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Ballistics of Evaporating Spray in Wake of Shattering Drop

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Abstract

Mathematical model of evaporation dynamics of a mist in a wake of a shattering in a speedy flow drop is elaborated on a base of obtained earlier distribution function for stripped droplets by sizes. Stripped droplets are considered as a multi-velocity evaporating continuum and a system of differential equations of two-phase polydisperse spray dynamics is composed. At one-dimensional spatial approximation of flowfield the mathematical problem is formulated and solved in a closed form in a dynamic 3D space. A detailed calculation of the ballistics of an evaporating spray, generated in the wake of a kerosene drop fragmented by air stream, is performed. The spray internal structure is investigated as related to the dynamic process of spray formation. Evolution of the dispersive characteristics of liquid-phase jet of the spray is studied. Analysis of the processes of liquid jet and vapor cloud formation is done and their structures are described.

System of spray dynamics equations consists of partial differential equations of torn-off droplets motion, evaporation and equation of evolution of density of their quantity distribution by sizes. Parent drop is regarded as a source of daughter droplets with given source distribution function and each daughter droplet – as moving point source of vapor. Dependencies of droplets drag coefficient on velocities and sizes, and intensification of evaporation due to their streamlining are taken into account.

The problem for system of spray dynamics equations is closed with obtained earlier source function. Non-stationary two-dimensional problem was formulated and solved numerically, and structure of two-phase spray was investigated. Calculations showed, that times of living of finest and largest droplets are the characteristics of liquid-phase jet formation in spray. Soon after moment $\tau_{\min}$ of entire evaporation of droplets of minimum in spray radius $r_{\min}$, that were stripped at $\tau = 0$, evaporation mass rate and current value of liquid-phase mass in spray exceed their maximum values because of beginning of droplets vanishing. After moment $\tau_{\max}$ of vanishing of droplets of maximum radius $r_{\max}$ the vanishing of droplets of new radii doesn't occur, and this is the necessary condition for stabilization of length of liquid-phase jet.

The proposed model allows to calculate spray mean diameters d_{ij}. Parameters of two kinds were considered: $\Omega_{ij}(x) = d_{ij}(x, \tau_c)$ are defined in any cross section of jet and characterize its spatial structure at fixed moment τ_c, while $D_{ij}(\tau) = \int d_{ij}(x,\tau)dx$ are calculated at any τ for the whole set of droplets and describe temporal changing of dispersity of jet in total. At the beginning bunch of curves $\Omega_{ij}(x)$ is narrow, that testifies to weak polydispersity of jet, but after droplets vanishing starts, the polydispersity increases. Stabilization proceeds gradually along jet from astern part to the tip. Soon after $\tau_{\max}$ all parts of $\Omega_{ij}(x)$ are stabilized. Dependencies $D_{ij}(\tau)$ confirm these conclusions. In final state jet polydispersity is much greater than that, produced by source.

Vapor cloud formation in spray was studied. At the beginning, intensification of evaporation due to rapid growth of liquid surface is so large, that vapor wave appears which has sharp front similar to blast wave. After losing contact with liquid phase this wave has convectional drift, keeping its form invariable. Gradual weakening of droplets source capacity generates rarefied wave in vapor mass distribution, so, far from source the distribution tends to "triangle" form.

Evaluations show that fuel – air mixture in wake of a shattering drop is substantially overreached in average, as vapor density several times exceeds the stoichiometric value. Vapor oversaturation leads to cooling of combustible mixture. Equation of heat balance for process of vapor – air mixing yields the temperature dropping in about $300^{\circ}\mathrm{K}$, which means that delay of ignition may jump several orders high.

Presented mathematical model of evaporation ballistics of sprays allows to investigate the formation dynamics of liquid-phase jet and vapor cloud in the wake of a shattering drop in closed form, by the given parent drop radius and physical properties of gas – liquid system.