

EXPERIMENTAL STUDY OF HEAT TRANSFER IN A THIN VERTICAL RECTANGULAR CHANNEL

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Abstract

Free convection cooling processes are often used in nuclear technology as well as in the vertical channel type structures of some systems, in electronic circuit board cooling and many other fields. TR-2 Reactor at Cekmece Nuclear Research and Training Centre (CNRTC) is a pool type research reactor with plate type fuel elements. The narrow vertical cooling channels of this reactor have a width of 2.1 mm. In case of an accident or a loss of cooling event, the heat in these channels are transferred by natural convection. An experimental setup was constructed to simulate the TR-2 cooling channels. Dummy fuel plates were heated by a DC source and temperature measurements were taken by copper-constantan thermocouples situated at different points. Cooling fluid is air. For several different powers and channel gaps the temperatures had been measured. The average Nu and Ra numbers were calculated for the channel and compared with the numerical results.

1. Introduction

The cooling of vertical plates in which energy is generated has become considerably important in recent years. The cooling of printed circuit boards of electronic devices by natural convection can be given as an example.

In nuclear reactor accident conditions, the cooling has been carried out by natural convection after the failure of the cooling systems. In plate type fueled, pool type reactors (MTR) cooling occurs in parallel narrow vertical channels in the direction from top to bottom. In case of a pump failure the cooling is supplied by natural convection from bottom to top.

A lot of theoretical and experimental studies were done for laminar flow with different fluids in narrow vertical channels (1-6). TR-2 is a 5 MW, plate type fueled, pool type research reactor. This reactor has 23 plane fuel plates per element which has 22 cooling channels between these plates and 2 cooling channels at the outer sides. Channels are narrow, vertical and rectangular having dimensions of 61 cm x 0.21 cm x 6.54 cm (7). A feedback dynamic analysis model was developed

for the safety analysis report of TR-2 Reactor. According to this model, reactor shuts down after pump failure and during the first 250 sec. no boiling occurs (8). It is also experimentally shown that, when the cooling channels of the used fuel elements are open to air, they can be cooled by natural convection (9).

In this study, an experimental setup was constructed to simulate the TR-2 cooling channels. The cooling fluid is air. At several powers and channel gaps the temperatures had been measured at different points. The average Nu and Ra numbers were calculated for the channels. These values were compared with the numerical results.

2. Experimental Set-up

In order to simulate the cooling channels of TR-2 an experimental setup was made for studying the cooling by air (Fig.-1). The geometry is shown in Fig.-2. The plates have a height of L , and spacing of b . Each fuel plate consists of two aluminum plates, heating resistances between these plates which also have two electrical isolation plates at the inner surface. Aluminum plates have 1 mm. thickness and same dimensions of the real plates. A mica plate, surrounded by resistance wire with identical intervals provides a homogen heating source. It was tried to make the heating source of the plates identical with each other. The sensitivity reduced up to 0.01 ohm between two resistance wires. Power was supplied by a 0-200 V, 0-7.5 A DC source. Channel width between plates was provided by sticks with different thicknesses. Seven thermocouples were used to measure the surface temperatures along the channel. The channel inlet, outlet temperatures and ambient temperature were measured by using other thermocouples. The temperature of the isolated outer faces of the two plates were also measured with thermocouples situated outside of each plate. On outer side of the plates there are 5 cm. wool-stone for thermal isolation. The thermocouples were stucked on the plate surfaces with a resin which is durable up to 120°C. In the construction of the thermocouples copper and constantan wires (diameter 0.2 mm) were welded in electrical arc in vacuum. The voltage was read on each thermocouple with a single precise multimeter (1 μ V sensitivity) and a scanner with 32 channels.

Channel gap values (2.1, 4, 6 and 8 mm) and the power given to the plates (2-20 W) are the input variables in the experiment. For a given channel gap and power, the temperatures at the inside of the plate surfaces, at the channel inlet and outlet, at the outside of the isolation material and ambient temperatures were measured.

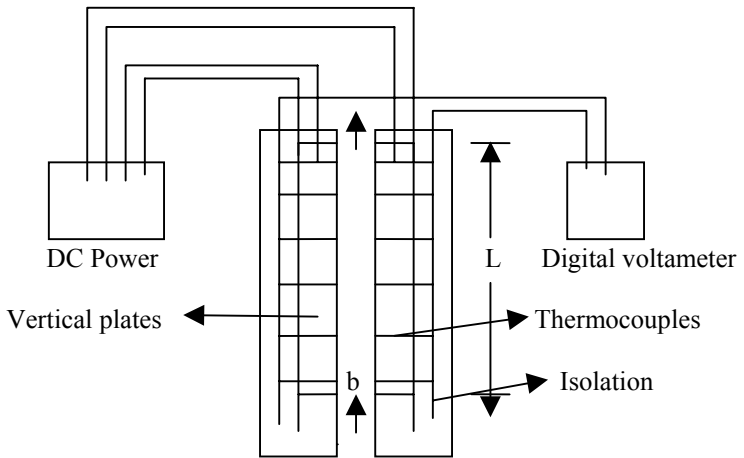


Figure - 1: Experimental apparatus

3. Experimental Data Analysis

A vertical rectangular channel with a height of L and a channel gap of b is heated through the walls, the fluid inside the channel starts to rise due to the decrease of the fluid density (**Fig.- 2**).

