



The mechanical strength analysis on the pool tub of loop heat pipe prototype using CATIA software

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Abstract

The NuScale Small Modular Reactor operates using a fully passive cooling system. Under normal operating conditions, the cooling water used to immerse the reactor has a temperature range of 30°C – 40°C. To reduce additional water due to evaporation, the use of a loop heat pipe (LHP) as a heat sink in the pool cooling water can reduce evaporation and increase the economic value of NuScale operations. To get a further basic understanding of LHP as an additional passive cooling system, a small-scale LHP prototype was made at the Center for Nuclear Reactor Technology and Safety, National Nuclear Energy Agency. This LHP prototype consists of several components, including a pool tub unit that simulates a pool of cooling water immersing the reactor. This research focuses on analyzing the mechanical strength of the pool tub before it is made and used as an experimental tool. The purpose of the analysis is to determine the mechanical strength of the pool tub including mechanical stress and translational displacement related to the level of safety and design safety. The method used is to simulate using CATIA software to analyze the mechanical strength of a swimming pool by making a 3-dimensional model according to an existing design, providing restraint on a 3-dimensional model, providing loads in the form of pressure and temperature on a 3-dimensional model, and testing mechanical strength. The simulation results show that the mechanical stress produced is 1.96×10^8 N/m² at the bottom of the pool tub. The mechanical stress that occurs is smaller than the yield strength of the AISI 1040 Carbon Steel material, which is 3.5×10^8 N/m². The translational displacement obtained of 0.844 mm is very small when compared to the dimensions of the pool basin, so it does not result in changes in the shape of the pool basin when pressure and temperature are given during the experiment. The conclusion of this simulation shows that the design of the pool tub unit is safe to manufacture and operate during the experiment.

Keywords: Mechanical strength; Mechanical stress; Translational displacement; Pool tub; Loop heat pipe.

1. Introduction

Based on the nuclear reactor accident at Fukushima Dai-Ichi in Japan, passive cooling systems in nuclear installations must be used to help dissipate residual decay heat that occurs continuously when the active cooling system is not functioning. The use of a passive cooling system is expected to improve the safety aspects of the operation of nuclear installations [1]–[3]. The concept of passive cooling has been applied in generation III+ nuclear reactors, and it has been included in the design of generation IV nuclear reactors [4], [5]. One type of generation IV nuclear reactor is the Small Modular Reactor, including the NuScale power reactor.

In its operation, the NuScale nuclear reactor uses a full passive cooling system facility. Under normal conditions, the cooling water used to immerse the reactor has a temperature range of 30°C – 40°C. The cooling water undergoes evaporation due to heat transferred from the reactor walls to the cooling water in the pond. The make-up water is always added to the cooling pool which

is needed to keep the cooling water volume always at a safe level for reactor operation. In the accident analysis, the rate of evaporation of the cooling water is getting faster due to a large amount of heat absorbed by the cooling water. Ideally, the less evaporation that occurs in the cooling water will further increase the safety of the reactor being operated. Besides that, economically it will be better because it doesn't require too much make-up water to maintain a safe operating level position [6].

One of the passive cooling concepts as an additional technology in the reactor pool is a heat pipe. The heat pipe technology will be submerged in the reactor cooling pool. In the event of an accident, the heat pipe as a passive cooling system must be able to extend the evaporation time of the pool water so that it does not run out quickly. The use of heat pipes as heat sinks in cooling water in ponds can add to the economic value of normal NuScale operations.

The research on the use of heat pipes to absorb residual decay heat in nuclear installations has been

carried out by simulation and experimentation by previous researchers. The investigations on large-scale separated heat pipe [7], loop heat pipe (LHP) [8]–[10], hybrid heat pipe [11]–[13], variable conductance heat pipe [14], two-phase thermosyphon [15], and higher temperature sodium-charged heat pipe heat exchanger [16] shows that heat pipes have the potential to be considered as an alternative technology for passive cooling systems for heat dissipation in nuclear installations.

Loop heat pipe was chosen as a passive cooling system technology in water submerging reactor pools because it has a simple shape, works without the need for an external drive source, and has a shape that can be adapted to the NuScale geometry.

