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# Experimental Study of Heat Transfer Analysis in Vertical Rod Bundle of Sub Channel with a Hexagonal on Small Modular Reactor

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***ABSTRACT:*** *The ability of the fluid in taking the heat generated by the nuclear reactor fuel is one important aspect of reactor safety. These capabilities must be kept high enough to maintain integrity of the fuel cladding as inside retaining radioactive substances. Study characteristics of forced convection in the fluid water using seven vertical cylinders heated uniformly in the composition ratio of hexagons with Pitch/Diameter (P/D) at 1.58 in the hexagon-shaped shell model of the reactor core test equipment in order to obtain the correlation equation displacement convection force. In this study, the heat flux and velocity of fluid flow greatly affect the temperature of the fluid. The greater the heat flux given the fluid temperature is getting higher because of the greater heat flux on the cylinder heating the heat absorbed by the fluid is also getting bigger. Similarly, the velocity of fluid flow, increasing the velocity of the fluid flow, the smaller the fluid temperature because by increasing the velocity of fluid flow in the sub channel the heat received by the fluid on the wane led to the smaller fluid temperature. Heat transfer coefficient results obtained at a velocity flow of 0.1 m $s^{-1}$ is 500 $Wm^{-2}K^{-1}$ to 23 500 $Wm^{-2}K^{-1}$, at a velocity flow of 0.3 m $s^{-1}$ is 3 100 $Wm^{-2}K^{-1}$ up to 2 800 $Wm^{-2}K^{-1}$ and in velocity flow of 0.5 m $s^{-1}$ is 3 500 $Wm^{-2}K^{-1}$ to 32 500 $Wm^{-2}K^{-1}$. In this experimental study use forced convection flow has a Reynolds number range from 3 991 to 29 537 and Graetz numbers from 1 371 to 41 244. The correlation of forced convection heat transfer as follows: $Nu_{forced} = 1.641\ Gz^{0.4267}$*

***Keywords:*** *correlation, forced convection, heat flux, heat transfer, hexagonal*

## I. INTRODUCTION

Estimates of the temperature distribution in the fuel bundle element are very important in a nuclear reactor. File cylinder used mostly as a nuclear reactor fuel element configuration, as well as heat exchangers and passive safety systems [1, 2]. This is certainly a challenge in improving the safety of nuclear reactors at the time of transfer of heat from the fuel element to the coolant [3, 4]. A fluid heat transfer coefficient is very important; because of the heat transfer coefficient can determine the fluid used to cool the fuel in a nuclear reactor works well or not [5, 6].

Phenomena occur in the convection flow into a turbulent or laminar including also affect the heat transfer coefficient. In NPP (Nuclear Power Plant) for this study used one type of reactor with low power that SMR (Small Modular Reactor) [7]. Magnitude thermal-hydraulics such as pressure, coolant flow rate and temperature of the fuel needs to be known, for example through the prediction calculations. For the development and application of nuclear reactor Small Modular Reactor (SMR) technology was developed for the implementation of passive cooling systems as well as systems integration to the Generation III + nuclear power plants. With leading technology and the power generated, it ought to be explored and researched the design and technology of nuclear reactor Small Modular Reactor CAREM type-25 for one of the new and renewable energy sources in Indonesia [8].

Experimental studies conducted, done about seven vertical cylinder is heated so as to provide a uniform constant heat flux with the ratio Pitch/Diameter (P/D) at 1.16 where the cylinder diameter of 3.75 cm and length of 60 cm. Still in a state of flow conditions develop. Empirical correlations generated as follows [9]:

Forced convection (turbulent flow): $Nu = 1.62\ Gz^{0.27}$ (1)

$$867 \leq Re \leq 4911$$
$$143 \leq Gz \leq 3087$$

## II. Research Method

This test uses 7 of diameter heating cylinders of 1.95 cm that form the sub channel to be studied only three cylinder heater to be heated electrically. The seventh cylinders arranged by the ratio of Pitch/Diameter (P/D) at 1.58 and put in the main test section hexagon shape with dimensions of 10 cm × 0.5 cm. The main test section has a height of 70 cm that has one hole in each side for water circulation. (Fig.1)

Heating cylinder has a length of 65 cm by 40 cm active part throughout. The remaining 25 cm was not heated that the velocity of the water is not immediately dropping so out of the heated section. Heating cylinder used a type of cartridge heater heating element made of pipe filled with the element or chrome wire with insulation elected. Each heater is capable of 1.5 kW electricity supplied from PLN net through the regulator.

