Performance Prediction of Mechanical Pump in STELLA-1

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1. Introduction

Under a mid- and long-term nuclear R&D program, STELLA (Sodium Integral Effect Test Loop for Safety Simulation and Assessment) project is in progress in KAERI (Korea Atomic Energy Research Institute).

In STELLA-1, the experiments for the evaluation of heat exchangers such as DHX (Decay heat exchanger) and AHX (Air heat exchanger) are being performed, and those for PHTS (Primary heat transport system) mechanical pump are being prepared[1]. The detailed design of each component is based on that of a 600MWe demonstration reactor.

The model pump installed in STELLA-1 was scaled down based on the scaling law[2]. Since the reference reactor of STELLA-1 is a 600MWe pool type demonstration reactor, some design modifications were inevitable between pool type prototype pump and loop type model pump, such as outer case and inlet pipe.

In this study performance evaluation on the model pump has been done by CFD methods. The Design modeler in ANSYS Workbench was utilized in modeling process. The computations were performed using the commercial code ANSYS CFX[3]. The overall hydraulic behaviors in the model pump have been predicted at a steady state condition.

2. Governing Equations

The governing equations for the continuity and Navier-Stokes for an incompressible flow can be written as follows;

$$\frac{\partial U_i}{\partial x_i} = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho U_i) + \frac{\partial}{\partial x_j}(\rho U_i U_j) = -\frac{\partial p'}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu_{eff}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right) + S_M \qquad (2)$$

The $k-\varepsilon$ model is employed as a turbulent model and related equations are as follows;

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho U_j k) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right) + P_k - \rho\varepsilon + P_{kb} \qquad (3)$$

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho U_j \varepsilon) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right) + \frac{\varepsilon}{k}(C_{\varepsilon 1}P_k - C_{\varepsilon 2}\rho\varepsilon + C_{\varepsilon 1}P_{\varepsilon b} \qquad (4)$$

3. Numerical Modeling and Results

Fig. 1 shows the main fluid domain in model pump. The sodium flows into a suction pipe, goes upward to guide vane, passes through impeller and diffuser and finally is discharged to pipe.

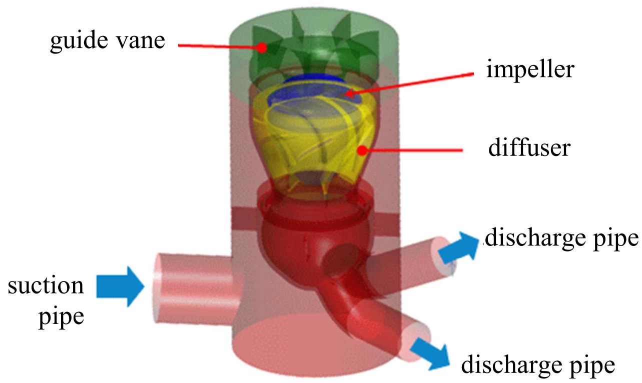


Fig. 1 Schematics of fluid domain in model pump

The numerical grid in fluid domain for the analysis is shown in Fig. 2. The number of numerical grid amounts to 752 million nodes and 2,297 million elements

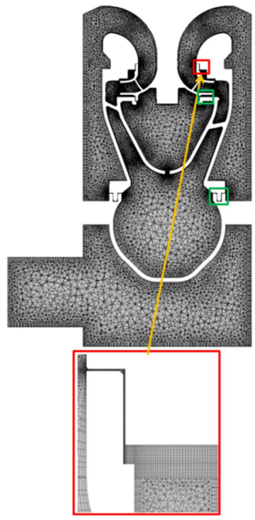


Fig. 2 Numerical grid of fluid domain

as shown in Table 1. For the efficient grid construction the unstructured grid is employed in the fluid domain except leakage flow path. The fluid is sodium.