In the research funded by the Education Fund Management Institute, the Center for Nuclear Reactor Technology and Safety - the National Nuclear Energy Agency of Indonesia as the recipient of the funds made an LHP prototype to determine the initial description of the characteristics and phenomena of heat transfer that occur in the LHP as a passive cooling system. In this prototype, there are several components, including a pool tub unit that simulates a pool of cooling water immersing a NuScale reactor. This pool tub has a volume of 2.5 m³. To determine the mechanical strength of the pool tub before it is fabricated and used as an experimental means, it is necessary to analyze the mechanical strength of the design of the pool tub unit.

The purpose of this analysis is to determine the description of the mechanical strength of the pool tub including mechanical stress and translational displacement related to the level of safety and design safety. The analysis of the mechanical strength of the pool tub was carried out using Computer Aided Three-dimensional Interactive Application (CATIA) software. In CATIA, a 3-dimensional model is made according to the design of the pool tub unit, the provision of restraint on the 3-dimensional model, the application of loads in the form of pressure and temperature on the 3-dimensional model, and testing of mechanical strength. By comparing the magnitude of the mechanical stress that occurs in the 3-dimensional model of the pool tub unit with the yield strength of Carbon Steel AISI 1040 material, the mechanical stress will be known. While the magnitude of the translation displacement that occurs is expected not to be too large so that it does not cause changes in the shape of the pool tub unit when the experiment is carried out.

2. Methods

A. Pool tub design

The LHP prototype consists of cooling fan components, ducting, and electrical and instrumentation panel, a base, a pool tub unit, and the LHP prototype as shown in Fig. 1.

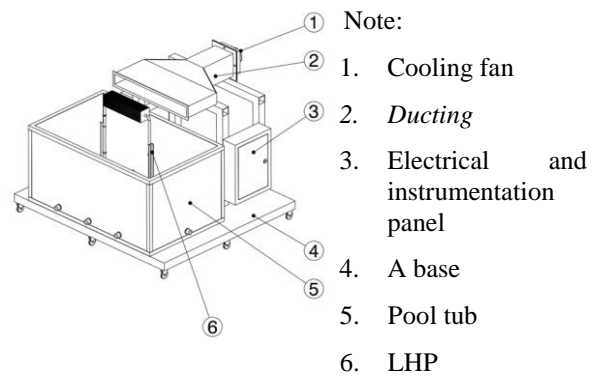


Fig. 1. LHP prototype

The initial stages carried out in LHP research, in general, are making facility designs including mechanical design, instrumentation design, and electrical design. The mechanical design section includes performing conventional calculations and calculations by code so that data is obtained to support the manufacture of design drawings. After the design drawings are obtained, then an analysis of the mechanical strength of each component in the facility is carried out with the type of material used. Mechanical strength analysis needs to be carried out before the manufacturing and operating stages are carried out. Mechanical strength analysis was carried out by simulation based on CATIA software. This simulation analysis has been carried out on the components of other research facilities which aims to determine the mechanical strength of the design of the components of the research facility [17]–[19].

The pool tub unit is equipped with 6 electric heaters with each power of 1 kW as shown in Fig. 2. The electric heater is used to simulate the heat coming from the reactor wall.

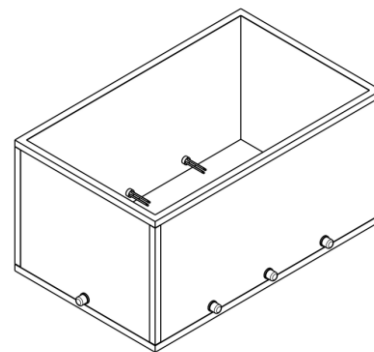


Fig. 2. Pool tub unit

The Pool Unit Design as shown in Fig. 3 has dimensions of the length of 2019 mm, a width of 1254 mm, and a height of 1004 mm. The design dimensions of the pool unit have a ratio of 0.33 for length, 0.2 for width, and 0.04 for height, all of which are compared to the dimensions of the actual NuScale reactor cooling pool [20]. This pool unit uses AISI 1040 Carbon steel plate material with a thickness of 5 mm, and it is reinforced with an

angled iron frame with AISI 1040 Carbon steel material with a size of 50 x 50 mm². The operation of 6 electric heaters is used to simulate the heat from the reactor walls. Thus the pool tub unit is one of the riskiest components in the LHP prototype research facility, so simulation testing to determine the mechanical strength is very necessary.