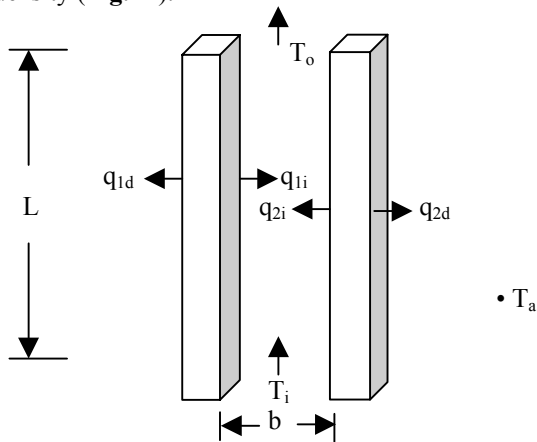


Figure - 2: Geometry of the vertical parallel plates and related parameters

In the analysis, the plate temperatures are the arithmetic means of the temperatures measured on the plates. The temperature of the fluid T_c is calculated as

$$T_c = \frac{T_i + T_o}{2},$$

where T_i and T_o is the fluid temperatures measured at the inlet and outlet of the channel.

The net heat given to the channel is taken as the heat produced at the plates minus the heat loss from outside of the plates.

Nusselt number, Nu , is calculated using net heat flux, q , mean temperature of the walls, T_w , temperature of fluid, T_c , channel gap, b , and the thermal conductivity of the fluid, k , as

Rayleigh number, Ra , is also calculated for each case.

$$Nu = \frac{qb}{k(T_w - T_c)},$$

where: g : Constant of gravitational acceleration,

β : Fluid thermal expansion coefficient,

$$Ra = \frac{g\beta qb^5}{Lv\alpha k},$$

L : Plate height,

v : Fluid kinematic viscosity,

α : Fluid thermal diffusivity,

The Nu and Ra numbers has been found by changing the plate power and channel width are shown in Table-1.

Table – 1: Experimental parameters

Power (w)	b= 2.1 mm		b= 4 mm		b= 6 mm		b= 8 mm	
	Ra	Nu	Ra	Nu	Ra	Nu	Ra	Nu
2	0.01088	0.3155	0.3262	0.5614	2.4708	0.8462	10.6290	1.11
4	0.01876	0.2930	0.7835	0.5763	4.3184	0.8979	18.5630	1.201
5	0.02187	0.2728	1.1340	0.5707	6.1054	0.9067	25.9450	1.233
7	0.03806	0.3557	1.5445	0.5918	8.7941	0.9156	40.0560	1.361
10	0.05099	0.3399	1.8972	0.5970	11.756	0.9382	53.5190	1.446
15	0.06229	0.2944	2.1620	0.5866	17.887	1.0363	79.8790	1.517
18	0.08798	0.3890	2.9845	0.6243	24.271	1.1399	94.9700	1.60
20	0.08583	0.3520					95.8330	1.615

The variation of Nusselt versus Rayleigh is given **Fig.-3**.

By using the least squares techniques for the values in **Fig.-3**

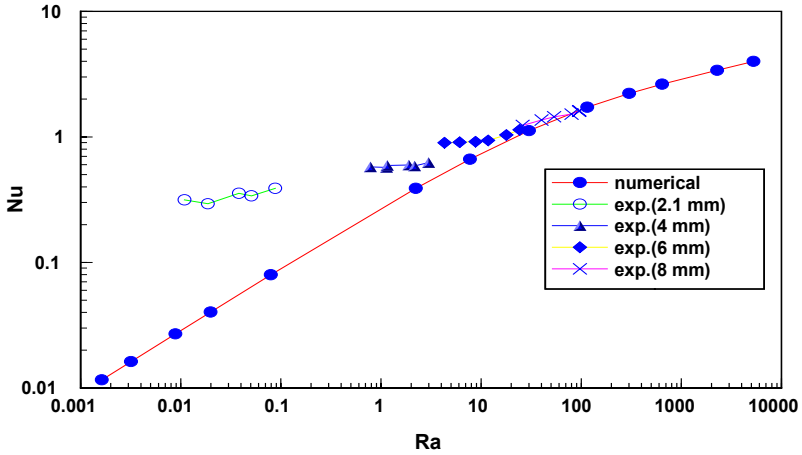


Figure – 3: Nusselt number as a function of Reyleigh number

$$Nu = A(Ra)^B \left(\frac{b}{L}\right)^C$$

equation can be found.

Here; A = 8.966

B = 0.1061

C = 0.5228

and R-square value is

$$R^2 = 0.8815$$

Simplified forms of Navier-Stokes equations for free convection cooling and incompressible flows were solved. Flow and temperature distributions inside the channel and some integral parameters, such as Nu number, were obtained (10). The results of this theory and the experimental study were compared. Numerical Nu and Ra is shown in **fig.- 3**.

4. Results

When the fluid is air and as the gap increased the experimental values approach to the theoretical values.

When the gap of the channel is narrow the Navier – Stokes equation can not be applicable since side layers interact each other and numerical solution results are different than the experimental values.

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