droplets when the fuel spray impinged on the wall surface, but hardly any of these studies made a detailed investigation of the amount of fuel adhering to the wall surface.

In this paper, a new method for evaluating the adhesion characteristics when spray droplets impinge on a wall surface is proposed, and it is verified in basic experiments in which droplets were sprayed onto a flat surface. The concentration of the air-fuel mixture and the thickness of the fuel film formed when a fuel spray is injected into an engine intake port model is also examined, and the validity of the proposed evaluation method is confirmed.

A METHOD FOR EVALUATING THE ADHESION OF FUEL SPRAY ON WALL SURFACES

In conventional simulations of the impact behavior of fuel droplets on a wall surface, the ratio of adhered fuel and redispersed fuel during splashing is either assumed to be constant regardless of the droplet impact conditions [6,12,14]

or is defined so that the ratio of redispersed fuel increases as the droplet impact velocity normal to the wall surface increases [7,8,9,10,11]. In splash behavior, the droplets impinging on the wall surface are assimilated into the liquid film on the wall surface together with their kinetic energy. Part of this energy is then expended in the redispersion of droplets (see Fig. 1). It is thus thought that the ratio of the adhered fuel and redispersed fuel depends on the impact angle and energy of the droplets. For example, even if the normal component of the velocity with which the droplets impact the wall surface is the same, the redispersion ratio will differ if the horizontal velocity component is different. This sort of trend has been reported in basic experiments where the quantity of redispersed droplets was investigated while changing the angle of incidence of droplets on the wall surface [15]. In these experiments, even if the absolute velocity of droplet impacts was the same, only a few percent of the droplet volume was redispersed when the angle θ between the droplet direction of motion and the normal direction to the wall surface was 0° (i.e., for droplets impacting the wall surface vertically), but a greater percentage of redispersion occurred for droplets impacting the wall surface at oblique angles, reaching several tens of percent at $\theta = 45^\circ$. On the other hand, in conventional simulations, the redispersion ratio was either fixed and invariable regardless of the impact angle of the droplets, or the amount of droplet redispersion decreased as the droplet velocity component normal to the wall surface became smaller due to impacts from oblique angles, and it was thus not possible to correctly evaluate the amount of fuel adhering to the wall surface when droplets impinge on the wall surface from a different angle.

In this paper, a method is proposed to evaluate the adhesion characteristics in splash behavior when there are changes in the angle at which the spray impinges on the wall surface.

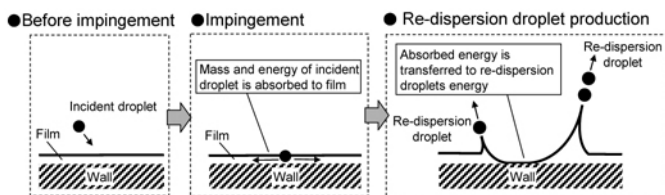


Figure 1. Outline of splash phenomenon

The wall surface adhesion behavior during splashing is thought to be affected by the droplet impact velocity components not only in the direction normal to the wall surface but also in the tangential direction. Therefore, the velocity component of droplets in the direction tangential to the wall surface is also considered, which has not been done previously. The mass ratio of droplets redispersed due to impacts of incident droplets can be expressed in terms of the Weber number We_{in-n} based on the velocity V_{in-n} of incident

droplets in the direction normal to the wall surface, and the Weber number We_{in-t} based on the velocity V_{in-t} in the tangential direction. Here, the momentum and the energy of incident droplets based on V_{in-n} are thought to diffuse in all directions on the wall surface, but the momentum and the energy based on V_{in-t} are thought to diffuse in one direction, so it is thought that the influence of We_{in-n} and We_{in-t} on the mass ratio of droplets redispersed is different. Therefore, the mass ratio of droplets redispersed is expressed as shown in Eq. (1) (See Fig. 2).

$$\frac{M_{out}}{M_{in}} = C \times \{C_n \times We_{in-n} + (1 - C_n) \times We_{in-t}\} \quad (1)$$

$We_{in-n} = \rho d V_{in-n}^2 / \sigma$, $We_{in-t} = \rho d V_{in-t}^2 / \sigma$, ρ is the liquid density, d is the droplet diameter, V is the droplet velocity, and σ is the surface tension. Also, C and C_n are constants. C_n shows the degree of influence of We_{in-n} and We_{in-t} on M_{out}/M_{in} , and lies in the range from 0 to 1.

