Application of porous matrix to high heat load removal system

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Abstract  In a future design of a compact fusion reactor with enhanced power density, how to remove heat from high heat flux components and to get higher temperature operating fluid for power generation will inevitably play an important role. In the present work, we propose a new cooling system, using sintered metal porous media. For the purpose of developing this cooling system, heat removal experiments were performed with varying geometrical parameters mainly this time. It is feasible for the proposed cooling system to remove heat flux up to 1.3 MW/m² at the present step, and there seems to be a great possibility of the enhancement of the heat removal capacity of this cooling system.

List of symbols

- \( C_p \) specific heat capacity
- \( m \) mass flux
- \( q_{\text{rem}} \) averaged removed heat flux

Greek symbol

- \( \Delta H_{\text{vap}} \) latent heat of vaporization

Subscripts

- \( l \) quantity associated with liquid phase
- \( g \) quantity associated with gas phase
- \( \text{in} \) at inlet
- \( \text{out} \) at outlet or the gap
- \( \text{sat} \) saturation

Superscript

- \( - \) spatial average quantity
- \( 1 \)

Introduction

According to the general concept of the fusion power generation system, most of fusion energy is given to blanket as volumetric heat generation, and then changes to thermal energy in it. After transmitted to working fluid, the energy is finally converted to the electric power in the generation system. The rest of the energy is given as surface heat load to the first wall and divertor. From standard design of the, maximum heat flux on the divertor surface becomes locally near 30 MW/m². How to cool down is mainly focused on about this part because of its much high heat load.

Several cooling methods using subcooled water have been proposed to enhance the critical heat flux more than 30 MW/m². But they cannot compose the cycle of power reactors since they only cool down and the temperature of water cannot raised enough in their systems.

It is necessary for effective use of energy to develop a new cooling system which can generate high temperature heat medium and remove very high heat load. In the present work, we propose a new concept of cooling system using metal porous media, which is based on heat removal by latent heat of vaporization of coolant flowing in the porous media. One side of the porous media is touched to high heat load surface, and the other side is soaked in coolant. Coolant penetrate into the porous media and evaporate due to transmitted heat. The merits of this cooling system are that thermal energy is transmitted into the inside of coolant because of large thermal conductivity of metal material, and high temperature steam is available because of making coolant evaporate positively.

Porous medium has been used widely in the field of chemical engineering, and its flow resistance and heat and mass transfer have been studied for many years. Heat transfer with phase change in the porous media is a topic which draws broad interest due to many applications, (Sahota 1979; Catton 1994; Gupta 1974; Zarotti 1984). Not a few studies concerned with it have been reported mainly from the point of geothermal usages. However, most researches have their interests in the case that capillary pressures is dominant. Few studies of convective heat transfer with phase change in porous media have been performed until now, although there are some reports on the geothermal problems dealing with condensation.

In this study, in order to obtain basic data to develop a new high heat flux cooling system using metal porous media, heat removal experiments have been performed with varying geometrical parameters mainly this time.

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2. Experiment

2.1 Experimental method
An experimental apparatus was composed of a heating section, a test section and a drain section as shown in Fig. 1, which also indicates flow of fluid by arrows.

Experiments were conducted by using distilled water as working fluid. The heating section was made of copper block, 128 mm × 120 mm (square) × 52 mm in thickness, in which four electric cartridge heaters were inserted and of which power were raised up to 650 W, and it was covered with the insulation made of ceramic fiber. The test section was a stainless steel tube, 64 mm long and 50 mm in inner diameter, and the one end of the test section tube was welded to a flange which was connected with the heating section. A gasket packing was inserted between the flange and the copper block, in order to prevent steam leaking. Connecting the test section with the heating section, there is a gap of 5 mm long between the flange and the copper block. That is called simply the ‘gap’ in this paper. Two pipes with a diameter of 8 mm were used as exhaust outlet pipes to guide steam from the test section to condenser.

Two kinds of porous media made of permeable sintered metal were used. Their characteristics were shown in Table 1. In order to keep good thermal conduction between the porous medium and copper block, the porous medium was tightly fixed with the copper block by screwing at its bottom end. Further, by taping silicon tape around the porous medium, water leakage passing through chinks between the porous medium and the tube was prevented. Temperatures at the heating section, and the inlet and outlet (gap) of the test section were measured by thermocouples.

The distilled water supplied from a constant-temperature reservoir at constant inlet pressure flowed into the porous media at its bottom end and flowed out at the side corresponding to the gap with being heated by imposing a constant heat flux from the heating section. Measurements were stated when the outlet temperature raised above the boiling point of water. The steam evaporated in the porous medium was bled off through the exhaust pipe, and its condensed water was collected in a graduated cylinder in order to measure the total mass flux of the fluid. The averaged heat flux, \( \dot{q}_{\text{rmv}} \), removed by the mass flux flowing in the porous medium, \( m \), was evaluated by the following equation.

\[
\dot{q}_{\text{rmv}} = m\left(C_{p1}(T_{\text{sat}} - T_{\text{in}}) + \Delta H_{\text{vap}} + C_{p2}(T_{\text{out}} - T_{\text{sat}})\right)
\]  

(1)

In this experiment, the measuring time was two minutes. The steam temperature at the gap, \( T_{\text{out}} \), which was fluctuated sharply, was averaged and applied for evaluating \( \dot{q}_{\text{rmv}} \) of Eq. (1).

The saturation temperature of the fluid, \( T_{\text{sat}} \), is essentially a function of pressure. But, within this study, \( T_{\text{sat}} \) is confirmed to differ not so much from the saturation temperature at atmospheric pressure. Therefore, it was assumed that \( T_{\text{sat}} \) in Eq. (1) was equal to that at 1 atm. The same assumption was also applied for the latent heat of evaporation, \( \Delta H_{\text{vap}} \).

We carried out experiment varying the width of the gap.

2.2 Experimental results

2.3 Fundamental property of present cooling system
With varying the inlet temperature, \( T_{\text{in}} \), of the liquid, relations between the heat flux \( \dot{q}_{\text{rmv}} \) and the mass flux are shown in Fig. 2. The points represent experimental data and the curves are calculated from Eq. (1) without considering the sensible heat of vapor, which is the third term of the right hand side.

![Fig. 2. \( \dot{q}_{\text{rmv}} \) vs \( m \) varying with \( T_{\text{in}} \)](image)