ET07: การทดลองเพื่อศึกษาพฤติกรรมการไหลของน้ำจากระบบการไหลเวียนตามธรรมชาติแบบสถานะเดียวที่สภาวะคงตัว

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บทคัดย่อ

ระบบการไหลเวียนตามธรรมชาติมีบทบาทสำคัญอย่างมากต่อการระบายความร้อนของเครื่องปฏิกรณ์นิวเคลียร์ในกรณีที่เกิดการรั่วของสารระบายความร้อนภายในระบบหรือหลังการปิดเครื่องแบบฉุกเฉิน งานวิจัยนี้ได้ทำการทดลองเพื่อศึกษาพฤติกรรมการไหลของน้ำจากระบบการไหลเวียนตามธรรมชาติแบบสถานะเดียวที่สภาวะคงตัวในวงรูปสี่เหลี่ยม โดยวัดอุณหภูมิของน้ำที่ตำแหน่งต่างๆ ภายใต้เงื่อนไขการเปิดและปิดระบบระบายความร้อนเมื่อให้กำลังไฟฟ้าแก่ขดลวดความร้อนที่ระดับต่างๆ ผลการทดลองพบว่าที่ขนาดกำลังไฟฟ้าของขดลวดความร้อนเท่ากัน อุณหภูมิของน้ำมีค่าสูงขึ้นในกรณีที่ปิดระบบระบายความร้อน อย่างไรก็ตามค่าผลต่างของอุณหภูมิที่เข้าและออกจากตัวทำความร้อนไม่มีความแตกต่างกันเมื่อมีการเปิดหรือปิดระบบระบายความร้อน นอกจากนี้ยังได้คำนวณหาค่าอัตราการไหลเชิงมวลอันเนื่องมาจากความแตกต่างของความหนาแน่น

คำสำคัญ: การไหลเวียนตามธรรมชาติแบบสถานะเดียว ระบบระบายความร้อน กระจายตัวของอุณหภูมิ

An Experimental Study of Steady State Behavior of Single-Phase Natural Circulation Loop

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Abstract

Natural circulation has an important role in long term cooling of a nuclear reactor during a loss of coolant accident or after an emergency shut down of the plant. An experimental study of steady state behavior for single-phase rectangular natural circulation loop with water as the working fluid was conducted. Measurement of the water temperature distribution around the loop was made under the on/off cooling system and with the different heating power levels. The results show that at the same heating power level, the water temperature is much higher when cooling system was turned off. However, the same temperature differences across the heater were measured with the cooling system being turned on and being turned off. In addition, the mass flow rate due to a density gradient was calculated.

Keywords: Single-phase natural circulation, Cooling system, Temperature distribution

1. Introduction

A natural circulation loop is a system in which the motion of the fluid is driven by thermally generated density gradients and body forces. Generally, the heat sink is located at a higher elevation than the heat source to enhance the circulation rate. The fluid absorbs the heat from the source, becomes less dense and rises to the sink, where it is cooled, becomes denser and falls. The process thus establishes the circulation. This simple phenomenon has several applications, i.e. nuclear reactor core cooling, solar water heaters, transformer cooling, gas turbine blade cooling, engine and computer cooling.

Several experimental and theoretical works are available in the literature dealing with the physics of the flow and how it influences the heat transfer in the natural circulation. In particular, natural circulation loops in the most common geometries and their applications are reviewed by Zvirin[1] and Greif[2]. For the case of closed and open rectangular loops, particular attention has been devoted to transient and steady state behavior, as well as to stability analysis of the system under various heating and cooling conditions.

Vijayan et al.[3] studied effect of the heater and cooler orientations on the single-phase natural circulation in a rectangular loop. From steady state considerations, the maximum flow for a specified condition was achieved for the orientation in which both the heater and the cooler lied horizontally. However, this orientation was found to be least stable while as the orientation where both the heater and the cooler were vertical was found to be most stable. Basu et al.[4] presented a numerical study for the effect of ambient heat loss on the steady state behavior of a single-phase natural circulation loop.

The objective of this study focused on the steady state behavior of single-phase rectangular natural circulation loop. Various test runs were conducted on the loop under the on/off condition for the cooling system and with the different heating power levels.

2. Experimental Equipments and Procedures

2.1. The test loop

Fig. 1 shows a schematic diagram of the rectangular natural circulation loop. The loop consists of the riser, the downcomer, the vertical heating and the cooling sections. The loop piping has the dimensions of 22 and 25 mm for the inner and the outer diameters. An expansion tank open to the atmosphere is installed on the topmost elevation of the loop to allow for the volumetric expansion of the fluid. The entire loop is made of glass tubes. The heating and cooling sections are of equal length. The heating section is an annulus; the inner heating rod is made of stainless steel while the outer tube is made of glass. The glass tube has dimensions of 47 mm for the inner and 50 mm for the outer diameters, with length equal to 50 mm. The inner heating rod (U-shape) is 8 mm in diameter and 40 mm long. The cooler is a tube-in-tube type with the cooling water flowing in the annulus formed between the glass tubes. The entire loop is in thermal contact with the atmosphere and is subjected to heat loss to the ambient environment.

