

STUDY HEAT TRANSFER LIQUID DROPLETS INJECTED INTO NON-ISOTHERMAL AND ISOTHERMAL JETS CASE

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Abstract: The paper presents the calculation and modeling of the heat transfer fuel droplets. In the monocomponents biphasic medias gaseou-thermo-dynamic processes that take place in the phases that are fundamentally different in an intimate mixture (liquid phase in the vapor phase) to the case when they are separated. Generally can not be precisely the boundaries separating the two situations.

The analytical study of the flow of the liquid phase of the biphasic mixture can be in suspension form if we use the following two hypotheses: The particles are non-deformable fluid; and The number of particles per unit volume of fluid of the environment of the two-phase substance remains constant;

Appears the problem of determining influence liquid particle the average travel speed of the gaseous phase. Inter-phase heat exchange medium with droplets of liquid, and the mechanical interaction between the phases, determining the modification parameters of the environment thermo-speed two-phase flow and the gas phase. For very small droplets of liquid can be determined that the velocity is approximately equal to the gaseous phase.

Keywords: Atomizing, jet fuel, the heat transfer drops.

1. Introduction

Consider a flow channel, figure 1, for a mixture of gas and liquid particles based on the following assumptions:

- Liquid particles, are non-deformable;
- The number of particles per unit volume of fluid of the environment of the two-phase substance remains constant;

The relations are valid for fluid injection during the intake stroke and compression.

During this time the end of the race is likely to occur in a reverse process of vapor condensation process that initially unwanted.

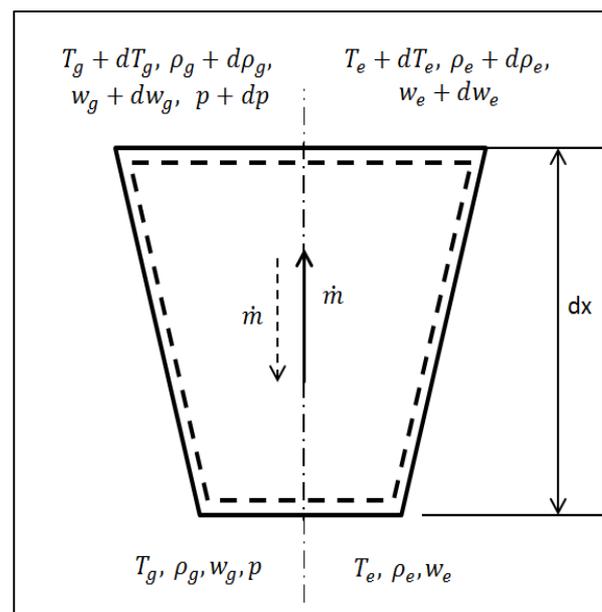


Figure 1: Flow channel scheme.

The equation of continuity for both liquid and gaseous phases of the mixture to a total flow rate m will be:

$$\rho_g AW_g = \dot{m}(1-x) \quad (1)$$

$$\rho_l AW_l = \dot{m}x \quad (2)$$

where: ρ_g = density of the gaseous phase;

ρ_l = density of the liquid phase;

x = the holding unit, the liquid phase of a biphasic mass;

The pressure of the gaseous phase can write as equation below:

$$p_g = \frac{m_g R_g T_g}{V_g} [N/m^2] \quad (3)$$

If replace ρ_g from equation (1) we result:

$$p_g = \rho_g R_g T_g = \dot{m}(1-x) \frac{R_g T_g}{W_g A} \quad (4)$$

The assumption of the first three constant terms, and considering the pressure as a function of compound $p = f(T_g, W_g, A)$ by deriving equation (4) yield equation (5):

$$dp = \dot{m}(1-x) R_g \left[\frac{dT_g}{AW_g} - \frac{T_g}{A^2} \frac{dA}{W_g} - \frac{T_g}{A} \frac{dW_g}{W_g^2} \right] \quad (5)$$

showing the variation of pressure of the biphasic mixture between the two sections A and $A + dA$.

