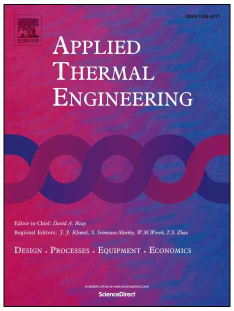

Non-equilibrium condensation of water vapor in sonic nozzle

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Non-equilibrium condensation of water vapor in sonic nozzle

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Abstract: The non-equilibrium condensation phenomenon during the operation of sonic nozzle is very complicated, and will affect the flow measurement and control of sonic nozzle. Two-dimensional multi-fluid k-ε turbulence models for both homogeneous and heterogeneous nucleation of condensation were constructed to investigate the effect of vapor condensation on mass flow-rate of sonic nozzle. These models were validated by experimental data of homogeneous nucleation in the moist nitrogen flow through a convergent-divergent nozzle by Wyslouzil and the numerical solutions of heterogeneous nucleation in wet steam flow by Dykas respectively. Finally, both models above were applied to study the condensation flow in sonic nozzle. It was showed that the discharge coefficient of sonic nozzle is affected by both homogeneous and heterogeneous nucleation. When the flow is homogeneous, there is significant influence on discharge coefficient with high inlet relative humidity, which agrees with the thermal choking theory. The discharge coefficient deviation reaches 0.275% when the inlet relative humidity is 95%, which is close to the Lim's experimental data with accuracy of 0.15%. However, under low relative humidity condition, the experimental discharge coefficient deviation is larger, which is explained by the heterogeneous nucleation fortunately.

Keywords: vapor condensation; nucleation; transonic flow; sonic nozzles; CFD

Nomenclature		T_s	saturation temperature, K
A	area, m^2	u	velocity, m/s
C_d	discharge coefficient, -	w	mass fraction of liquid, m_L/m, -
C^*	critical flow function, -	Y	wetness fraction,-
c_p	specific heat capacity, J/(kg·K)	x_v	inlet mole fraction of water vapor, -
d	throat diameter of nozzle, mm	Y_s	inlet mass fraction of water vapor, -
E	energy, J/kg	*Greek*	
h_{lg}	latent heat of water, kJ/kg	α	heat transfer coefficient, $W/(m^2\cdot K)$
J	nucleation rate, $kg^{-1}\cdot s^{-1}$	κ	isentropic exponent, -
k	Boltzmann's constant. 1.38×10^{-23} J/K	λ	thermal conductivity, W/(m·K)
l	mean free length of vapor molecule, m	μ	viscosity, Pa·s
M	Mach number, -	ρ	density, kg/m^3
m_m	mass of water molecule, 2.99×10^{-26} kg	σ	liquid surface tension, N/m
m_v	liquid mass changing rate, kg/s	τ	reduced temperature, T_0/T_c,-
n_p	the droplet number density, kg^{-1}	υ	volume of liquid molecule, m^3