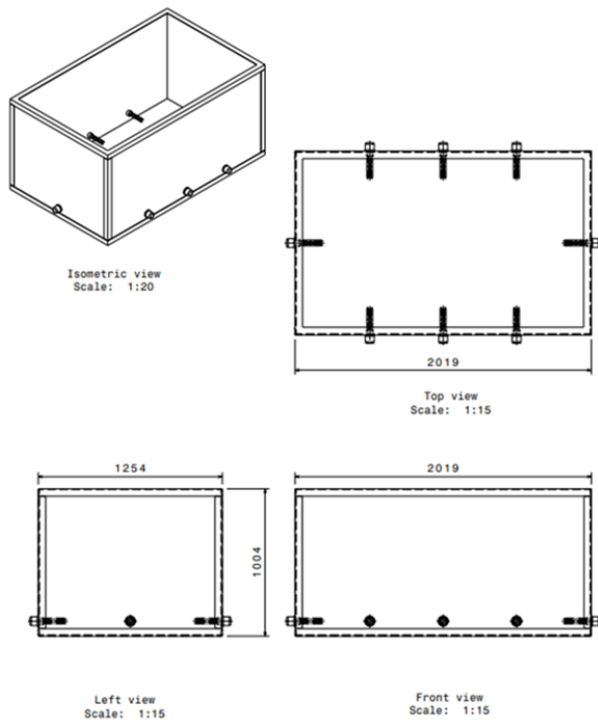


Fig. 3. The dimensions of the pool tub unit

This simulation required input data in the form of mechanical properties of the material used. The mechanical properties of the AISI 1040 Carbon Steel material are shown in Table 1.

Table 1. Mechanical properties of *Carbon steel* AISI 1040 on temperature range of 25°C – 790°C [21]

Parameter	Value
<i>Young Modulus</i>	$2.10 \times 10^{11} \text{ N/m}^2$
<i>Poisson Ratio</i>	0.3
<i>Density</i>	7845 kg/m^3
<i>Thermal Expansion</i>	$1.36 \times 10^{-5} \text{ K}^{-1}$
<i>Yield Strength</i>	$3.5 \times 10^8 \text{ N/m}^2$

This simulation uses 3-dimensional modeling of the pool tub unit design and includes the values of the AISI 1040 Carbon steel material. Thus, this simulation will produce mechanical strength including mechanical stress and translational displacement in the design of the pool tub unit.

B. Simulation steps

The simulation steps that carried out in analyzing the mechanical strength of the pool tub unit are as follows:

1. Three dimension modeling.
The 3-dimensional model is equipped with material properties used in the design as input data.
2. Mechanical loading.
The maximum mechanical loading given to the pool tub is in the form of giving a value of 1.5 times the hydrostatic pressure and operating temperature of the LHP.
3. Restrain.
In this study, restraint is to simulate a 3-dimensional model of a pool tub under static conditions. The restraint uses a clamp type with a temperature of 60°C (333 K), a pressure of 15000 N/m², and gravitational acceleration of 10 N/m².
4. Mechanical stress and translational displacement.
To determine the magnitude of the mechanical stress and translational displacement, the magnitude of the mechanical stress is compared with the yield strength of the material used.

C. Hydrostatic pressure

For safety and security factors, the test is carried out by applying pressure and temperature of 1.5 times of pressure and experiment operating temperature [22]. The hydrostatic pressure of water to the inner pool tub wall is calculated by the following equation [23]:

$$p = \rho \times g \times h \quad (1)$$

where:

- p = Hydrostatic pressure (N/m²)
 ρ = Density of water (kg/m³)
 g = Gravitational velocity (m/s²)
 h = height of water (m)

3. Results and discussion

The hydrostatic pressure received by the inner wall of the pool tub is obtained as follow:

$$p = 1000 \text{ (kg/m}^3\text{)} \times 10 \text{ (m/s}^2\text{)} \times 1 \text{ (m)} = 10000 \text{ (N/m}^2\text{)}$$

While the mechanical strength of the pool tub design at a pressure of 15000 N/m² and a temperature of 60°C with restraint and mechanical loading is shown in Fig. 4.

