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A PHENOMENOLOGICAL MODEL OF TWO-PHASE (AIR/FUEL) DROPLET DEVELOPING AND BREAKUP

by

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Effervescent atomization namely the air-filled liquid atomization comprehends certain complex two-phase phenomenon that are difficult to be modeled. Just a few researchers have found the mathematical expressions for description of the complex atomization model of the two-phase mixture air/diesel fuel. In the following review, developing model of two-phase (air/fuel) droplet of Cummins spray pump-injector is shown. The assumption of the same diameters of the droplet and the opening of the atomizer is made, while the air/fuel mass ratio inside the droplet varies.

Key words: *effervescent atomization, two-phase, droplet, diesel injector*

Introduction

Since 1980's a procedure, which atomizes liquid fuel (diesel), filled with the gas (air), under the pressure was known, this procedure is known in the newest editions [1] as the effervescent atomization – the atomization of the gas/liquid mixture. In the aerator, by means of special supplying system, gas is slowly injected in a liquid current, and on the exit of the atomizer a two-phase mixture – a liquid current mixed with air bubbles (air fractions) is created. The atomization process is stimulated with the gas expansion at very high speed on the atomizer exit, and this disintegrates fuel current on ligaments, lamellas, and droplets [1].

Previous research

Roesler and Lefebvre [2, 3] were investigated fluctuation of gas/liquid two-phase mixture. Through the atomizer's outlet, flowing can be in a form of bubbles, in a form of cylindrical gas tampons or in a form of the annular flow. On the outlet of the atomizer, gas fractions are getting into the phase of the relaxed pressure, they spreading very fast and disintegrate liquid into the droplets. The experiments that Sovani *et al*. [1], Santangelo and Sojka [4], and Sovani *et al*. [5] performed have shown the similar mechanism atomization.

Model of two-phase droplet developing and default assumptions

A gas phase that is used for two-phase production, and which is consisting of air and the combustion products, comes into the Cummins's pump-injector out of the cylinders of the diesel engine, it is actually, being aspirated by the needle of the pump-injector, during its lifting of the seat in the atomizer. A liquid phase, fuel, comes into the chamber, under the injector nee-

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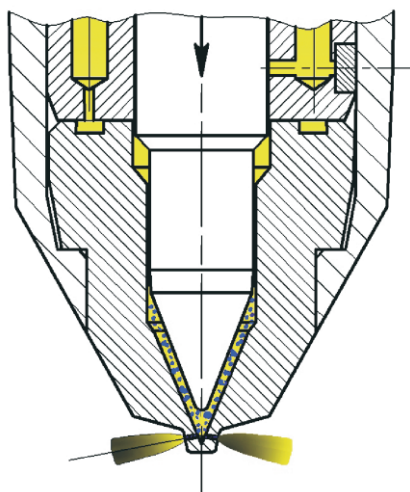
Figure 1. A mixture of gas phase and diesel fuel under the needle of Cummis's pump-injector [6]

dle; it comes under the fuel pressure in the inlet channel which is approximately same as the fuel pressure inside the fuel supply pump p_{gnp}. A needle of Cummins's pump-injector is pushing out a two-phase mixture through the openings of the atomizer, fig. 1.

The observation of the fluctuation process that occurs through the Cummins's atomizer outlet and the influence of the compressed air onto disintegration of the liquid flow can be significantly simplified in the first approximation, by means of the following assumption. The air-filled liquid fragments (a chain of primary droplets) of diesel fuel in the shape of the sphere, and inside the sphere's core is a bubble of compressed air, fig. 2, are being injected.

Diameter of the primary droplet D_{kapl}f(p), varies in the range of D_{kaplpb} – a primary droplet diameter under the injection pressure p_b, up to the "rupturing" droplet diameter itself D_{kaplkr}. D_{vp} is a diameter of the air bubble in the spherical droplet under the pressure p.
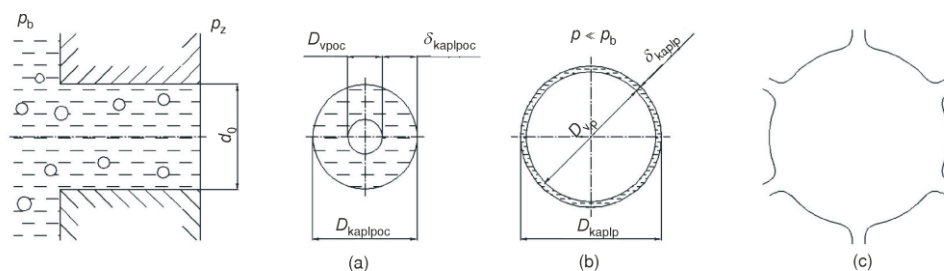

