Application of dimensional analysis in estimating the wall film thickness created by a liquid spray impact

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Abstract

It has become apparent in recent years that the liquid film formed on the wall plays an important role in determining the velocity and size of ejected droplets as well as the deposited mass fraction. Nevertheless, the formation of a wall film is often neglected in spray impact models. In the present study, a new expression is given based on the dimensional analysis for predicting the average film thickness accumulated on the wall due to a liquid spray impact. The theoretical derivation for the average film thickness then compared with the measured data in the thin film condition.

In the impingement region of an inertial spray, the average film thickness created on the wall depends on the several parameters of the impacting spray ; normal and tangential component of impact velocity $\bar{u}_b$ and v_b , volume flux density of impacting spray ($\dot{q} = q/A$; "q" and "A" to be volume flux of the impacting spray(m^3/s) and the reference area over which flux is measured), volume-averaged diameter of impacting droplets (d_{30b}) defined by $d_{30b} = \left(\sum_{i=1}^{N} d_i^{\,3}/N\right)^{1/3}$, density ($\rho_L$) and dynamic viscosity of the liquid (μ), as well as the boundary condition of the target (e.g., flat or curved target surface or target surface completely covering with spray); average target surface roughness ($\bar{\varepsilon}$) and target size (D). Therefore based on the dimensional analysis, a general expression for the average film thickness accumulated on the wall due to a normal spray impact (negligible tangential velocity component of the impacting droplets) and for a spray covering the target surface (i.e., $D_{spray}/D>1$) can be written as

$$\left(\frac{\bar{h}}{d_{30b}}\right) = f\left(\frac{1}{Re_b}, \frac{\dot{q}_b}{\bar{u}_b}, \frac{\bar{\varepsilon}}{d_{30b}}\right) \quad (1)$$

An asymptotic solution of the average wall film thickness for a relative sparse but inertial spray can be obtained from result of a single drop impact. Based on the work of Pasandideh-Fard et al., 1996, the dimensionless splat thickness of a spreading droplet on a rigid wall can be written in the form of

$$h^* \cong 2.67 Re_b^{\,-1/2} \quad (2)$$

The dependency of h^* on $Re_b^{\,-1/2}$ in the case of a single drop impact for inertial impact condition indicates that we can extract the Reynolds number outside of Eq. (1). One simple form of the (1) for a negligible surface roughness can be written as

$$\bar{h} = \alpha d_{30b} Re_b^{\,-1/2} \left(\frac{\dot{q}_b}{\bar{u}_b}\right)^{\gamma} \quad (3)$$

where α and γ are constant values found to be 4 and -0.5, respectively. These constants have been found based on the measured data in this study for a water spray impacting onto a stainless steel target with 5 mm in diameter, negligible surface roughness and normal impact condition. The only important condition in using this expression for film thickness is that the entire target surface should be exposed to the impacting spray. The theoretical derivation exhibits good agreement with the measured data in the thin film condition.

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