If we derive the expression of the pressure p_g from equation (4) it results equation (6):

$$\frac{dp}{p} = \frac{dT_g}{T_g} - \frac{dW_g}{W_g} - \frac{dA}{A} \quad (6)$$

Applying the law of conservation of momentum as the liquid phase and the gas phase momentum equation obtained is:

$$-dp = (1-x) \frac{\dot{m}dW_g}{A} + x \frac{\dot{m}dW_l}{A} \quad (7)$$

Assuming an adiabatic flow-isotropic (friction work null) biphasic current energy conservation law will be:

$$\dot{m}(1-x) c_{pg} T_g \frac{W_g^2}{2} = \dot{m}x c_{pl} T_l \frac{W_l^2}{2} \text{ constant} \quad (8)$$

where: c_{pg} = specific heat of the constant pressure gas phase;

c_{pl} = specific heat of the constant pressure liquid phase;

Relationship in which one can determine the current temperature of the gaseous phase:

$$dT_g = \frac{W_g dW_g}{c_{pg}} - \frac{x}{1-x} \left[\frac{c_{pl}}{c_{pg}} dT_l + \frac{W_l dW_l}{c_{pl}} \right] \quad (9)$$

From equality of relations (5) and (6) results:

$$dT_g = \frac{dA}{A} T_g - \frac{x}{1-x} \frac{W_g dW_l}{R_g} - W_g dW_g \left[\frac{1}{R_g} - \frac{W_g}{W_g^2} \right] \quad (10)$$

It is noticed that the temperature variation depends on the variation rate of the gas phase and the gaseous phase and the liquid flow path modification.

If it equals the last two equations we obtain the expression variation of the flow rate of the gas phase will depend on the change in speed, the change in temperature of the liquid phase flow path.

From the analytical expressions of the equations above equations are obtained for the calculation of the pressure change, temperature and velocity of the gas phase portion dx .

$$\frac{dW_g}{dx} = \frac{\frac{T_g R_g}{A} \frac{dA}{dx}}{W_g \left[1 - \frac{R_g}{c_{pg}} - \frac{R_g T_g}{W_l^2} \right]} - \frac{x}{1-x} \left[\frac{c_{pl}}{c_{pg}} R_g \frac{dT_l}{dx} - \frac{W_l R_g}{c_{pg}} \frac{dW_l}{dx} + W_g \frac{dW_l}{dx} \right] \quad (11)$$

$$- \frac{W_g \left[1 - \frac{R_g}{c_{pg}} - \frac{R_g T_g}{W_l^2} \right]}{\left[1 - \frac{R_g}{c_{pg}} - \frac{R_g T_g}{W_l^2} \right]}$$

$$\frac{dT_g}{dx} = \frac{T_g}{A} \frac{dA}{dx} - \frac{x}{1-x} \frac{W_g}{R_g} \frac{dW_l}{dx} - W_g \frac{dW_g}{dx} \left[\frac{1}{R_g} - \frac{T_g}{W_l^2} \right] \quad (12)$$

$$\frac{dp}{dx} = R_g \dot{m} (1-x) \cdot \left[\frac{1}{AW_g} \frac{dT_g}{dx} - \frac{T_g}{A^2 W_g} \frac{dA}{dx} - \frac{T_g}{AW_g^2} \frac{dW_g}{dx} \right] \quad (13)$$

Since the liquid between the gas phase and in the actual case is exchanged by the heat convection of the convection we are interested in determining coefficient $\alpha_c [W/m^2k]$ with which the heat flow is changed determine wear or the amount of heat exchanged.

Analytical solving of the problem is difficult and leads through the simplifying assumptions adopted in which differ from the experimental results.

For these reasons we rely on similarity theory, the calculation of heat exchange between moving particle and the gas surrounding it recommends the following relationship:

$$Nu_e = 2 + 0.6Re^{0.5} Pr^{0.333} \quad (14)$$

Because $Nu_e = \frac{\alpha d_0}{\lambda_{fl}}$, get relationship convection coefficient:

$$\alpha_c = \frac{\lambda_g}{d_l} (2 + 0.6Re^{0.5} Pr^{0.333}) \quad (15)$$

where: Re = Reynolds number;
 Pr = Prandtl number;

$$Re = \frac{W_{lg} d_l}{\nu_l} \quad (16a)$$

$$Pr = \frac{\nu}{\alpha} = \frac{\nu \rho c_p}{\lambda_T} = \frac{\eta c_p}{\lambda_T} \quad (16b)$$

where:

