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Experimental study on friction and heat transfer characteristics of pulsating flow in rectangular channel under rolling motion

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ABSTRACT

Friction and heat transfer characteristics of pulsating flow induced by rolling motion are experimentally studied. A series of single-phase forced circulation flow experiments are conducted in a vertical narrow channel. In the present study the flow rate is adjusted through control the impeller rotator speed of the pump. The results show that the flow rate pulsation simultaneously with the rolling motion and the relative amplitude of the flow rate pulsation decreases with the increasing flow rate. Accordingly, the relationships between the relative pulsation amplitude of friction factor, heat transfer coefficient and flow rate are classified. Therefore, the correlations have been developed to calculate the friction and heat transfer coefficient based on the relative pulsation amplitude of the flow rate.

1. Introduction

In recent years, the single-phase thermal–hydraulic characteristics of pulsating flow induced by the ship motion have attracted increasing attention, and until now a large number of researches have been carried out.

Ishida et al. (1995) experimentally studied the effect of sea wave on the thermal hydraulics of the first Japanese nuclear ship 'Mutsu'. They found that the vertical acceleration due to ship motion directly leads to the variation of water levels in the steam generators and the pressurizer. Murata et al. (2002) experimentally studied the single-phase natural circulation thermal–hydraulics in a model reactor under rolling motion condition. They found the loop flow rate in each leg changes cyclically with the rolling angle due to the inertial force that introduced by rolling motion. As the rolling period becomes shorter, the amplitude of the loop flow rate oscillations becomes larger, and the phase lag between the rolling angle and loop flow rate oscillations becomes larger. In addition, the flow rate in the core does not oscillation with the rolling motion, but the heat transfer characteristic in the core is enhanced caused by the internal flow due to the rolling motion. Pendyala et al. (2008a,b) experimentally studied the single-forced circulation pulsation flow friction and heat transfer characteristics in a vertical circular pipe under heaving motion condition. They found the relative pulsation amplitude decreases with the increase of flow rate. Thus in the laminar flow regime, the friction and heat transfer coefficient both increased with heaving motion, however, as the Reynolds number larger than 2100, the effect of heaving motion does not show significant change in the flow and heat transfer characteristics, and as the Reynolds number larger than 5000, the flow shows a muted response in terms of both flow rate pulsations and increase in friction factor. However, Chang et al. (2008) researched the turbulent heat transfer in a swing tube with a serrated twist tape insert under swing oscillation condition. The results show that single rolling or pitching oscillation with swinging frequencies ranging from 0.333 to 1 Hz reduces heat transfer levels from the static references. However, synergistic effects of compound rolling and pitching oscillations with either harmonic or non-harmonic rhythms improved heat transfer performances.

Tan et al. (2009a,b) experimentally studied the single-phase natural circulation flow and heat transfer characteristics in a circular pipe under rolling motion condition. They found the rolling motion enhanced the heat transfer, and the heat transfer coefficient of natural circulation flow increases with the rolling amplitude. However, it decreases with the increasing rolling period. They also found that the increasing flow resistance coefficient leads the average mass flow rate of natural circulation decrease. Furthermore, based on the experimental data, a mathematical model was developed to calculate the natural circulation flow under rolling motion condition.

Yan et al. (2010a–f) theoretically studied the friction and heat transfer characteristics of pulsation flow induced by rolling motion

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Nomenclature

A	area, m^2
c_p	specific heat, kJ/(kg °C)
D_e	hydraulic diameter, m
E	dimensionless parameter
f	function
g	gravity acceleration, m/s^2
G	mass flux, kg/(m^2 s)
h	heat transfer coefficient, kW/m^2
j	variable parameter
k	heat conductivity, kW/(m^2 °C)
L	length, m
m	mass flow rate, kg/s
Nu	Nusselt number
p	pressure, kPa
P	perimeters, m
Q	heat power, kW
Re	Reynolds number
t	time, s
T	period, s
u	velocity, m/s
V	volume, m^3
x, y, z	coordinates

Greek symbols

θ	rolling angle, °
Θ	dimensionless rolling amplitude
β	angular acceleration, rad/s^2
λ	friction factor
ω	angular velocity, rad/s
Ω	dimensionless rolling period
Λ	dimensionless parameter
ν	kinematic viscosity coefficient, Pa s
ρ	density, kg/m^3
δ	thickness of the wall, m

Subscript

ave	average
amp	amplitude
f	frictional
l	liquid
max	maximum
meas	measured values
R	rolling
w	wall
wi	inner wall
wo	outlet wall

both in the pipes or channels through establishing mathematical models. They found the present empirical correlations could not capture the flow and heat transfer characteristics under rolling motion condition, thus, a series of theoretical models were developed to solve these problems. More recently Xing et al. (2013a,b, 2012) conducted some experiments to investigate the single-phase forced circulation friction factor of isothermal flow in an organic material rectangular channel under rolling motion condition. They indicated that the influencing degree of rolling motion on the friction pressure drop depends on the driven head, the flow rate in rolling motion condition oscillation amplitude decreases rapidly with the driven head. When the system supplies a low driven head, the frictional pressure drop fluctuates synchronized with the flow rate and could not be predicted by conventional

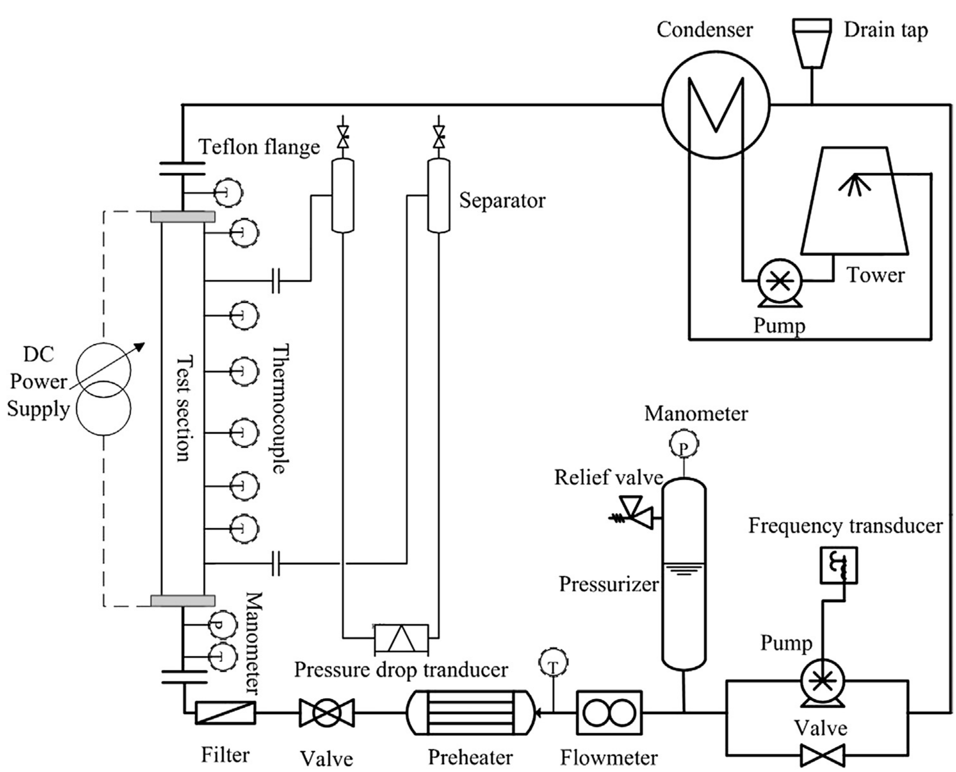

Fig. 1. Experimental loop.