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Analytical Estimation on the Heat Losses in an Open Pool-type Research Reactor

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1. Introduction

A low-power research reactor without a primary cooling system adopts the free convection flow for cooling the core. The heated pool water is purified and cooled by a Pool Cooling and Purification System (PCPS). In order to design the PCPS that meets the reasonable cooling capacity, thermal energy and uncertainty estimations are some of the important issues that must be considered. Analytical approaches are used to analyze the energy losses of a reactor pool. This work presents the rate of environmental heat losses – such as evaporative, convective, and conductive heat losses – in an open pool-type research reactor.

2. Methods and Results

The reactor pool is considered as a control volume to define the energy balance. The environmental heat losses in an open pool-type reactor can be categorized into two factors, namely heat losses on the free-surface and the pool wall. Figure 1 shows the schematic of a pool-type research reactor. Heat balance can be expressed as Equation (1), and to estimate environmental energy losses, the PCPS and core energies are excluded in this work. Table 1 shows the environmental conditions used for calculating heat losses.

$$0 = q_{conv.} + q_{conc.} + q_{evap.} + q_{PCPS.out} - q_{PCPS.in} - q_{core} \quad (1)$$

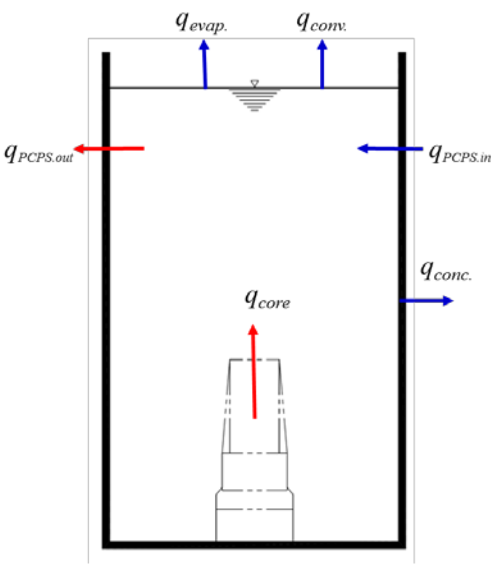

Fig. 1 Schematic of an open pool type reactor

Table I: Environmental conditions

	Initial temp. (℃)
Atmosphere, T_A	21 / 26
Pool water, T_W	40
Concrete wall, T_C	18
Reactor Pool	Dimension (m)
	2(W)*2(L)*7(H)

2.1 Conductive heat loss through the wall

The conductive heat loss through the concrete wall and the temperature distribution can be expressed by equations (2) and (3), respectively [1]. To solve the transient heat conduction problem, the pool wall is assumed as a semi-infinite solid and constant surface temperature. Thermal conductivity of concrete, *k* is 1.5 W/m·K and the thermal diffusivity, *a* is 1.4 m^2/s.

$$q_s'' = -k\frac{\partial T}{\partial x}\bigg|_{x=0} = \frac{k(T_W - T_C)}{\sqrt{\pi\alpha t}} \quad (2)$$

$$T = (T_C - T_W)\, erf\left[\frac{x}{\sqrt{4\alpha t}}\right] + T_W \quad (3)$$

The calculated result of heat loss through the wall is shown in figure 2. It reduces as time goes by. It can be observed that excessive rate of heat loss is calculated initially. This is because, the initial pool water temperature is not 40℃ under actual condition. The conductive heat loss through the concrete wall is approximately 8.2kW at 24 hours.