W_{lg} = the relative velocity of the droplet to gas;

d_l = the relative feature size of the liquid droplet, from the gas (usually it is considered droplet diameter);

ν = the kinematic viscosity;

ρ = density;

c_p = the specific heat at constant pressure;

λ_T = coefficient of thermal conductivity;

In view of the expression (16) above, we get the equation convection coefficient of the following form:

$$\alpha_c = \frac{\lambda_g}{d_l} \left[2 + 0.6R \left(\frac{W_l d_l \rho_l}{\eta_l} \right)^{0.5} \left(\frac{\eta_l c_{pl}}{\lambda_l} \right)^{0.333} \right] \quad (17)$$

From the expression for the thermal conductivity coefficient can be observed that it corresponds to the maximum diameter of droplets of the smallest possible speeds as high as possible. So to intense heat exchange is required spray speed as fine as possible and as large drops of liquid.

Drops, after being sprayed in a very short time of the order of $10 \div 20 \cdot 10^{-3}$ seconds continues its trajectory but their speed is strongly braked.

For these reasons, the theoretical calculations α_c is very high in the initial phase of spraying, but basically there is a lag behind heat exchange to exchange table. In subsequent calculations is not just taking the best values of the coefficient of convective heat exchange, but an average drop its case by the end of tire development stream.

Convective heat exchanged during $d\tau$, dx length corresponding browsing between particles whose outer surface A_l will be given by:

$$\alpha_c A_l (T_g - T_l) d\tau = \dot{m}_l c_{pl} dT_l \quad (18)$$

Changes in temperature of the liquid phase due to interphase heat flow will be:

$$W_l \frac{dT_l}{dx} = - \frac{\alpha_c A_l (T_g - T_l)}{\dot{m}_l c_{pl}} \quad (19)$$

or, given the average convection coefficient expression:

$$W_l \frac{dT_l}{dx} = - \frac{6\lambda_g}{\rho_l c_{pl} d_l^2} \cdot (2 + 0.6Re^{0.5} Pr^{0.333}) (T_g - T_l) \quad (20)$$

If we denote by y the following expression:

$$y = \frac{6\lambda_g}{\rho_l c_{pl} d_l^2} (2 + 0.6Re^{0.5} Pr^{0.333}) \quad (21)$$

differential equation may take two forms:

$$W_l \frac{dT_l}{dx} = -y(T_g - T_l) \quad (22)$$

$$\frac{dT_l}{(T_g - T_l)} = -\frac{y}{W_l} dx \quad (23)$$

If integration is performed using the substitution differential equation: $u = T_g - T_l$ follows:

$$T_{l(x)} = T_g - k_l e^{\frac{y}{W_l} x} \quad (24)$$

$$T_{l(x)} = T_g - k_l e^{\frac{y}{W_l} x} \quad (25)$$

The constant k_l should be determined from the boundary conditions.

If the fluid temperature change is ignored until the injection route (changer no significant) for $x = 0$.

$$T_l = \dot{T}_{\text{initial}},$$

where: \dot{T}_{initial} = the initial temperature of the injected droplets, we have:

$$\dot{T}_l = T_g - k_l \Rightarrow k_l = T_g - \dot{T}_l \quad (26)$$

and then the solution of the equation becomes:

$$\dot{T}_{l(x)} = T_g - (T_g - \dot{T}_l) \cdot e^{\left[\frac{6\lambda_g}{\rho_l c_{pl} d_l^2} \cdot \frac{2+0.6Re^{0.5} Pr^{0.333}}{W_l} x \right]} \quad (27)$$

Equation (27) allows the calculation of the temperature of the liquid phase to the space traversed by the two-phase drops to a medium without taking into account the phenomenon of diffusion and subsequently analyzed.

The temperature of the liquid phase is influenced by the environment in which the temperature of vaporization, the average size of the liquid droplets, space and average speed of the liquid droplets.

It is seen from the relationship that when $x=0$ $T_l = \dot{T}_l$, so the equation is verified.

The calculations were made taking into account the characteristics of the fuel jet sprayed. It is therefore necessary for the

calculation of these parameters characteristic of the injection system.

