EFFECT OF HEAT EXCHANGE ON THE INTERFACIAL INSTABILITY OF GAS-LIQUID JET

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Abstract: The classical linear instability theory was applied to the planar stratified two-layers flow with high speed compressible gas layer impacting on incompressible viscous liquid layer. The walls were kept at different temperatures, resulting in heat transfer across the layers. The thermal conductivity and the density of the gas were altered when the temperature changes. After some treatment, a four-order stiff ordinary differential equation was derived, and numerical integration and multi-shooting method were used to solve this equation for its spatial mode calculation. The numerical results of characteristic parameters show good coincidence with other models. At the same time, when the wall temperature ratio decreases, as well as the Reynolds number and the gas thermal conductivity change increases, the atomization would be more efficient and producing finer droplets. And the results show good fit with the experimental datum of HJE. Co. Inc (Glens Falls, NY, USA).

Key words: heat exchange; jet; interfacial instability; spray forming

Chinese Library Classification: O358 Document code: A
2000 MR Subject Classification: 80A20; 76T10

Introduction

In recent years, the prosperity of metal powder market[1] and the development of spray forming techniques make it necessary to study the mechanism of jet atomization. Freely falling high temperature metal liquid, impacted by high speed gas around, breaks into droplets of different sizes, which procedure is called air-blast atomization or spray atomization. In fact, this process has a wider engineering applications, ranging from fuel injectors in gas turbines and jet engines, to two-phase flow chemical reactors, spray drying, and so on.

On the basis of Kelvin-Helmholtz instability theory, investigators do a great deal of work...
on the mechanism of spray forming (G. I. Taylor (1965)\textsuperscript{[2]}, D. Bradley (1973)\textsuperscript{[3]}, S. J. Leib and M. E. Goldstein (1986)\textsuperscript{[4]}, S. P. Lin and D. J. Kang (1987)\textsuperscript{[5]}, S. P. Lin and Z. W. Lian (1990)\textsuperscript{[6]}, S. A. Berger (1988)\textsuperscript{[7]}, Zhou Zhe-wei and Tang Xiao-dong (1998)\textsuperscript{[8]}, Ma Zhen and Zhou Zhi-wei (1998)\textsuperscript{[9]}, and so on), they studied different flow configurations and reaction manners, and bring us a glimpse of the corner of the iceberg. Contemporarily, we realize that, for practical applications, that is not enough. We note that, for the procedures mentioned above, temperature, as a real factor, is not touched upon.

The emphasis of our study will be cast on the thermal conditions and the phenomena related. Unlike the studies mentioned above, we consider planar flow pattern instead of cylindrical flow pattern, because of its geometry simplicity and its analytic resolution of basic state. Up to now, articles on this subject are sparse, so this work may be a preliminary step.

1 Mathematical Formulation

The physical problem considered here is a high speed gas flow impacting on the relatively slow metal liquid. In our model, the liquid layer has relatively stable physical characters (such as constant density, constant thermal conductivity or constant thermal capacity), also we treat it as a incompressible and viscous flow. And we see the gas as a compressible liquid, whose thermal conductivity and density are all functions of temperature.

![Fig. 1 Schematic of two layer gas-liquid flow](image)

Our model can be depicted as the figure below:

Seen from Fig. 1, the upper wall is bounded, with free-slip wall condition given. The right part is the temperature profile. Symbols $V$, $p$, $T$, $\rho$ represent speed vector, pressure, temperature and density, respectively; "-' represents basic state characters, so our basic state is expressed by the following forms:

$$\vec{V}_i(x, y; t) = (\vec{U}_i, 0) = \text{const}; \quad \bar{p}_i = \text{const};$$

$$\bar{T}_i = \bar{T}_i(y); \quad \bar{\rho}_2 = \rho_2(T_g)\rho(y) = \bar{\rho}_20\rho(y).$$

Let $\kappa_20 = \kappa_2(T_g)$, then thermal conductivity for gas is $\kappa_2 = \kappa_20\kappa(T_g(y))$. Take $W$ (in our article, $W = \bar{U}_2$) the gas velocity, liquid thickness $a$, liquid density $\bar{\rho}_1$ and upper wall temperature as our characteristics, and we get

$$\bar{\tau} = \frac{tW}{a}; \quad \bar{V}_i = \frac{V_i}{W} = (u_i, v_i); \quad (\bar{x}, \bar{y}, \bar{d}, \bar{L}, 1) = \frac{(x, y, d, L, a)}{a};$$

$$\bar{P}_i = \frac{P_i}{\bar{\rho}_1 W^2}; \quad \bar{\rho}_2 = \frac{\rho_2}{\bar{\rho}_1}; \quad \bar{T}_i = \frac{T_i}{T_g}; \quad \bar{T}_g = \frac{T_g}{T_g} = 1; \quad \bar{T}_L = \frac{T_L}{T_g}.$$  

To reflect the physical invariable characters, we use some non-dimensional parameters as follows:

$$Q = \frac{\bar{\rho}_20}{\bar{\rho}_1}; \quad We = \frac{\sigma}{\bar{\rho}_1 W^2 a}; \quad Pe_1 = \frac{\kappa_1}{C_p1\bar{\rho}_1 a W}; \quad U_1 = \frac{\bar{U}_1}{W};$$

$$U_2 = \frac{\bar{U}_2}{W}; \quad Pe_2 = \frac{\kappa_20}{C_v2\bar{\rho}_20 a W}; \quad Re = \frac{\bar{\rho}_1 a W}{\mu_1}; \quad r = \frac{\kappa_21 y = a + d}{\kappa_1}.$$