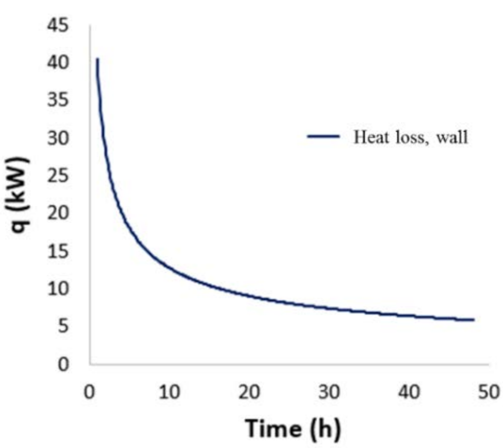

Fig. 2 Rate of conductive heat loss through the wall

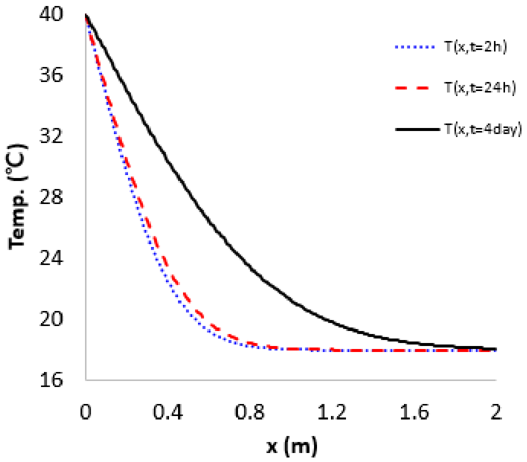

Fig. 3 Temperature distributions on the concrete wall

Figure 3 represents the temperature distributions by the conductive heat loss through the wall. The results indicate that the temperature converges from pool water temperature of 40℃ to 18℃ with wall thickness increases.

2.2 Convective and evaporative heat losses

The calculations for heat losses on the pool water free-surface have been segregated by the physical phenomena, evaporation and convection. An atmospheric temperature range of 18 - 32℃ was used to compute the evaporative heat loss. The range is wider than the normal operating conditions of a HVAC system in order to consider various air conditions. The rates of evaporation and heat loss can be expressed by Equations, (4) and (5) [2].

$$\dot{m} = A(P_w - P_a)(0.089 + 0.0782V) / h_{fg} \qquad (4)$$

$$q = \dot{m}\lambda \qquad (5)$$

Here, $\dot{m}$ dot is evaporation rate, A is pool area, and V is air velocity assumed as 0.1m/s. P_w and P_a are saturation vapor pressure at surface water temperature and room air dew point, respectively. h_{fg} is the latent heat, which requires evaporation at surface water temperature and λ is the enthalpy difference between water and steam. The evaporative heat losses with temperature changes are shown in figure 4. The heat losses decrease with increasing temperature and humidity. The heat losses are 0.0838kW and 0.0589kW for 21℃ and 26℃ under 40% of humidity, respective, the considered temperature and humidity are representative operating conditions in the room. The Rayleigh number for calculating convective heat loss on the free surface can be expressed as Equation (6). Here, L_c is characteristic length of free-surface area (pool area per perimeter): 0.5 meter and Ra_L is 2.951E+08. Therefore, the Nusselt number Equation (7) can be recommended [3].

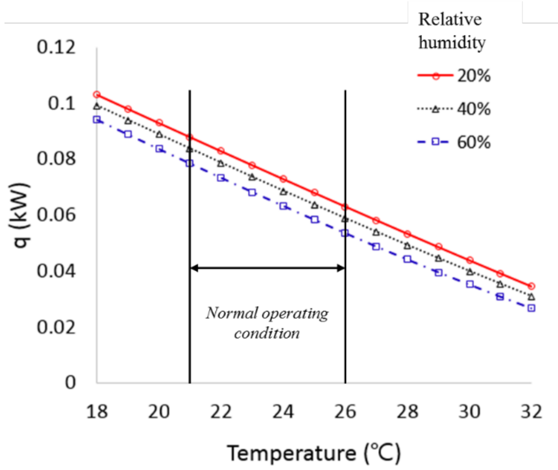

Fig. 4 Rate of heat losses by evaporation

$$Ra_L = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu\alpha} \qquad (6)$$

$$Nu = 0.15{Ra_L}^{1/3} \ for \ (10^7 \le Ra_L \le 10^{11}) \qquad (7)$$

$$Nu = \frac{hL_c}{k} \qquad (8)$$

The heat transfer coefficient can be obtained using Equation (8), the convective heat losses under 40% of humidity are 0.393kW and 0.26kW under atmospheric conditions of 21℃ and 26℃, respectively.

3. Conclusions

The analytical methods and the heat losses were presented in this work and the calculated heat losses were maximum 8.67kW and minimum 8.51kW. Additional analyses are necessary to reduce uncertainties so that the results will give information on the designing of the PCPS, which is the scope of the future work.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Yunus. A. Cengel and Afshin J. Ghajar, Fundamentals of Heat and Mass Transfer: Fundamentals and Applications, Fifth Edition, McGraw-Hill Education, New York, 2015.
[2] ASHRAE, ASHRAE Handbook HVAC Applications (SI), p.5.6, 2011.
[3] J. R. Lloyd and W. R. Moran, Natural Convection Adjacent to Horizontal Surface of Various Planforms, Journal of Heat transfer, Vol.96(4), p.443-447, 1974.