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Design Evaluation of a Piping System in the SELFA Sodium Test Facility

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1. Introduction

The Sodium thermal-hydraulic Experiment Loop for Finned-tube Sodium-to-Air heat exchanger (SELFA) is finned-tube Sodium-to-Air heat exchanger test facility for simulating thermal hydraulic behavior of the 150MWe Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR) under development at Korea Atomic Energy Research Institute (KAERI). There are two main piping systems in the SELFA test loop.

In this study, the integrity of the SELFA piping system has been evaluated according to the two design-by-rule (DBR) codes of ASME B31.1[1] and RCC-MRx RD-3600[2]. B31.1 is an industry design code for power piping while RD-3600 is a class 3 nuclear DBR code. The conservatism of the two codes was quantified based on the evaluation results as per the two DBR codes.

2. Design Features of the SELFA Test Loop

2.1 Configuration of the SELFA

The design features of the SELFA are shown in Fig. 1, which shows it has two loop systems consisting of Finned-tube sodium-to-air Heat eXchanger (FHX), Test section, expansion tank, and other supplementary systems [3].

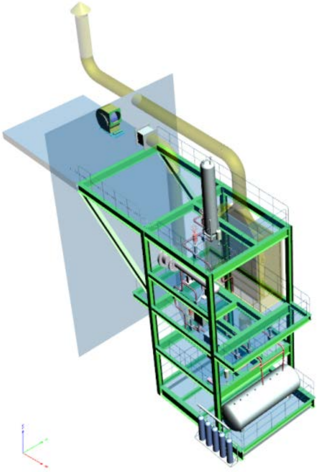


Fig. 1. Schematic of the SELFA test loop

In Fig. 2, pink-color line is a primary sodium pipe and design evaluation has been conducted for this piping system to evaluate the integrity and to compare the conservatism of the two design codes.

There are hot-leg and cold-leg piping systems in the SELPA test loop as shown in Fig. 2. Piping analysis has been conducted separately for two piping systems. The material of the two piping systems is austenitic stainless steel 316L and size of the pipe in the two loops is 2”SCH20S.

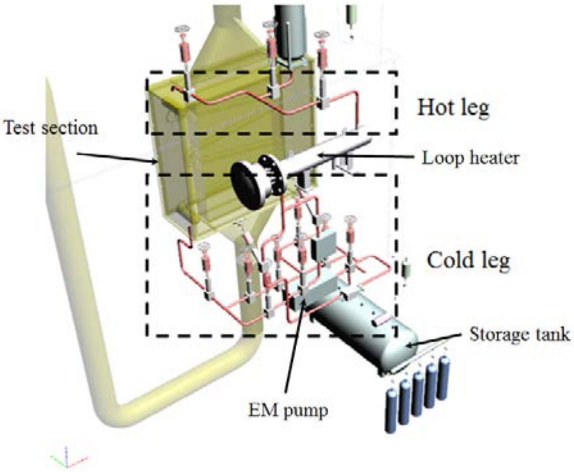


Fig. 2. Piping system of the SELFA loop

As shown in Table 1 on design parameters of the SELFA test loop, the maximum temperature of the piping system is 480°C[3].

Table 1**:** Pipe system design data

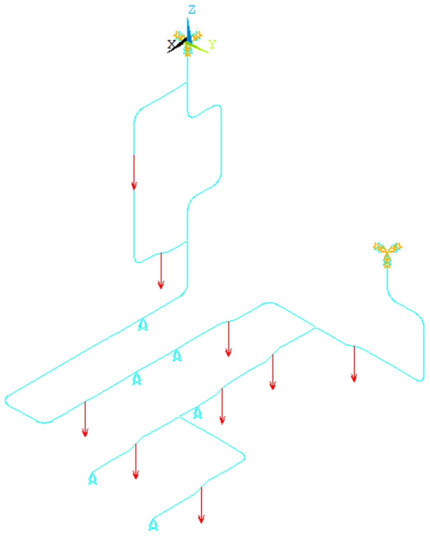
Parameter	Unit	value	Remarks
Pipe OD / thickness	mm	60.5	2’’SCH20.
Pipe thickness	mm	3.5	
Design pressure	MPa	0.5	
Design temperature (H/L)	°C	480	
Design temperature (C/L)	°C	400	

