# Estimating the natural circulation flow rate through the core in a research reactor

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## 1. Introduction

Many research reactors use natural circulation to cool the reactor core [1-3]. The research reactors are usually submerged in a pool. The pool water comes in to the core from the bottom of it, passes it through, and goes out to the pool - Fig. 1.

In a preliminary design phase of a research reactor, the precise calculation of the natural circulation flow rate is inadequate since the detail design specification of the flow paths is not fixed. In the present paper, a simple procedure to obtain the rough estimation of the natural circulation flow rate through the core will be presented.

## 2. Mass flow friction factor

In this part of this paper, the mass flow friction factor will be described. The concept will be useful for a quick evaluation of the natural circulation flow rate.

The pressure drop through a flow path can be stated by the following relation.

$$\Delta p = k\frac{1}{2}\rho V^2 = k\frac{1}{2}\frac{\dot{m}^2}{\rho A^2} = K\dot{m}^2 \tag{1}$$

where,

- $\Delta p$ pressure drop
- $k$ friction factor depends on flow path geometry and Reynolds number
- $\rho$ fluid density
- $V$ fluid velocity
- $A$ characteristic flow path area
- $\dot{m}$ mass flow rate
- $K$ mass flow friction factor

The following assumptions will be applied to the equation (1).

(1) Density is constant
(2) Ignoring the Reynolds number effect on the flow friction factor

With the assumptions mentioned above, the mass flow friction factor, $K$, for given flow path geometry can be assumed to be constant regardless of mass flow rate.

For a serial flow path, the total mass flow friction factor can be stated by the following relation.

$$\begin{aligned} K\dot{m}^2 &= K_1\dot{m}^2 + K_2\dot{m}^2 + \cdots + K_n\dot{m}^2 \\ K &= K_1 + K_2 + \cdots + K_n \end{aligned} \tag{2}$$

For a parallel flow path, the total mass flow friction factor can be stated by the following relation.

$$\begin{aligned} \dot{m}_{total} &= \dot{m}_1 + \dot{m}_2 \\ K\dot{m}_{total}^2 &= K_1\dot{m}_1^2 = K_2\dot{m}_2^2 \\ \frac{1}{K} &= \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{\sqrt{K_1K_2}} \end{aligned} \tag{3}$$

The above relations are similar to those of electric resistance for serial and parallel circuit.

## 3. Natural circulation flow rate

The water column weight difference (buoyancy force) between the pool water and the primary coolant inside the vessel would be the driving force of the natural circulation flow. As the water flows through the core its temperature would rise and its density would drop. For a conservative approach, the density is assumed to drop at the core exit.

In the water temperature range of 30℃ ~ 60℃, the density variation with respect to the temperature is almost linear[4] and can be approximated by the following equation.

$$\frac{\Delta\rho}{\Delta T} \approx \frac{2kg/m^3}{5°C} \tag{4}$$

The height of the water column of the core to the reactor exit to the pool is assumed to be 3 m where the water column weight is lower than the pool water due to the temperature rise at the core exit. Then the water column weight difference per unit area, which will be the pressure difference, can be calculated by the following relation.

$$\begin{aligned} \Delta p &= (3.3m)\times(9.81m/s^2)\times\frac{(2kg/m^3)}{5°C}\times\Delta T_{core} \\ &\cong 12.9\Delta T_{core}\text{, Pa} \end{aligned} \tag{5}$$

Using the pressure drop and mass flow friction factor relation,

$$12.9\Delta T_{core} = K\dot{m}^2 \quad (6)$$

The design variables of HANARO[1] research reactor are used for this study. The thermal power is 30MWt, the pump capacity is 700kg/s, and the pressure drop through the core is about 200kPa. Most of the pressure drop occurs in the reactor core. Therefore, the mass flow friction factor through the reactor of the HANARO in natural circulation mode can be approximately obtained as below.

$$200kPa = K(700kg/s)^2$$
$$K \cong 0.408 \quad (7)$$

The water temperature rise through the core can be calculated by the following equation.

$$P_{decay} = \dot{m}C_p\Delta T_{core} \quad (8)$$

The decay heat power, $P_{decay}$, is as follows [5].

$$\frac{P_{decay}}{P_0} = 0.066\left[t^{-0.2} - (t+\tau)^{-0.2}\right] \quad (9)$$

For a conservative approach, the operating power, $P_0$, is set to 30MW and operation time( $\tau$ ) is set to infinite. Then, the equation (9) becomes,

$$0.066P_0t^{-0.2} = \dot{m}C_p\Delta T_{core} \quad (10)$$

Using the equation (6) and (10), the natural circulation flow rate can be obtained.

$$\dot{m} \cong 24.7t^{-(1/15)} \quad (11)$$

And, the temperature rise is as follows.

$$\Delta T_{core} = 19.2t^{-(2/15)} \quad (12)$$

The natural circulation flow rate and the flow temperature rise through the core are shown in Figure 2. Since the primary cooling pump would operate more than an hour after the reactor shutdown, Fig. 2 shows the calculated results after an hour. The natural circulation flow rate is above 12 kg/s for more than 10 hours. The water temperature rise through the core is below 6 ℃.

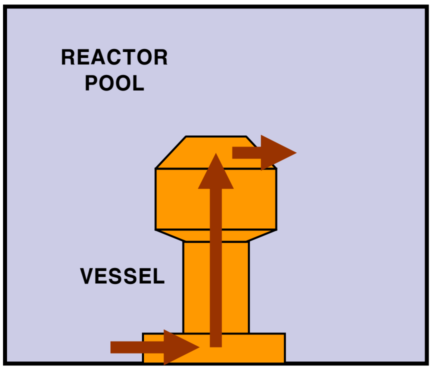


Fig. 1. Natural circulation flow path in a research reactor

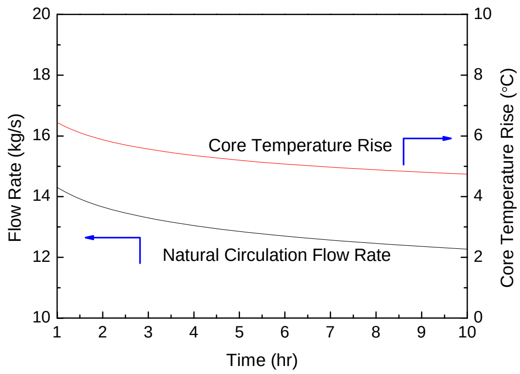


Fig. 2. Natural circulation flow rate
and water temperature rise through the core

## 4. Conclusions

A simple procedure estimating the natural circulation flow rate for a research reactor has been shown. The presented method has been applied to calculate the natural circulation flow rate of the HANARO [1] research reactor. In the preliminary design phase of research reactors, the presented procedure will be useful to evaluate the natural circulation flow rate through the core.

## REFERENCES

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