For this purpose they were used the following relationship:

$$\sigma_\alpha = \frac{2}{\varepsilon - 1} + (1 - \cos \varphi) + \frac{\Lambda}{4} (1 - \cos 2\varphi) \quad (28)$$

where:

φ = the current angle;

Λ = ratio of the length of the crank and connecting rod;

$$\Lambda = r / b$$

For calculation of the compression in the cylinder using the following relationship:

$$p_c = p_a \left[\frac{2\varepsilon}{(\varepsilon - 1)\sigma_\varphi} \right]^s \quad (29)$$

where: s = polytropic exponent.

$$W_0 = \varphi_0 \sqrt{\frac{2 \cdot 10^5 (p_{ic} - p_c)}{\rho_l}} \quad (30)$$

From equation (30) gives the required injection pressure:

$$p_{ic} = p_c + \frac{10^{-5} \rho_l W_0^2}{2\varphi_0^2} \quad (31)$$

To determine the z average number of drops and the total surface area of contact with air to an excess air $\lambda = 1.5$ were used the following relationships:

$$m_a = V_s \cdot \eta_u \cdot \rho_o \quad (32)$$

$$\tilde{m} = \frac{m_a}{\lambda \cdot L_{min}} \quad (33)$$

$$z = \frac{6 \cdot \tilde{m}_l}{\pi \cdot r^3 \cdot \rho_l} \quad (34)$$

where: η_u = yield filling;

L_{min} = minimum air necesari;

r = radius of the droplet;

m_a = cyclic flow of air;

m_l = cyucllic liquid flow;

The penetration of the liquid jet using the general relationship of Lisevschi has the form:

$$L_m = A \frac{d^a W_0^b \rho_a^c \eta_a^d \tau^e}{\rho_{aer}^f \sigma_a^g} \quad (35)$$

Equation momentary speed of the jet with the crossing area x has the form:

$$W_x = B \frac{d^a W_0^b \rho_l^c \eta_l^d}{l_x^e \rho_{aer}^f \sigma_l^g} \quad (36)$$

where: d = mean droplet diameter;

W_0 = the average speed of the droplets at the points a,b,c,d,e;

After the calculations can be drawn characteristics of $L = f(\tau)$, or $W = f(\tau)$, the calculations will be carried to a droplet diameter of between 10 and 100 μm .

2. The heat transfer considering phenomenon of thermal diffusion

This model corresponds to the volume vaporization characteristic calculation jets which do not touch the walls.

The process follows the isobaric-isothermal vaporization and vapor diffusion is determined by the (molecular diffusion).

At the same time due to the different values of the concentration of the surface of the droplet evaporates, the concentration respectively at a larger radius than the radius of the liquid droplet, a field concentration occurs noted d_c/d_r .

There is described a mass transfer Fick's law for molecular diffusion, of the following form:

$$J_{az} = -D_{ab} \frac{d_c}{d_r} [kmol / m^2 s] \quad (37)$$

where:

J_{az} = which represents the change in molar flow of the molar mass transported per unit time through a unit area normal to the direction of travel;

D_{ab} = the diffusion coefficient of the substance a through the substance b m^2/s ;

d_c/d_r = concentration gradient.

3. Calculation of the thermal diffusion coefficient in the case of fuel injection

To carry out these calculations on the values of the diffusion coefficient of the gas mixture will approximate the residual petrol vapor and unvaporized liquid droplets with a gas mixture. It is known that vapors are similar to the behavior of ideal gases, the only difference in this case being a liquid droplets with a volume share insignificant.

Hirschfelder, Bird Spatz based on kinetic theory of gases recommends the following calculation equation:

$$D_{ab} = \frac{1,858 \cdot 10^{-3} T^{\frac{3}{2}} \left(\frac{1}{M_a} + \frac{1}{M_b} \right)^{\frac{1}{2}}}{p_g \sigma_{ab}^2 \Omega} \quad (38)$$

where:

D_{ab} = diffusion coefficient m^2/s ;

T = intake air temperature $^{\circ}k$;

M_a = molecular mass of the intake air;

M_b = molecular weight of gasoline atomized jet of air sucked in;

$M_a = 28.96443$ g/mol;

$M_b = 115$ g/mol;

p_g = intake air pressure;

σ_{ab} = the diameter of the collision;

$$\sigma_{ab} = \frac{\sigma_a + \sigma_b}{2} \quad (39)$$

For the theoretical average droplet diameter was used in all the settings made during the tests with the $\sigma_b = 87.2 \mu m$.