Figure 2. Injecting scheme of air-filled liquid fragment of diesel fuel (a primary droplet), with the spherical shape and the air-compressed core

According to this model, an initial calculation diameter of the droplet $D_{kaplpoc}$ at the maximum pressure that can be achieved at the atomizer's outlet, and this value is approximate to the injection pressure – p_b, is equal to the diameter of the atomizer's outlet – d_o (fig. 2a).

$$D_{kaplpoc} = D_{kaplp_b} = d_o \tag{1}$$

Under the pressure of the engine cylinder – p_z, a droplet is spreading very fast, until the moment when it breakup (fig. 2b and c). While the droplet is spreading, a thickness of the liquid phase has been reduced more and more until the moment when a critical thickness of the liquid phase δ_{kaplkr} is reached, then, a droplet has been breakup – it decomposes. In that moment a droplet diameter is D_{kaplkr}.

In this model is made an assumption that the same mass quantum is in every primary droplet and then the calculation is performed. Ratio in between the air mass M_v and the fuel mass M_g inside the droplet is called air/fuel mass ratio glr:

$$glr = \frac{M_v}{M_g} \tag{2}$$

Mathematical model description of this problem is given in [7].

Analysis of obtained results from two-phase droplet model

Outer diameter of the two-phase droplet and thickness of the liquid cover of two-phase droplet depend on the environmental pressure.

At the fig. 3, a calculated correlation in between the outer diameter of the two-phase droplet of diesel fuel and air, $D_{kaplp} = D_{kapl}f(p, glr)$ and calculated correlation in between the thickness of the liquid cover of two-phase droplet, $\delta_{kaplp} = \delta_{kaplp}f(p, glr)$. On the other hand, a presence of even small air quantities inside the mixture, at the low environmental pressure, increases very fast the outer diameter of the droplet – until it breakup, in that moment a droplet diameter is D_{kaplp}.
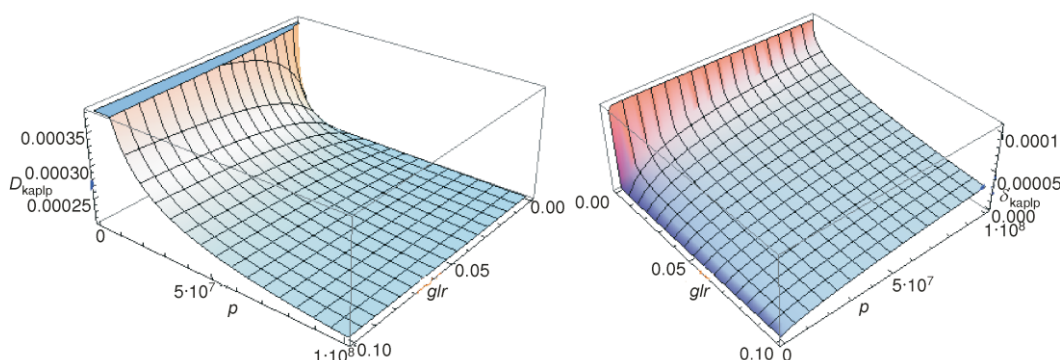

Figure 3. Outer diameter D_{kaplp}, of the two-phase droplet of diesel fuel and air, and thickness of the liquid cover of two-phase droplet – mixture of diesel fuel and air δ_{kaplp}, depending on the droplet gassy/fuel phase mass ratio glr, and the pressure in the area close to the droplet p. Atomizer's outlet diameter $d_o = 0.215$ mm, injection pressure $p_b = 1\cdot10^8$ Pa

Thickness of the liquid cover of two-phase droplet is depending on the pressure in the area close to the droplet, it decreases as the pressure decreases. With the increase of the droplet gassy/fuel phase mass ratio, glr, the thickness of liquid cover is reduced, a droplet become thinner.