2.2 Finite Element Modeling and Analysis

Piping analysis has been conducted by using the pipe elements in ANSYS[4] and the finite element models of the two piping systems are shown in Fig. 3. There are 3 fixed boundary conditions, that is, at pipe end, one z-axis support near tee and 3 concentrated loads for valve weight (–z axis, red arrow). In case of cold leg piping system, both upper end parts which are connected to loop heater and test section were completely fixed while

EM pump, sodium storage tank and tee part have been vertically supported. Nine concentrated loads (red downward arrows) were applied to take the valve weights into account.

(a) Hot leg



(b) Cold leg

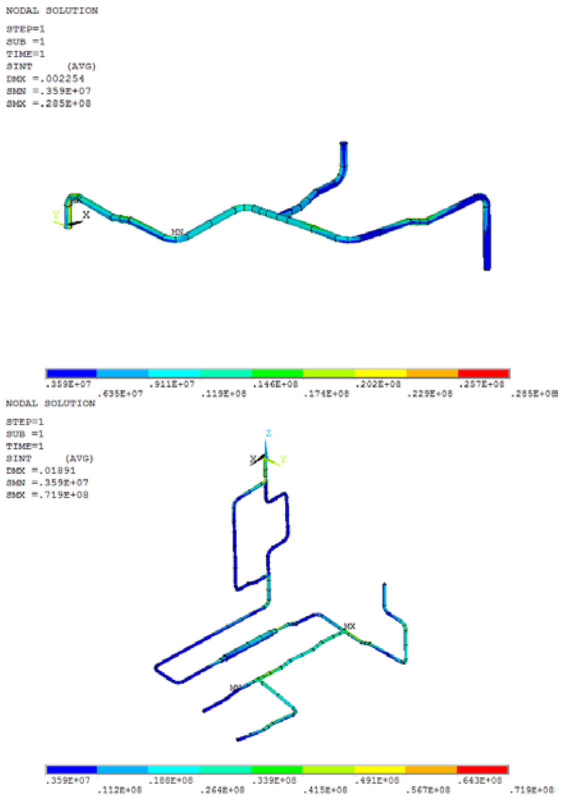
Fig. 3. Pipe element models of the SELFA loop

Table 2 shows the material properties as function of temperature for stainless steel 316L.

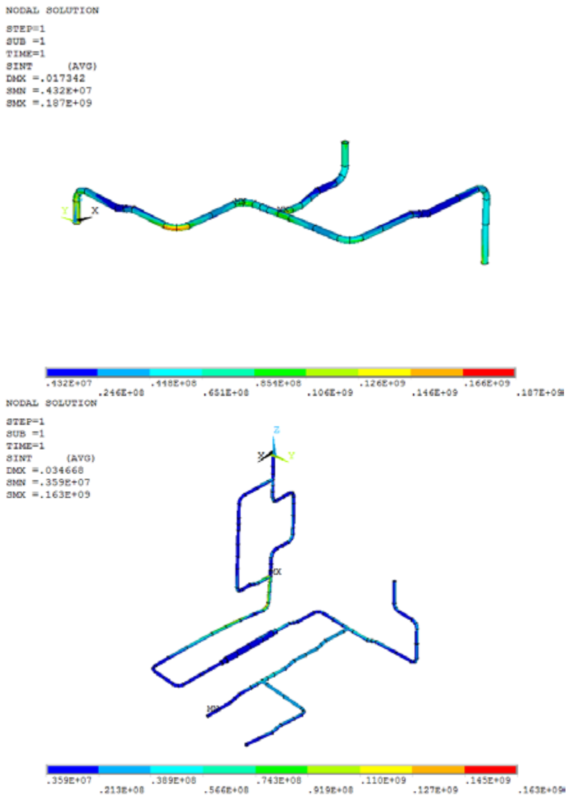
Table 2: Material properties of stainless steel 316L

