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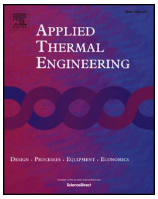

Research Paper

Experimental study on steady-state heat transfer characteristics of the Nozzle-atomized dispersed flow

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HIGHLIGHTS

- A new application of coolant for the fast neutron reactor was proposed.
- 50 times of heat transfer enhancement could be obtained.
- The effects of various operating and design parameters are quantified.

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ABSTRACT

The fast neutron reactor, one of the promising generation-IV nuclear reactors, particularly requires its coolant to have a strong capacity of transferring heat allied with a weak ability of moderating neutrons, and thus a new scheme of applying the dispersed flow as the coolant is presented in this study. Such a flow was generated by injecting subcooled droplets into the overheated steam with the help of a nozzle, simply referred to as the nozzle-atomized dispersed flow. The obtained heat transfer coefficients maintain high values, vary from 40 to 90 kW/m^2/K and are greatly improved as high as 50 times compared to those of the traditional annular-mist flow. The result implies that the nozzle-atomized dispersed flow, especially in the saturated boiling region, meets the heat transfer requirements of the coolant for a fast neutron reactor. Through meticulous analyses, appropriately higher inlet pressure, increased wall heat flux, larger inlet quality, boosted mass flow rate and shorter mix chamber length were found to either reinforce the heat transfer process or shorten the boiling regions along the tube. The standard database on hydrodynamic and heat transfer characteristics of the nozzle-atomized dispersed flow under violent conditions at the pressure of ~7 MPa and the mass flow rate of ~250 kg/m^2/s was established and laid foundations for further engineering design.

1. Introduction

In developing advanced reactors, the fast neutron reactor is a hot research direction due to its exclusive ability of proliferating fuel and evolving long-life radioactive fission products. However, popular coolants for the fast neutron reactor, e.g. sodium, lead, lead-bismuth eutectic (LBE) and other liquid metals, could lead to many problems, such as high price, seismic problem, eroding wall materials, exploding and so on [1]. By contrary, using the high-void-fraction dispersed water flow could relieve these problems. This flow has a weak ability of moderating neutrons, which exactly meets the requirements of the fast neutron energy spectrum. Additionally, dispersed flow cooling has a high heat transfer efficiency capable of attaining lower wall temperature than the single-phase liquid water that has already been used as the moderator and coolant for the typical pressurized water reactor (PWR). More importantly, this ideal coolant could reduce the system pressure from 15.5 to 7 MPa, minimizing susceptibilities of the reactor [2]. Considering the special properties of the dispersed flow, its application as the coolant for the fast neutron reactor is proposed in this study.

There are two kinds of dispersed flows: one is the annular-mist flow, directly-heated by a boiler, and the other is the nozzle-atomized dispersed flow investigated in this study. However, a thorough

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Nomenclature

DP	steam pressure drop (MPa)
h_{in}	steam enthalpy entering the test section (kJ/kg)
$h_{1,i}$	steam enthalpy entering preheater *I* (kJ/kg)
$h(z)$	mainstream enthalpy in the test section (kJ/kg)
$h_s(z)$	saturated steam enthalpy in the test section (kJ/kg)
I	heating current (A)
L	effective length of the test section (mm)
P	steam pressure (MPa)
q_c	total heat loss of the test section (kW)
q_s	wall heat flux (kW/m^2)
q_r	vaporization latent heat of water (kJ/kg)
Q	mass flow rate (kg/ m^2/s)
r	radius of the test section (mm)
R_i	inside radius of the test section (mm)
R_o	outside radius of the test section (mm)
T_{i1}	inlet steam temperature of preheater *I* (°C)
T_{o1}	outlet steam temperature of preheater *I* (°C)
T_{i2}	inlet steam temperature of preheater *II* (°C)
T_{o2}	outlet steam temperature of preheater *II* (°C)
T_{o1s}	inlet steam temperature of the mix chamber (°C)
T_{o2s}	inlet water temperature of the mix chamber (°C)
T_5	outlet steam temperature of the test section (°C)
$T_{wi}(z)$	inner wall temperature along the test section (°C)
$T_{wo}(z)$	outside wall temperature along the test section (°C)
$T_{j-1}(z)$	inner layer wall temperature along the test section (°C)
$T_j(z)$	outer layer wall temperature along the test section (°C)
$T_b(z)$	bulk steam temperature along the test section (°C)
U	heating voltage (V)
z	axial position along the test section (mm)