It is very hard to distinguish criteria when the droplet is actually breakup. Inside the droplet, a spreading air is effecting, and from the outside an aerodynamic force, which is formed due to high values of relatives speed in between the droplets and the nearby air in a combustion area.

At figs. 4 values of environmental pressure and gassy/fuel phase mass ratio, in the moment of the two-phase droplet breakup are shown. A thickness of liquid cover in the moment of two-phase droplet breakup is assumed to be $\delta_{kaplkr} = 0.00002$ m (fig. 4, left) and $\delta_{kaplkr} = 0.000015$ m (fig. 4, right). According to previously shown calculated values, it can be concluded following: if the two-phase droplet (air/fuel) has plenty of air (a gassy phase), then it will breakup at higher pressures. In that moment a droplet diameter is D_{kaplkr}.

Conclusions

Here presented computer model shows the influence of the gassy phase (*i. e.* air) onto the development of the two-phase droplet – a mixture of diesel fuel (*i. e.* a liquid phase) and the
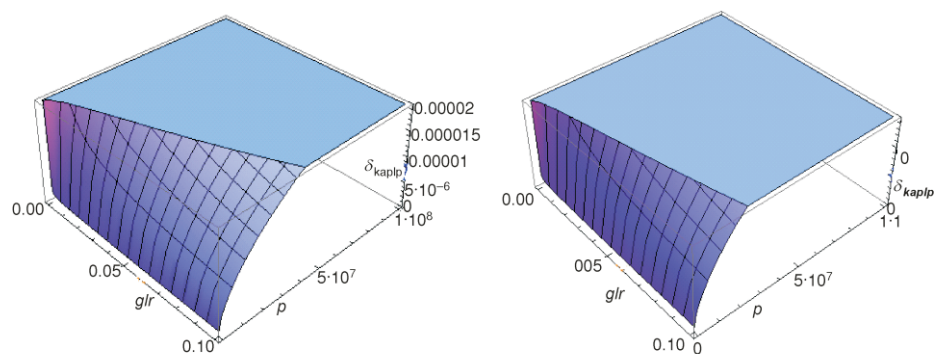
Figure 4. The pressure in the area close to the droplet p, gassy/fuel phase mass ratio glr, in the moment of two-phase droplet breakup, with the liquid cover thickness δ_{kaplp} = = 0.00002 m and δ_{kaplp} = 0.000015 m, atomizer's outlet diameter d_o = 0.215 mm, injection pressure p_b = 1·10^8 Pa

air, depending on the gassy/fuel phase mass ratio glr, and the pressure in the area close to the droplet p. Initial calculation droplet diameter $D_{kaplpoc}$ is equal to the atomizer's outlet diameter d_o. A process of air compression is considered as adiabatic change of the state, and that's the reason of high temperatures of compressed air. A relative speed in between the droplet and a nearby air is not taken into consideration. A volume of the liquid phase (a fuel) practically is not depending on the environmental pressure. Intensity of volume alteration of the gassy phase (*i. e.* the air) and the alteration of the outer two-phase droplet diameter are higher at lower environmental pressures. Compressed air inside the two-phase droplet has a devastated effect on it. If there is more air inside the droplet, then it will breakup at higher environmental pressures, actually it breakup faster. Though this model is made with the variety of assumptions, it is indeed "rough", the obtained results are giving the essential basic information regarding a two-phase flow inside the engine cylinder behavior.

Any form of the liquid phase, with a certain gas quantity, can be identified to "equivalent" spherical liquid-phase droplet with the spherical gassy volume inside it.

It is necessary to upgrade this calculation model and by means of experimental testing to determinate the criteria of droplet decomposing.

Nomenclature

D	– diameter, [m]		g	– liquid (fuel) phase
d_o	– diameter of the atomizer's outlet, [m]		gnp	– fuel supply pump
glr	– air/fuel mass ratio (= M_v/M_g), [–]		v	– gas (air) phase
M	– mass		kapl	– the spherical droplet
p	– pressure, [Pa]		kaplpoc	– the primary spherical droplet
V	– volume, [m^3]		kaplp$_b$	– the spherical droplet at the pressure p_b
			kaplp$_z$	– the spherical droplet at the pressure p_z

Greek letters

δ — thickness of the liquid phase, [m]

Subscript

b — chamber under the top of the needle of the pump-injector

kaplkr — critical moment when a droplet has been breakup

z — engine cylinder

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