Design of KALIMER-600 Primary Pump and Analysis of Coastdown Flow Rate

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1. Introduction

The KALIMER-600 is a 600MWe electric power liquid metal reactor being developed at Korea Atomic Energy Research Institute. A centrifugal type mechanical pump is adopted as a primary pump in the KALIMER-600 design. The primary objective of the present study is design of the mechanical pump and analysis of its performance to remove the decay heat during the coastdown. The design parameters of the primary pump and the transient coastdown flow rate and rotational speed are obtained from the present study.

2. Pump Design

The criteria for designing the primary pump are as follows;

(1) The pump is a centrifugal pump.
(2) The temperature of the sodium is 370℃.
(3) The pump head is 0.42Mpa.
(4) The flow rate is 240 m^3/min.
(5) The maximum rotational speed is 450rpm.

Using the above design criteria, the design is performed following the method given in Ha and Shon [1]. The detailed design process is given in Choi [2]. The shape of the pump and its dimensions are given Fig.1 and detailed design specifications of the pump are given in Table.1.

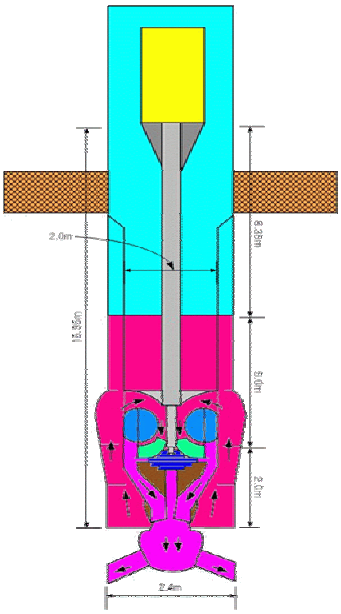

Figure 1. The shape and dimensions of pump

Table 1. Design Parameters of KALIMER-600 Pump

Design Parameters	KALIMER-600	Reference
Type of Pump	Centrifugal	
Flow Rate (m^3/min)	238.43	=3.97 m3/s
Temperature of Sodium (℃)	370.4	
Pump Actual Head (Mpa)	0.42 (=49.64m)	Core : 0.27,
Total Head (m)	59.49	20% margin
Rotational Speed (rpm)	450	
Specific Speed [rpm][m3/min][m]	310	
Suction Pipe Diameter (m)	1.09	
Discharge Speed (m/s)	7.86	
Water Horse Power (Mw)	2.0	
Pump Efficiency (%)	85	
Shaft Horse power (Mw)	2.36	
Motor Power (Mw)	2.83	
Impeller Boss Diameter (m)	0.54	
Torque (kgf-Cm)	534,218	=52,353(N-m)
Impeller Shaft Diameter (Cm)	30.	
Impeller Inner Diameter (m)	1.19	
Impeller Outer Diameter (m)	1.65	
Peripheral Velocity (m/s)	37.58	
Number of Impeller Vane	8	
Required NPSH (m)	9.83	
Available NPSH (m)	13.99	
Cavitation Margin (m)	3.64	
Discharge Pipe O.D (m)	1.95 (2.0)	5cm Margin
Suction Pipe O.D. (m)	2.25 (2.4)	5cm Margin
Pump Height (m)	15.35	

3. Analysis of Coastdown Flow Rate

When the electric power is not supplied to the pump, the pump stops quickly and loses power to pump the coolant. However, there should exist a fluid flow to remove the decay heat of the reactor core. Usually that is done by providing the inertial moment through installing a solid body above the pump. Thus, the magnitude of the inertial moment of the solid body should be provided when one designs the pump. In the present study we analyze the transient flow rate and rotational speed as well as the magnitude of the inertial moment of the solid body.

