

Comparison of the cooling performance between coil-type and water-jacket type cooling system for the main coolant pump

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1. Introduction

The Main Coolant Pump (MCP) for Small Modular Reactor (SMR) has inner flow path filled with primary coolant. If the motor of the pump is not properly cooled down, the lifetime and performance of the pump can be severely deteriorated. Therefore, appropriate cooling systems are required for MCP.

There are two typical cooling types for MCP: 1) cooling coil type, 2) water jacket type. In coil type cooler, cooling coils are inserted into the pressure boundary, and directly cool down the inner flow. However, the penetration in the pressure boundary is undesirable in the perspective of structural reliability. In water jacket type, on the other hand, cooling performance is expected to be lower. However, the structural reliability is better than coil type cooler. Therefore, the engineer needs to select proper cooler type according to design requirements.

In this study, the two types of the coolers are compared quantitatively by modeling them into 1-D heat transfer problem. From heat sources to sinks, thermal resistances are modeled with conductive and convective heat transfer models. Using the models and input geometric and physical parameters, their thermal performances and each path's thermal resistances are presented. The results will help engineers to determine which cooler type is suitable for their systems.

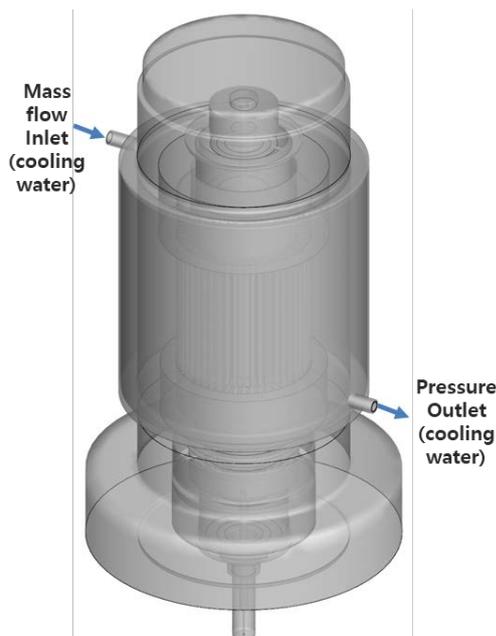


Fig. 1. Cooling concept for the main coolant pump

2. Methods

The configurations of cooling systems are depicted in Fig. 1. Heat is dissipated from stator and rotor of the motor, so they become a heat source. There is another heat source for the pump. Since the entire reactor system is highly integrated, there is a constant temperature heat source. It was assumed that the additional heat is transferred from this constant temperature heat source to the motor with a proper value of the thermal resistance.

In the coil type system, cooling coil is located just outside the stator, and the pressure boundary covers the entire system. The amount of heat transferred through this pressure boundary was assumed negligible. The inner flow circulates, and transfers heat from the motor to cooling coils. In the water jacket type system, the inner flow takes heat from motor and transfers it to the pressure boundary. Then, the heat flow through the wall and cooled by water jacket.

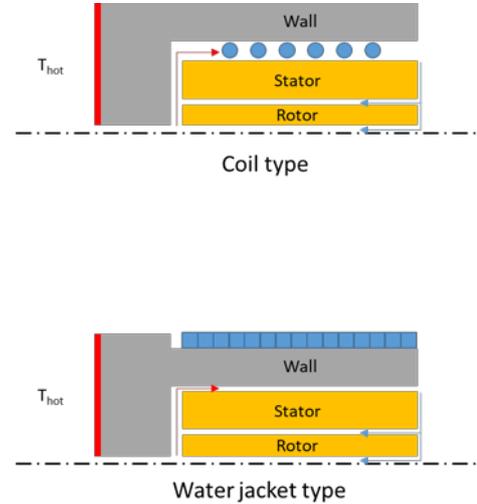


Fig. 2. Configuration of cooling types

Fig. 2 presents the circuits for the thermal resistance for each cooler type. Except the conduction thermal resistances at constant temperature heat source and pressure boundary walls, they are modeled as the convective thermal resistances [1]. The convective thermal resistance is expressed as follows:

$$R_{th} = 1/hA, \quad (1)$$

where R_{th} is the thermal resistance; h is the heat transfer coefficient; A is the surface area.