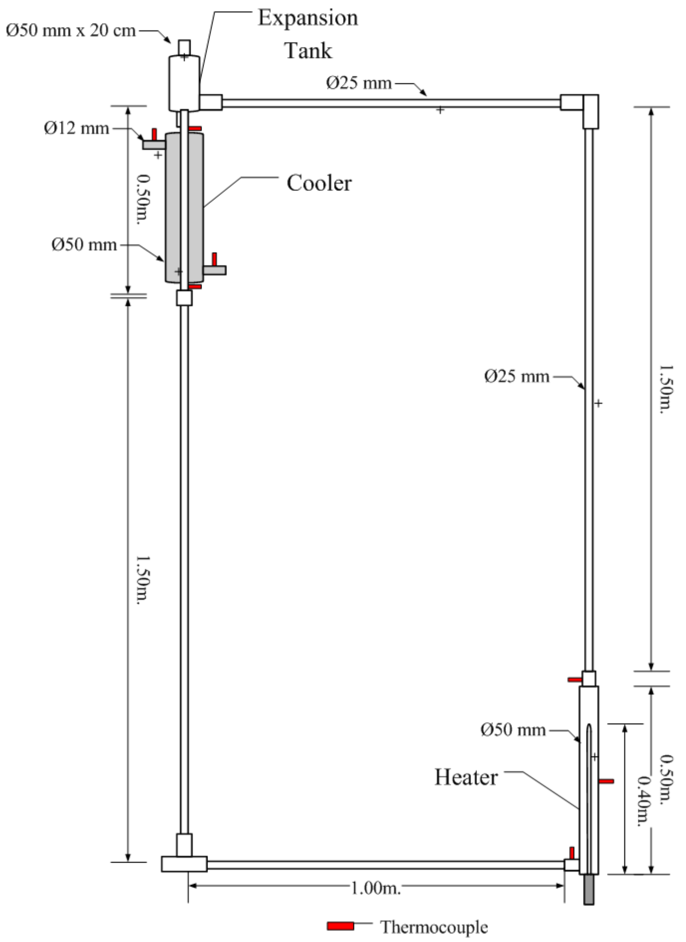


Fig. 1. Schematic of the rectangular natural circulation loop.

The loop is installed with the 1.6 mm diameter type K thermocouples to measure the temperature changes across the heater and across the primary and secondary sides of the cooler. The thermocouples are positioned to measure the temperature at the pipe center. In addition, the installation also includes a wattmeter to measure the heating power. The uncertainty for the measured water temperature is within ± 1 ^{o}C. Data are acquired and stored in the computer via RS-232 interfacing.

2.2. Experimental procedures

Single-phase natural circulation experiments were carried out in this loop for a wide range of heating power levels under the on/off condition for the cooling system. The heating power and the cooling water flow rate were maintained at the constant level during the entire duration of an experiment. The cooling water inlet temperature was 24 ± 1 ^{o}C. The tests were conducted with water as the working fluid.

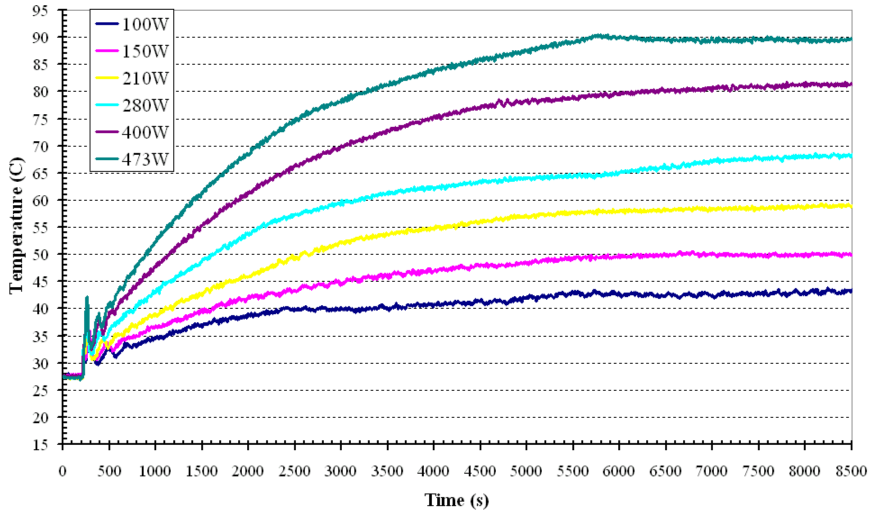
The main features of the tests were as follows:

1. Series of tests were performed under the on/off condition for the cooling system.
2. The input power was varied between 100 and 500 W.
3. The following procedure was used for each test.
   - Check of the uniformity of the system temperature and comparison with the ambient temperature;
   - Start the acquisition; start the cooling flow; start the heating power;
   - Check the power level every 30 min;
   - Data acquisition from 7 detectors is performed every 2 s (time needed to record all the signals were 1 s);
   - The test was concluded after 8500 s.