Greek letters

η	heat balance efficiency of the test section
η_1	thermal balance efficiency of preheater *I*
λ	thermal conductivity of the test section (kW/m/°C)
ϕ	volume heat flux (kW/m^3)
X_i	inlet quality of the test section
X_e	thermodynamics vapor quality along the test section
σ	uncertainty of the measurement

Abbreviations

$HTC(z)$	convective heat transfer coefficient vs. z (kW/m^2/K)
$HTC(X_e)$	convective heat transfer coefficient vs. X_e (kW/m^2/K)

Subscripts

1	preheater *I*
2	preheater *II*
t	the test section

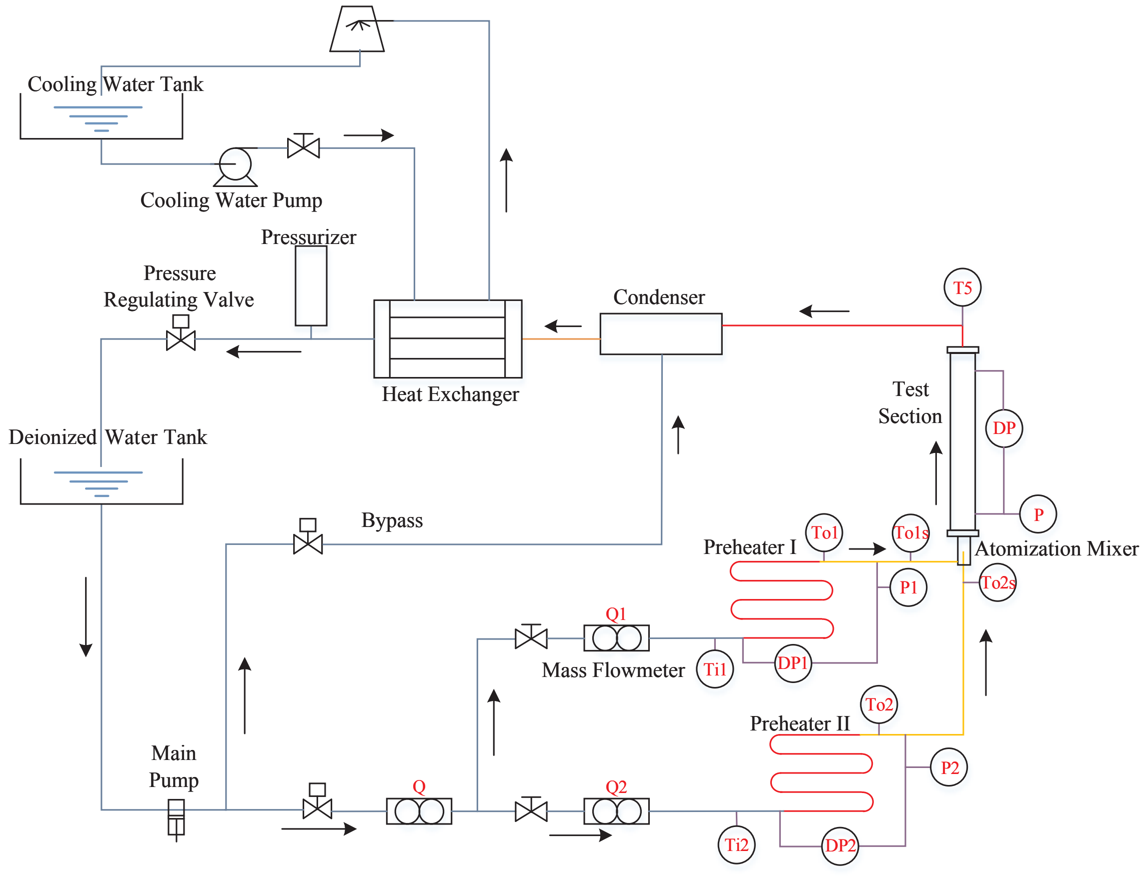

Fig. 1. Schematic diagram of the experimental loop.