In the active part of the fruit is placed thermocouple type K which are used to measure temperature vertically. To read the results of the temperature of the thermocouple digitally used thermo control. Thermocouple electrical voltage can be converted to Celsius and Fahrenheit by using thermo control.

In this study, water enters from 0.5 inch diameter inlet pipe into sections with a velocity of 0.1 m $s^{-1}$; 0.3 m $s^{-1}$; and 0.5 m $s^{-1}$. Variation for each cylinder heating power is 0 W; 2985 W; 29.85 W; 149.25 W and 298.5 W, each of which is equivalent to the heat flux at the surface of the cylinder 0 $Wm^{-2}$; 10 000 $Wm^{-2}$; 100 000 $Wm^{-2}$; 500 000 $Wm^{-2}$ and 1 000 000 $Wm^{-2}$.

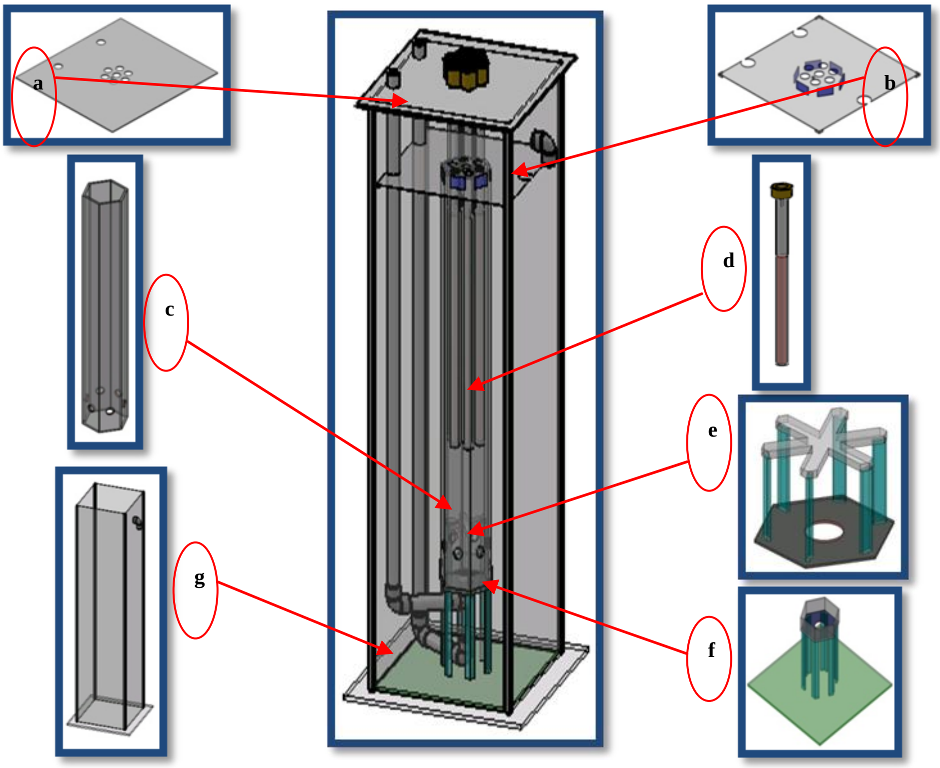


**Fig. 1:** Experimental section test

**Specification:**
a**.** Heating Cylinder hanger, b. *Spacer*, c. Test section *Main*, d. Heating cylinder, e. *Distributor*, f. Holder Test Section Main, g. Section Test.

For each heat flux, temperature and water heating cylinder was observed to obtain a steady state then conducted data collection in sub channel water temperature ($T_a$) and in the cylinder wall heater ($T_w$) at a height that corresponds.

## III. Result And Discussion

The results obtained from experimental testing of test equipment in the reactor core model of the sub channel arrangement of hexagons that things affect the temperature of the fluid in the sub channel including the magnitude of the heat flux in the heating cylinder and fluid inflow velocity. To determine the fluid temperature distribution based on the influence of velocity to 0.1, 0.3 and 0.5 m $s^{-1}$ can be seen in the following Fig. 2 - 4:

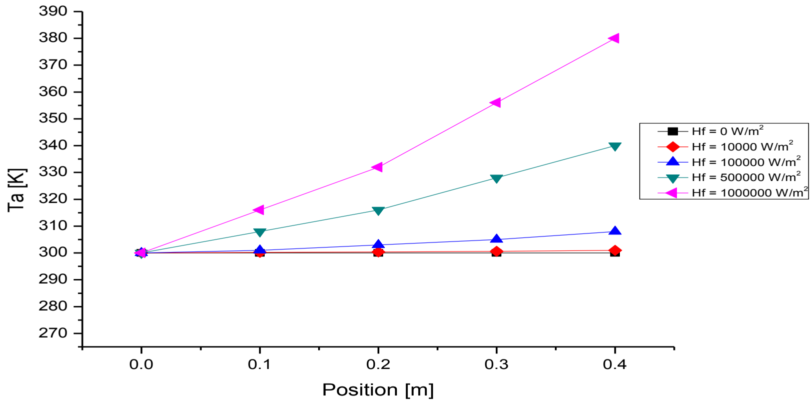


**Fig. 2.** The temperature of the fluid to the height based on variations in the heat flux in the sub channel on forced convection heat transfer to the incoming fluid velocity of 0.1 m $s^{-1}$

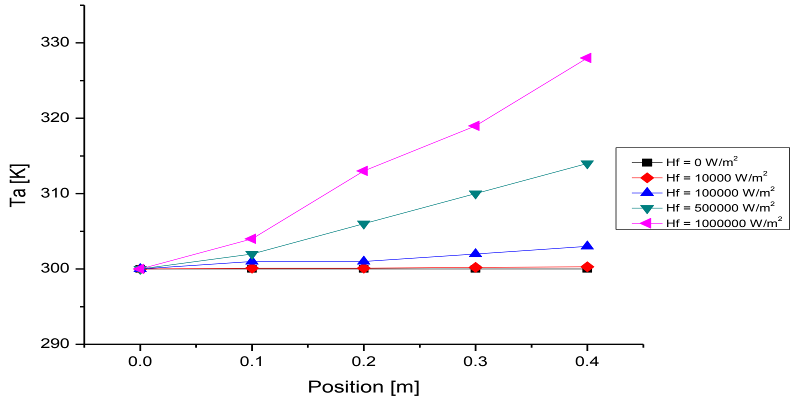


**Fig. 3.** The temperature of the fluid to the height based on heat flux variation at the sub channel on forced convection heat transfer to the incoming fluid velocity 0.3 m $s^{-1}$

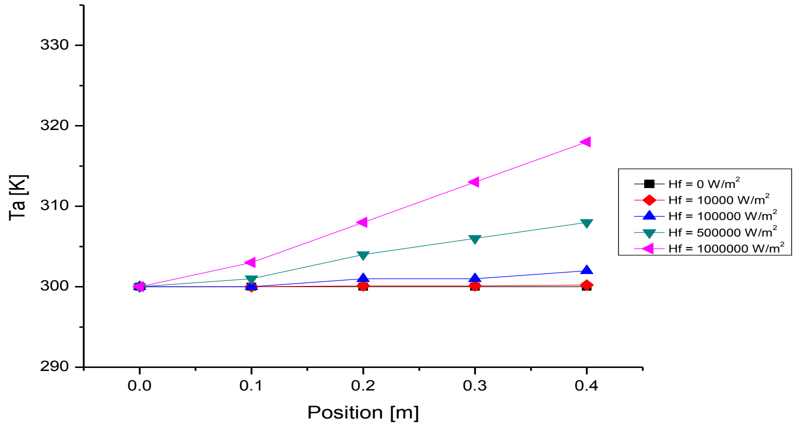


**Fig. 4.** The temperature of the fluid to the height based on heat flux variation at the sub channel on forced convection heat transfer to the incoming fluid velocity of 0.5 m $s^{-1}$

Fig. 2 **-** 4 can be seen that the fluid temperature increases due to the heat flux on the heater cylinder to increase as well, so the greater the heat flux on the heater cylinder resulting fluid temperature goes up, it is because the larger the heat flux on the heating cylinder heat absorbed fluid also increases.

For heating wall temperature, the magnitude of the heat flux to the wall temperature cylinder affect heating. The greater the heat flux is given, and then the temperature of the cylinder wall heater will also be more in line with the increase in height of the cylinder heater. This occurs because the temperature rise in the fluid absorbs heat from the surface of the heating cylinder required high surface temperatures of the height underneath. Here is a heat transfer coefficient which is derived in this study with numerical calculations at a velocity of 0.1 m $s^{-1}$, 0.3 m $s^{-1}$ and 0.5 m $s^{-1}$ with a heat flux of 100 000 $Wm^{-2}$.