Table 1 No. of nodes and elements in fluid domain

Domain	No. of Nodes	No. of Elements
Suction&Discharge	214 X 1E+6	641 X 1E+6
Guide vane	70 X 1E+6	262 X 1E+6
Impeller	347 X 1E+6	964 X 1E+6
Diffuser	119 X 1E+6	428 X 1E+6
Total	752 X 1E+6	2,297 X 1E+6

Fig. 3 and Fig. 4 show the predicted performance and efficiency, respectively. The efficiency was calculated based on the following equation.

$$\eta = \frac{Q\rho gh}{2\pi NT/60} \tag{5}$$

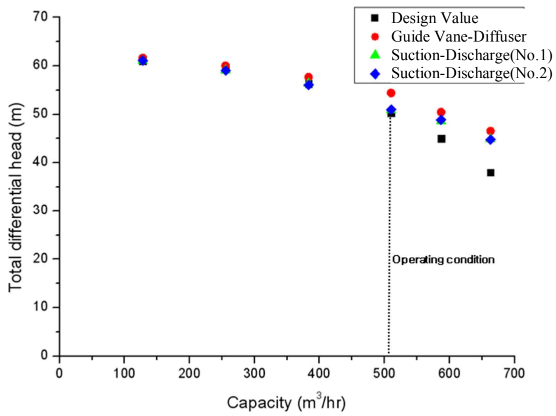


Fig. 3 Curve for head and capacity of model pump

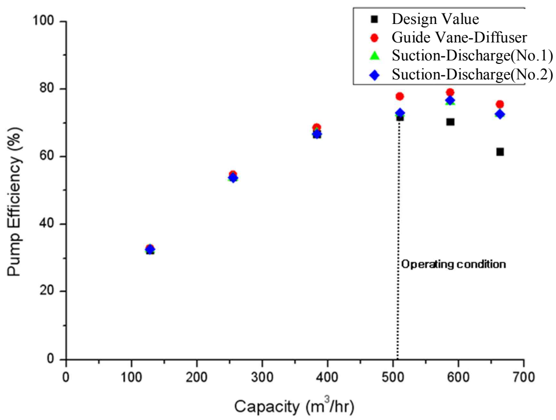
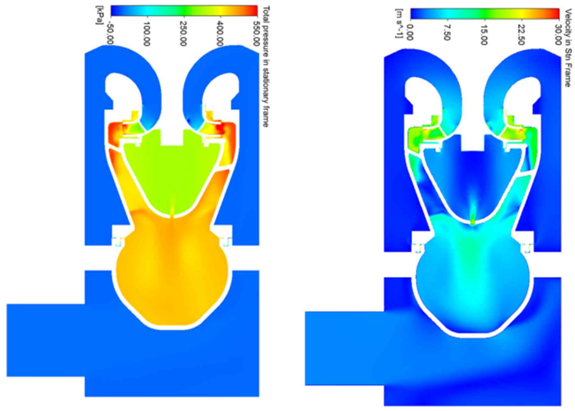


Fig. 4 Curve for efficiency of model pump

The predicted values are evaluated at two sections. One is from guide vane to diffuser and the other is from suction pipe to discharge pipe(No.1 and No. 2). As shown in Fig. 3 and 4 the predicted values at low capacities show little differences with design values. However the differences become increase for high capacity conditions. The maximum efficiency based on predicted value was 77.5% at 115% of rated capacity.

Fig. 5 shows total pressure and velocity distribution in model pump at rated condition. The reference pressure at suction pipe was assumed to be zero. As shown in figure the pressure between suction pipe to guide vane is negative value. It changes to positive value at impeller region and reaches the highest value at impeller tip. The velocity also shows the peak value at this region.



(a) Pressure (b) Velocity

Fig. 5 Predicted pressure and velocity distribution

In this research the hydraulic behaviors inside of model pump were predicted based on CFD analysis. The predicted results show little differences at low capacity conditions, however, some discrepancies exist at high capacity conditions comparing to design value.

4. Acknowledgement

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