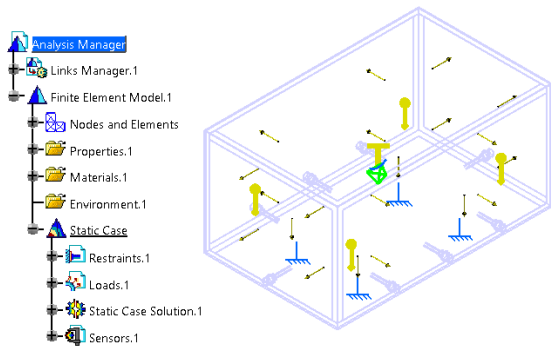


Fig. 4. Restraint and mechanical loading in pool tub

Fig. 4 shows that the pool tub unit in a static position on the LHP prototype base still allows a shift due to expansion towards the vertical Z+ (to the top). Expansion towards Z+ can occur because the top of the pool tub unit is released from the clamp. Loading in the form of the hydrostatic pressure of 15000 N/m² provides pressure to all the inner walls of the pool unit. Likewise, the inner walls of the pool tub all receive the heat provided.

The simulation results regarding the value of the mechanical stress that occurs in the design of the pool tub are shown in Fig. 5.

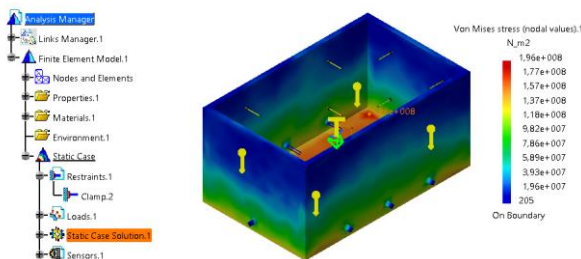


Fig. 5. Mechanical stress in pool tub.

Fig. 5 shows that the mechanical stress of $1.96 \times 10^8 \text{ N/m}^2$ occurred at the bottom of the pool tub. This value indicates that the applied mechanical stress does not harm the design of the pool tub made of Carbon Steel AISI 1040, because the magnitude of the mechanical stress that occurs is smaller than the yield strength of the Carbon Steel AISI 1040 material, which is $3.5 \times 10^8 \text{ N/m}^2$ [14] and this value is still in the elastic region of the AISI 1040 Carbon Steel material. If the load in the form of pressure and temperature is removed, the stress will disappear from the pool tub.

The simulation results to determine the amount of translational displacement that occurs in the design of the pool unit are shown in Fig. 6.

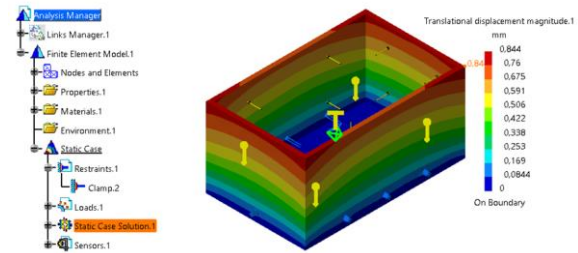


Fig. 6. Translational displacement in pool tub

It can be seen from Fig. 6 that the maximum translational displacement that occurs in the design of the pond is 0.844 mm. When compared with the design size of the pool tub, this value is only 0.0008 (1/1250) of the total length of the pool tub. The results of this comparison show that the translational displacement that occurs is very small. The translational displacement of 0.844 mm in the direction of Z+ (to the top) does not affect the shape of the pond when an experiment is carried out.

4. Conclusions

The mechanical strength analysis on the pool tub of loop heat pipe prototype using CATIA software has been carried out. The magnitude of the mechanical stress obtained is $1.96 \times 10^8 \text{ N/m}^2$ at the bottom of the pool tub. This mechanical stress is smaller than the yield strength of AISI 1040 Carbon Steel material, which is $3.5 \times 10^8 \text{ N/m}^2$. Likewise, the translational displacement of 0.844 mm is very small when compared to the dimensions of the pool tub, which does not result in changes in the shape of the pool tub unit and will not interfere with the LHP prototype experiment to be carried out. Thus the design of the pool tub is safe to be manufactured and operated to support the LHP experiment.

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