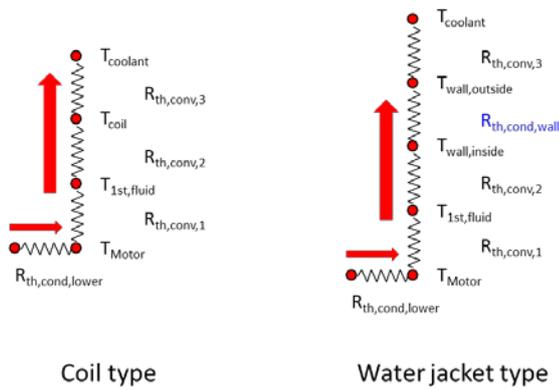


Fig. 3. 1-D heat transfer model

For each heat transfer paths, proper Nusselt number correlations were used. Among them, the correlation suggested by Dittus-Boelter [2] was used for the turbulent flows with the concept of hydraulic diameter.

3. Results

With geometric and physical information, the temperatures and thermal resistances corresponding to each flow path were obtained. T_c is the cooling water temperature and the results were presented as the non-dimensional form with the cooling temperature.

Results in Table 1 shows that the coil type cooler has much better cooling performance than the jacket type cooler. However, it should be noted that too low pump core temperature could cause other problems related to thermal stresses. Therefore, if predicted motor temperature satisfies the allowable maximum temperature [3], relatively high values of the motor temperature are acceptable. From the listed thermal resistances, we can find that the thermal performance of the jacket type cooler mainly depends on the thermal resistance of the pressure boundary ($R_{th,w}$).

Table 1. Results for the reference design

Coil	T_{motor}	$R_{th,c1}$	$T_{1st,f}$	$R_{th,c2}$	T_{coil}	$R_{th,c3}$		
T (°C)	$1.59T_c$	-	$1.19T_c$	-	$1.05T_c$	-		
R_{th} (K/W)	-	$4.75e-4$	-	$1.64e-4$	-	$5.55e-5$		
Jacket	T_{motor}	$R_{th,c1}$	$T_{1st,f}$	$R_{th,c2}$	T_{wj}	$R_{th,w}$	$T_{w,o}$	$R_{th,c3}$
T (°C)	$2.12T_c$	-	$1.98T_c$	-	$1.75T_c$	-	$1.1T_c$	-
R_{th} (K/W)	-	$1.88e-4$	-	$3.09e-4$	-	$8.82e-4$	-	$1.34e-4$

Table 2. Comparison of motor temperatures at various wall thickness

$k_c = 55$ W/m-K	t_{wall} (m)	0.01	0.02	0.03	0.04	0.05
T_{motor} (°C)	Coil	$1.59T_c$				
	Jacket	$1.89T_c$	$2.12T_c$	$2.32T_c$	$2.49T_c$	$2.64T_c$

Table 2 shows the comparison of motor temperatures at various wall thickness. As the wall thickness decreases, the motor temperature of jacket type cooler approaches the cooling performance of coil type cooler.

Table 3. Comparison of motor temperatures at various flow rates of sub-impeller

$t_{wall} = 0.02m$	Q_{sub} (m³/s)	$2.0e-4$	$4.0e-4$	$8.0e-4$	$16.0e-4$	$24.0e-4$
T_{motor} (°C)	Coil	$2.20T_c$	$2.02T_c$	$1.59T_c$	$1.39T_c$	$1.31T_c$
	Jacket	$2.59T_c$	$2.31T_c$	$2.32T_c$	$2.00T_c$	$1.95T_c$

In Table 3, the effect of inner flow rates provided by sub-impeller on the motor temperature is presented. The higher flow rates increase cooling performance, however, it should be noted that the sub-impeller takes away the power of the pump.

4. Conclusions

In this study, the coil type and jacket type MCP cooling systems were compared in terms of cooling performance. For the analysis, the heat transfer path from heat source to sink was modeled with thermal resistance circuits. The results presented that the coil type cooling system has better performance than the jacket type cooling system. The main reason for this difference is the existence of pressure boundary. If a system allows relatively high operating temperature, the jacket type cooling system, which provides the better structural reliability, can be an option. However, for the case where cooling performance is much more important, it would be better to use coil type cooling systems.

REFERENCES

- [1] F. P. Incropera et al., Fundamentals of Heat and Mass Transfer, 6th edition, John Wiley & Sons, 2007.
- [2] R. H. S. Winterton, Where did the Dittus and Boelter equation come from, Int. J. Heat Mass Transfer, 41, 809, 1998.
- [3] Insulation systems and thermal life expectancy, www.marathongenerators.com.