The average diameter of the droplets by collision with gas molecules sucked air atomized on all settings is $\sigma_b = 44.1 \mu m$.

Ω = dimensionless full collision;

The integral of the collision is a function of temperature and potential for intermolecular field of the a molecule respective one molecule of component b (air, gas).

$$\Omega = f(KT / \varepsilon) \quad (40)$$

where: K = Boltzman's constant J/K ;

T = temperature $^{\circ}k$;

ε_{ab} = intermolecular interaction energy for binary system;

$$\varepsilon_{ab} = (\varepsilon_a \cdot \varepsilon_b)^{\frac{1}{2}} \quad (41)$$

4. The presentation of graphics thermal diffusion coefficient

Depending on the thermal diffusivity of the engine intake air temperature variation:

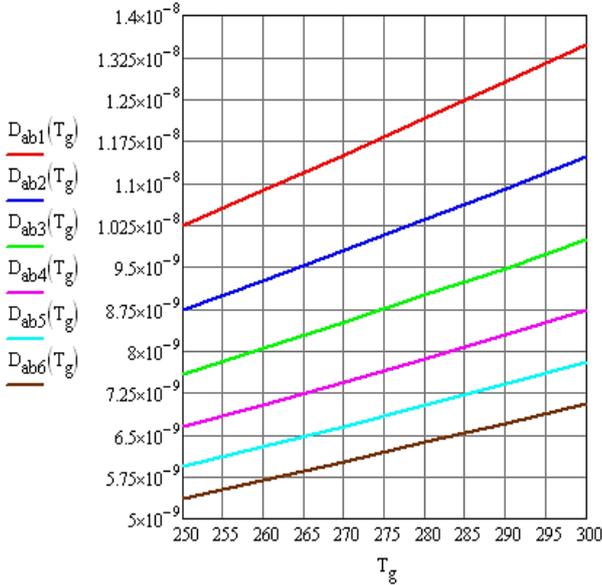


Figure 2: Thermal diffusion for varying air temperature.

Temperature factor was used as a high impact in the study, significant variations occur because of the shape of the fuel jet in the formation of atomized fuel air mixture into the engine.

Thermal diffusion coefficient based on the variation of the pressure in the engine intake air:

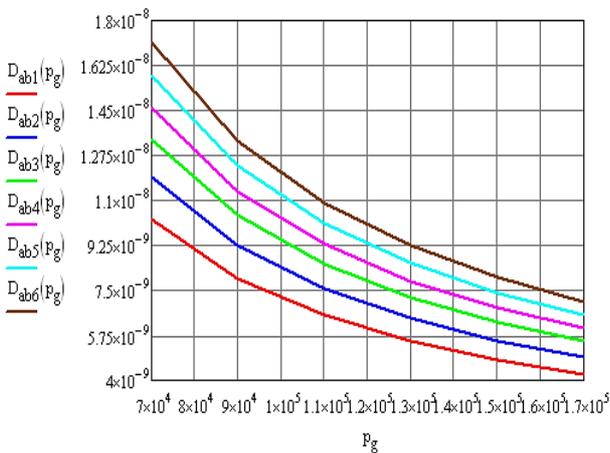


Figure 3: Thermal diffusion for varying the air pressure.

Air pressure in the intake manifold air to internal combustion engines can be controlled with a variety of electronic systems and mechanisms according to need assisted engine operating regime.

5. Conclusions

As can be seen in figure 2, the thermal diffusion of the liquid droplets and the air drawn into the intake manifold it has an increasing value with increasing air temperature. This is taduce through better atomization of gasoline in a shorter time.

Therefore, the temperature of the ambient air entering the engine is an important factor in the optimal operation of an internal combustion engine.

In figure 3, it is concluded that the absorbed air pressure through the intake manifold of internal combustion engines, bears a minimum the thermal diffusion coefficient.

It should be noted that the thermal diffusion is directly proportional to the temperature increase could be seen even if the absorbed air pressure variation (figure 3).

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