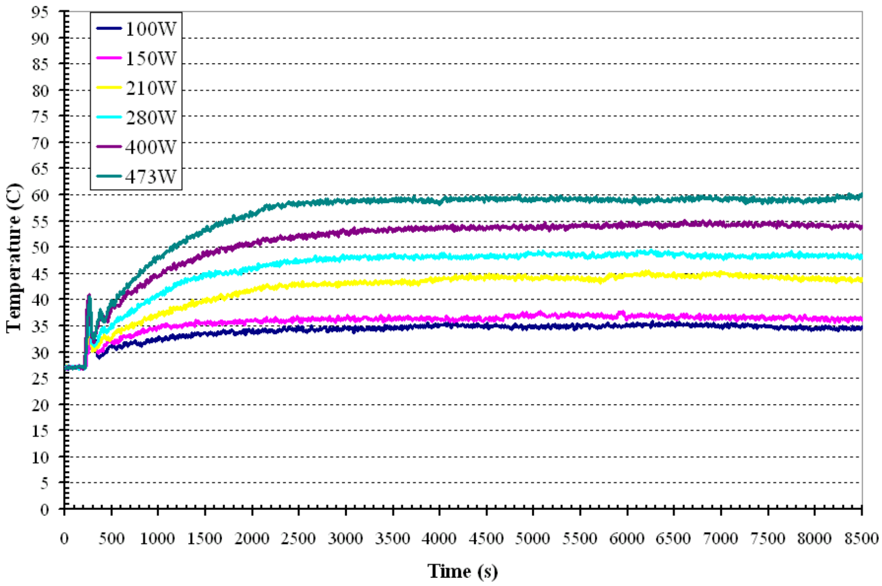
3. Results and Discussions

Measurement of water temperature at the heater outlet for different heating power levels were as shown in Fig. 2. It was found that the water temperature at any given time was increased with the increasing heating power. In addition, for the same heating power, the water temperature was much higher when the cooling system was turned off (Fig. 2a) compared with that obtained when the cooling system was turned on (Fig. 2b). The time required to reach the steady state was decreased with the cooling system turning on. It should be noted that the heating power level was limited to 473 W because the water temperature in the heating section was already very close to the saturating temperature for the water at atmospheric pressure.

Fig. 3 shows the temperature differences across the heater for different heating power levels with the cooling system turning off (Fig. 3a) and turning on (Fig. 3b). It was found that at any given time the temperature difference only was slightly increased with the increasing heating power. The same behaviors for temperature differences were observed regardless of the turning condition of the cooling system.



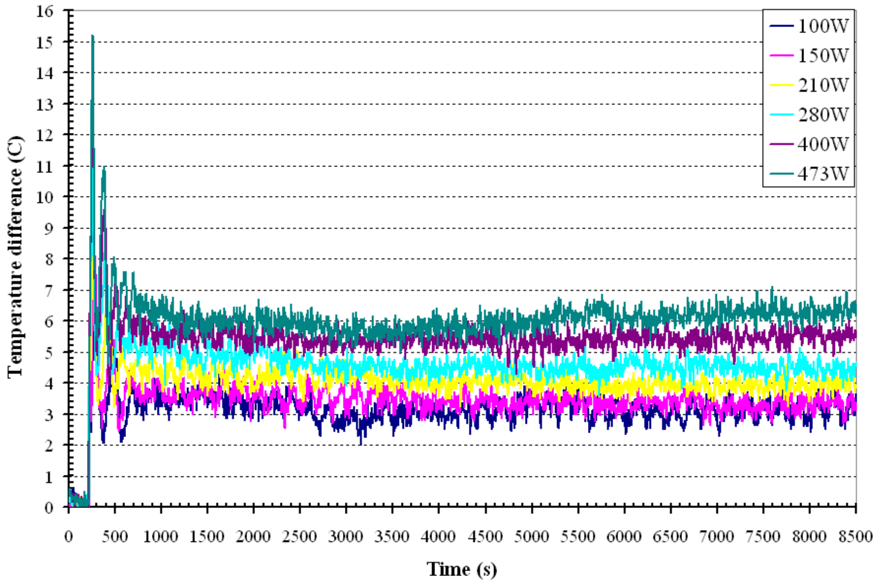
(a)