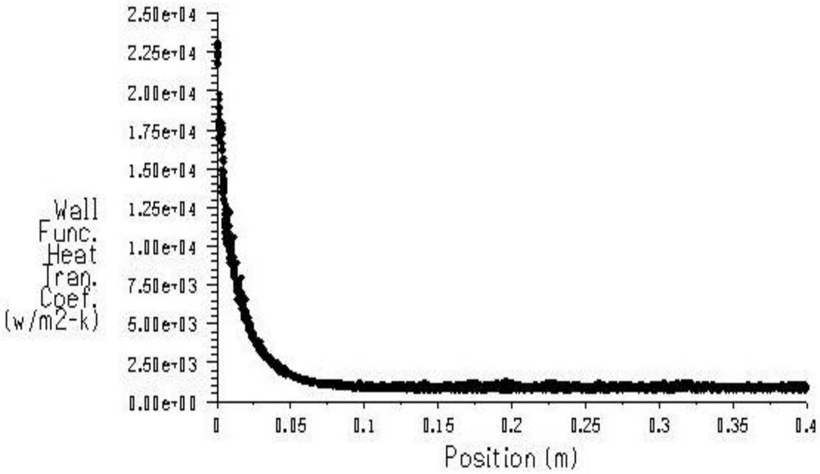


**Fig. 5.** Forced convection heat transfer coefficient on the fluid flow velocity of 0.1 m $s^{-1}$and heat flux 100 000 $Wm^{-2}$

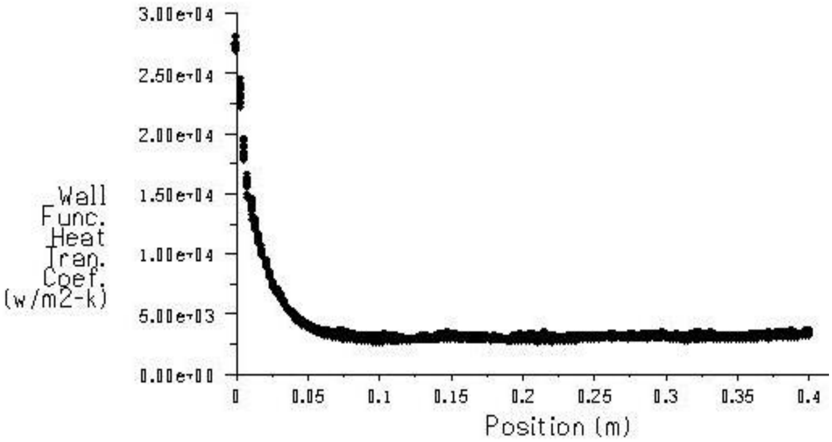


**Fig. 6.** Forced convection heat transfer coefficient on the fluid flow velocity 0.3 m $s^{-1}$ and heat flux 100 000 $Wm^{-2}$

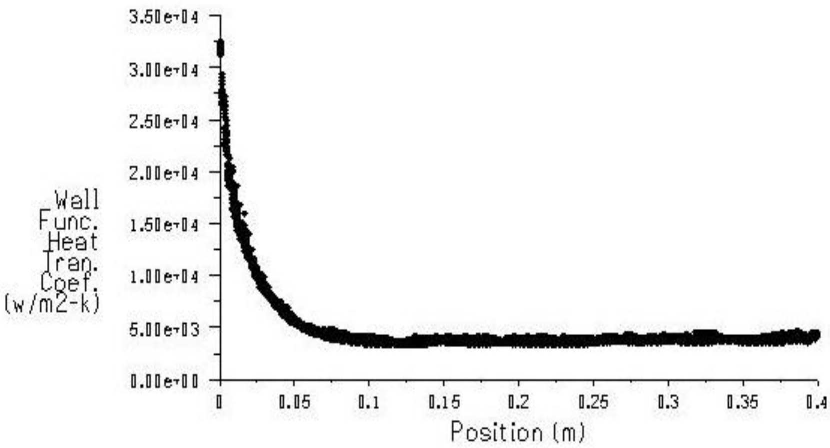


**Fig. 7.** Forced convection heat transfer coefficient on the fluid flow velocity of 0.5 m $s^{-1}$ and heat flux 100 000 $Wm^{-2}$

Fig. 5 - 7 at the early entry of high fluid velocities resulting heat transfer coefficient value was high. Flowing fluid velocity will decrease due to the forced convection flow is driven by the size of the initial input velocity submerged by a wall heater so the heat transfer coefficient was reduced. Velocity affects the heat transfer coefficient, the greater the velocity of fluid flow heat transfer coefficient increases. This occurs because the faster fluid flow turbulence in fluid bigger so it can transfer heat rapidly and lead to the heat transfer coefficient becomes large.