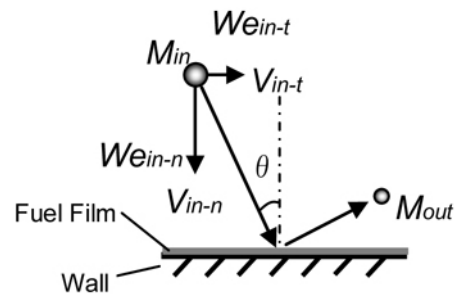


Figure 2. Re-dispersion droplet mass

Figure 3 shows the relationship between the redispersed droplet mass ratio M_{out}/M_{in} and the droplet angle of incidence θ according to Eq. (1). When $C_n > 0.5$, We_{in-n} dominates the redispersion mass ratio, and when the impact angle θ increases, the redispersion ratio decreases as We_{in-n} decreases. When $C_n = 0.5$, We_{in-n} and We_{in-t} both change equally with changes in the impact angle θ , so the amount of redispersion has a fixed value that depends only on θ . On the other hand, when $C_n < 0.5$, We_{in-t} becomes dominant, and when θ increases, the redispersion ratio increases as We_{in-t} increases.

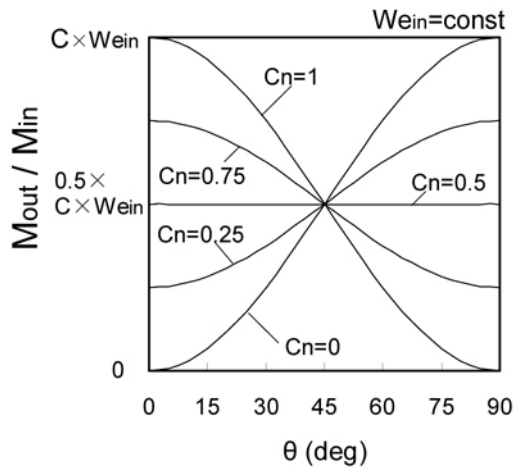


Figure 3. Relation between θ and M_{out}/M_{in} in Eq. (1)

SIMULATION OF SINGLE-DROPLET IMPINGEMENT

Using Eq. (1), a numerical simulation of the impact of a single droplet against the wall surface was performed, and the calculated droplet redispersion mass ratio M_{out}/M_{in} was investigated. For the simulation of a droplet striking the wall surface, the droplet/wall interaction model developed by Bai and Gosman [6] was used, and Eq. (1) was introduced into the calculation of the droplet redispersion mass ratio. By way of comparison, a conventional evaluation method based on the droplet velocity in the direction normal to the wall surface [7] was also introduced into the calculation of the droplet redispersion mass ratio. The impacting droplets were assumed to have a diameter of 500 μm , and the impact velocity V_{in} (2-20 m/s) and droplet impact angle θ (0° , 45°) were varied. The CFD code STAR-CD Ver. 3.26 was used for the simulation. The calculated results are shown in Fig. 4. The horizontal axis of this figure shows the Weber number We_{in} based on the droplet impact velocity V_{in} . When using the conventional evaluation method, increasing We_{in} at a constant droplet impact angle θ causes the droplet redispersion mass ratio to increase, and increasing the droplet impact angle at the same We_{in} causes the droplet redispersion mass ratio to decrease. When using Eq. (1), for $C_n > 0.5$, as in the conventional method, the amount of redispersion increases as We_{in} becomes larger and decreases as θ increases. At $C_n = 0.5$, the amount of redispersion increases as We_{in} becomes larger, but does not change as θ changes. On the other hand, when $C_n < 0.5$, the droplet redispersion mass becomes larger with increases in both We_{in} and the droplet impact angle θ . In the results of the basic experiment above, in which a single droplet was impacted at an oblique angle on a liquid film on a wall surface [15], the droplet redispersion mass increased with increased We_{in} and θ . This does not correspond to the trend of the results calculated with the

conventional method, but matches the trend exhibited by our proposed method for $C_n < 0.5$. These results indicate that We_{in-t} is more predominant for the droplet redispersion mass ratio M_{out}/M_{in} than We_{in-n} .