Temperature (°C)	100	200	300	400	500	600
Elastic modulus (GPa)	186	178	170	161	153	145
Coefficient of thermal expansion (10^{-6}/°C)	16.4	17.0	17.5	17.9	18.3	18.7
Poisson's ratio	0.272	0.279	0.287	0.295	0.302	0.31
Density (kg/m^3)	7932	7889	7846	7803	7760	7717
Thermal conductivity (W/m-°C)	15.08	16.52	17.95	19.39	20.82	22.25
Specific heat (J/kg-°C)	486	508	529	550	571	592

Piping stress analyses for the two piping systems have been conducted for the present piping systems. Loading conditions of steady state assuming the same sodium pressure and temperature with Table 1 were applied and bulk temperature was assumed as 25 °c.



(a) Stress intensity (SI) profile under sustained loads



(b) SI profile under thermal expansion loads

Fig. 4. Stress distributions of the cold leg and hot leg pipe systems

Table 3: Piping system analysis results

Parameters		Max.deflection (mm)	Max.stress (MPa)	Remarks (Max location)
Structural	H/L	2.25	28.5	On elbow
	C/L	18.9	71.9	On Tee
Thermal	H/L	17.3	187	On Tee
	C/L	34.7	163	On Tee

The stress and strain distributions of the two piping systems are shown in Fig. 4. Table 3 shows the summary of stress and strain values in hot leg and cold leg. Table 3 shows that maximum stress occurred on or near the elbow or tee but the level of stresses were not high.

2.3 Application and comparison of the codes based on the design evaluation

A set of formula are provided in ASME B31.1 and RCC-MRx RD-3600. Except for geometrical parameters and design pressure condition, the two design-by-rule formula requires moment values. In the SELFA piping system, the term of occasional load, M_b was ignored because maximum flow velocity in pipe system of SELFA loop is very low with approximately 1~2 m/s, which is so slow that negligible thrust load due to valve operation is expected.

Each code has different forms of mathematical formula but the basic concepts of the equations with the terms on design pressure, bending and thermal expansion are the same. Design evaluations were conducted according to B31.1 and RD-3600, and the calculated results for hot leg and cold leg piping are shown in Table 4 and Table 5, respectively.

Table 4: Evaluation results as per design codes for hot leg piping

Parameters		Sustained loading	Thermal expansion
ASME B31.1	Calculated	22.0	171.4
	Allowable limit	83	225
	Ratio	0.27	0.76
RCC-MRx RD-3600	Calculated	22.0	171.4
	Allowable limit	90	176
	Ratio	0.24	0.97

Table 5: Evaluation results as per design codes for cold leg piping

Parameters		Sustained loading	Thermal expansion
ASME B31.1	Calculated	78.9	133.5
	Allowable limit	91	178
	Ratio	0.87	0.75
RCC-MRx RD-3600	Calculated	78.9	133.5
	Allowable limit	97	176
	Ratio	0.81	0.76

Generally, industry codes such as ASME Section VIII are known to be more conservative than nuclear codes such as ASME Section III. In the present analysis when comparing B31.1 and RD-3600, B31.1 was shown to be more conservative for sustained loading but less conservative for thermal expansion loading. However, all the results showed that present piping design is within the code limits for the intended design transients.

3. Conclusions

The sodium test facility of the SELFA is under construction at KAERI for the investigation of thermo-hydraulic behavior of finned-tube sodium-to-air heat exchanger. In this study, design evaluations on the SELFA piping system has been conducted according to the ASME B31.1 and RCC-MRx RD-3600. The conservatism of the two codes was quantified based on the evaluation results. It was shown that B31.1 was more conservative for the sustained loads while less conservative for thermal expansion loads when compare with those of RD-3600. However, all the evaluation results according to the two codes were within the code allowables.

ACKNOWLEDGEMENT

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