In this study, the physical properties of water are evaluated at the film temperature is the average of the temperature of the cylinder wall heater with water temperature. While the dimensional characteristics used is the hydraulic diameter. In forced convection, due to an outside force that generates the flow Nusselt numbers correlated with Graetz numbers.

$$Gz = Re\ Pr\ Dh / x \tag{2}$$

In these experimental studies of correlations obtained a relationship between the Nusselt numbers with another dimensionless number that allegedly correlated with the Nusselt number. Letting X and Y is a dimensionless number that is believed to correlate with the Nusselt number, the shape of the correlation equation can be in the form of Equation (3).

$$Nu = aX^{b} \tag{3}$$

Then the modification of Equation (3) with the operation logarithm to the base ten of the left and right side of the equation. This is done to change the shape of the rank of Equation (3) into a linear equation. Thus Equation (3) turns into Equation (4).

$$\log Nu = \log a + b \log X \tag{4}$$

To obtain Equation (4), heat transfer data is first processed so that the data obtained Nusselt numbers, X, and Y. Then the data is correlated by using the linear regression analysis of the data, either a variable or multivariable regression, which is available in Excel software. The results of the regression are a log value as *intercept* and b as a constant value, equipped with a statistical analysis that shows the level of correlation is generated. Then the equation in the form of Equation (3) can be obtained by using the inverse-log operation against the results obtained by linear regression.

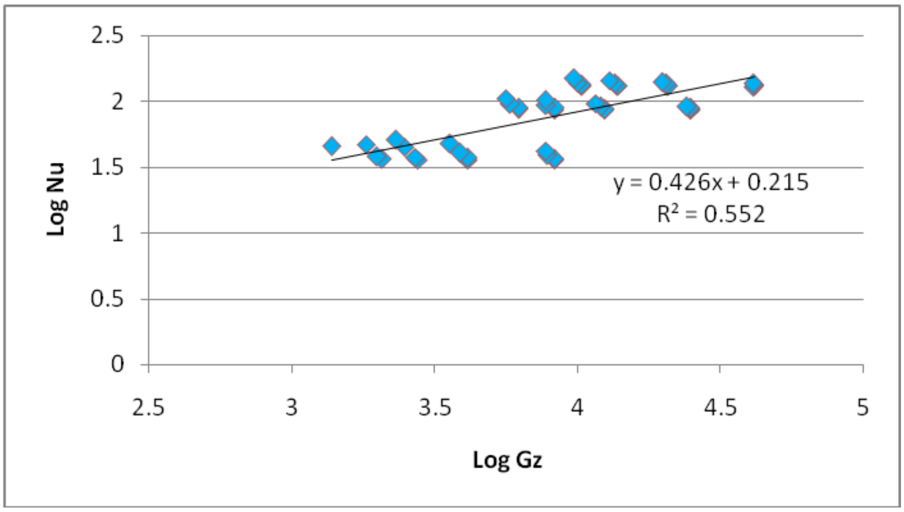


**Fig. 8.** Correlation forced convection heat transfer in the sub channel with hexagonal arrangement for turbulent flow regime

Correlation in Fig. 8 above is obtained by connecting between Nu Log in Log Gz results of this test are statistically coefficient of determination $R^2 = 0.5524$.

From the above description in order to get a new correlation in this study derived from Figure 8 above equation y = 0.4267x + 0.2152 may be compared to 0.4267 with b as constants and 0.2152 with a log as the *intercept*. To get a, log a must in the log so that *the inverse inverse* log of 0.2152 is 1.641. so that the results of the experimental data, obtained correlation equations for forced convection in turbulent flow regime as follows:

$$Nu_{forced}\ \mathrm{Gz} = 1.641^{\ 0.4267} \quad (5)$$

This correlation applies to 1 371 ≤ Gz ≤ 41 244 and 29 537 ≤ Re ≤ 3 991 or streams that are in the turbulent regime.

## IV. CONCLUSION

From the results obtained the following conclusions:

1. At the same measurement position, the greater the heat flux supplied to the cylinder wall heater, the higher the temperature of the cylinder wall heater. So also with the fluid temperature, the greater the heat flux, the fluid temperature is also higher.
2. The physical properties of water are evaluated at the film temperature and heat transfer data is correlated with the length of the characteristics of a hydraulic diameter.
3. The experimental results in forced convection flow shows that the flow in a turbulent state.
4. Correlation forced convection heat transfer as follows: $Nu_{forced}$ Gz = $1.641^{\ 0.4267}$

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