The analysis of coastdown process requires the solutions of the following two governing equations such as the momentum equation and the angular momentum equation.

$$\left(\frac{l}{A}\right)_{Total}\frac{dM}{dt} = \Delta P_{pump} - \Delta P_{friction} \qquad (1)$$

$$I\frac{d\omega}{dt} = \mathrm{T}_{motor} - \mathrm{T}_{hydraulic} - \mathrm{T}_{friction} \qquad (2)$$

where M is the mass flow rate and I is the moment of inertia of solid body . Since the following relations holds

$$\Delta P_{pump} = \rho g H_{head} \qquad (3)$$

$$\Delta P_{friction} = C_R \frac{M^2}{2\rho} \qquad (4)$$

$$C_R = RM^{-n} \begin{cases} n = 0.2 & for\ turbulent\ flow \\ n = 1.0 & for\ laminar\ flow \end{cases} \qquad (5)$$

then, Eq.(1) becomes

$$\left(\frac{l}{A}\right)_{Total}\frac{dM}{dt} = \rho g H_{head} - C_R \frac{M^2}{2\rho} \qquad (6)$$

The value of $\left(\frac{l}{A}\right)_{Total}$ is not a time varying quantity and can be obtained from the geometries of components of the reactor. The value of R in Eq.(5) can be obtained from the steady state solution. In the steady state, $\Delta P_{pump} = \Delta P_{friction}$, then, the Eq.(6) can be written as follows;

$$\rho g H_{head} = C_R \frac{M^2}{2\rho} \qquad (7)$$

In the steady state $\rho = 863.41\,[kg/m^3]$, $H_{head} = 59.56\,[m]$, $M = 3431\,[kg/m^3]$, and $C_R = RM^{-0.2}$, then we obtain $R = 377.3$.

Since the motor torque is zero during the coastdown process, Eq.(2) can be written as;

$$I\frac{d\omega}{dt} = -(\mathrm{T}_{hydraulic} + \mathrm{T}_{friction}) \qquad (8)$$

The solutions of the Eq.(6)-(8) requires the values H_{head}, $\mathrm{T}_{hydraulic}$, $\mathrm{T}_{friction}$ which can be obtained from the homologous curves of the pump. The homologous curve of the KALIMER-600 pump which can be obtained from experiment or CFD analysis is not yet established. In the present analysis the homologous curve given in the SSCK code is used.

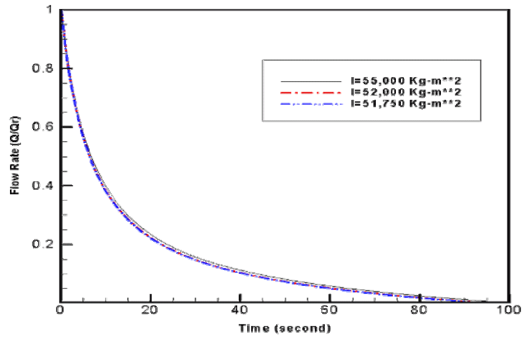

Fig.2-(a) Flow rate according to the magnitude of inertia

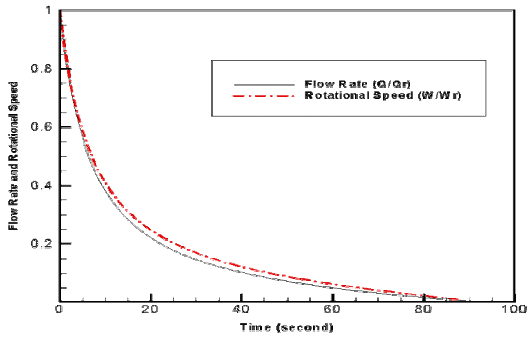

Fig.2-(b) The transients of flow rate and rotational speed when I=51,700 Kg-m^2

Fig.2-(a) shows the transients of the coastdown flow rate according to the magnitude of the inertial moment of the solid body, and we can see that when I=51,700 Kg-m^2 , the flow rate becomes 5% after 60seconds. Fig.2-(b) shows the transient flow rate and rotational speed when I =51,700 Kg-m^2. The detailed analysis is given in Choi [3].

4. Conclusions

The design of the KALIMER-600 primary pump is performed and detailed design parameters are given. The coastdown process is analyzed and the magnitude of the inertial moment is shown to be I=51,700 Kg-m^2 which satisfies the design condition that the flow rate is 5% after 60 seconds. The transient of the mass flow rate which can be used for the safety analysis is provided.

REFERENCES

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[3] S. K. Choi, "Analysis of the Magnitude of Inertial Moment and Coastdown Flow Rate for KALIMER-600", KAERI Internal Report, 2004.