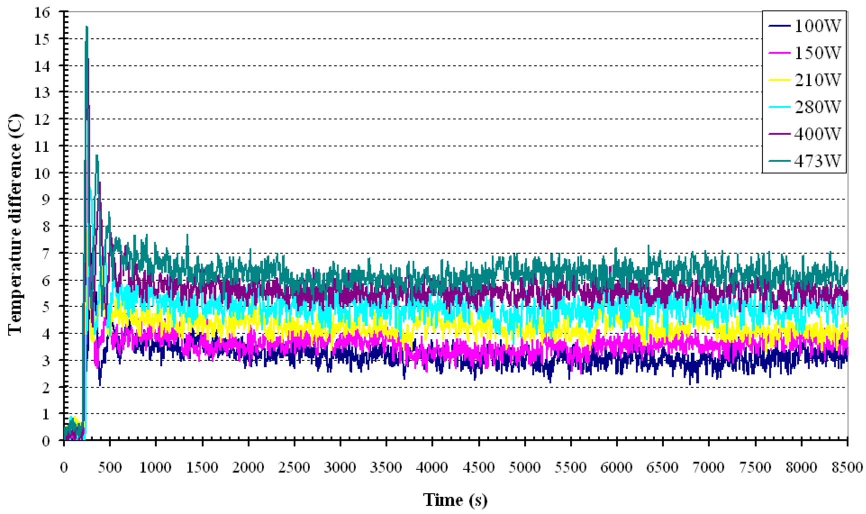
(b)

Fig. 2. Measurements of the water temperatures at the outlet heater for the different heating power levels when (a) the cooling system was turned off and (b) the cooling system was turned on.

The water temperature at the heater outlet was found to depend on both the heating power level and the presence of the cooling system. However the temperature difference across the heater was only affected by the heating power level. This was considered due to the limitation of the heater capacity. In effect the amount of heat received by the water flowing through the heater remained the same regardless of the inlet temperature.



(a)



(b)

Fig. 3. Effect of heating power on the temperature difference across the heater when

(a) the cooling system was turned off and (b) the cooling system was turned on.

The mass flow rate due to the density gradient at the steady state was computed from the heating power and the temperature difference across the heater based on the conservation of energy. The macroscopic conservation of energy equation for a steady flow was expressed as

$$Q = \dot{m}C_p(T_o - T_i)$$

where T_i and T_o were respectively the mean fluid temperatures at the inlet and the outlet of the heating section, $\dot{m}$ was the mass flow rate, C_p was the specific heat capacity, and Q was the heating power. The value of C_p is temperature dependent[5]. For this study, the value averaged from that at the inlet and the outlet is used. The values of mass flow rates computed at various heating power levels were as plotted in Fig. 4. The result indicated that the mass flow rate was increased with the increasing heating power. Again, the same mass flow rates were acquired regardless of the turning condition of the cooling system.

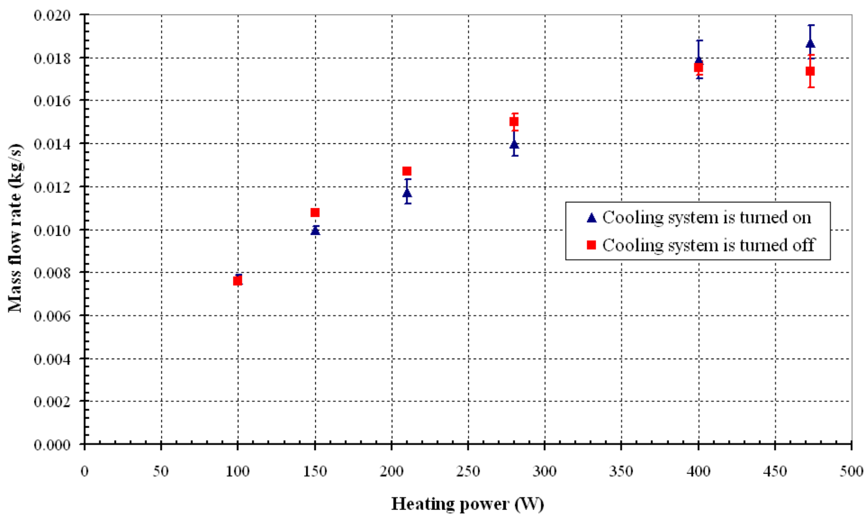


Fig. 4. Effect of heating power on the mass flow rates.

4. Conclusion

The investigations on single-phase natural circulation experiments were conducted for various the different heating power levels under the on/off cooling system conditions. It was found that at the same heating power level, the water temperature was much higher when the cooling system was turned off. Regardless of the turning condition of the cooling system, the same temperature differences across the heater were measured. The mass flow rate due to the density gradient was also found to be increased with the increasing heating power level.

5. Acknowledgments

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