Development of a Hydraulic Resistance Correlation for the Heat Exchangers in a Pool-type Sodium-cooled Fast Reactor

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Purposes and Ultimate Goal

Purposes : 1) To develop a hydraulic resistance correlation for the shell-side fluid flows in the SFR heat exchangers as a form of the combination of conventional correlations
2) To verify the developed hydraulic resistance correlation

Ultimate Goal : Validation and Improvement of the proposed SALUS design

Heat Exchangers for SALUS

SALUS (Small, Advanced, Long-cycled and Ultimate Safe SFR) reactor:

- A pool-type sodium-cooled SFR (Sodium-cooled Fast Reactor) generating 100MWe with a long refueling period of ~20 years.
- Under design-development in KAERI

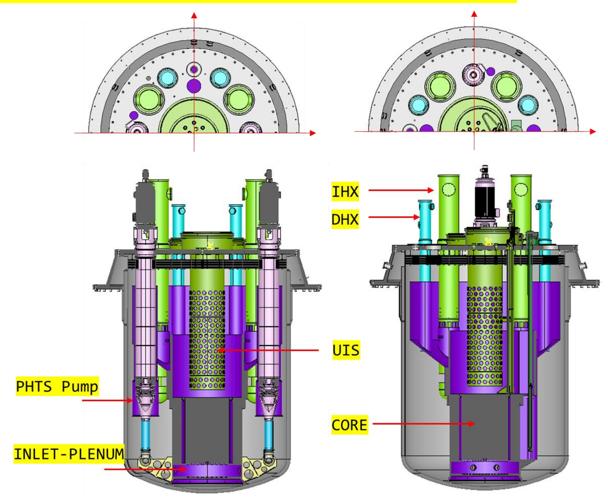


Fig. SALUS Primary System

Heat Exchangers in Primary System:

- IHX(Intermediate Heat Exchanger) & DHX(Decay Heat Exchanger)
- Both have a similar configuration

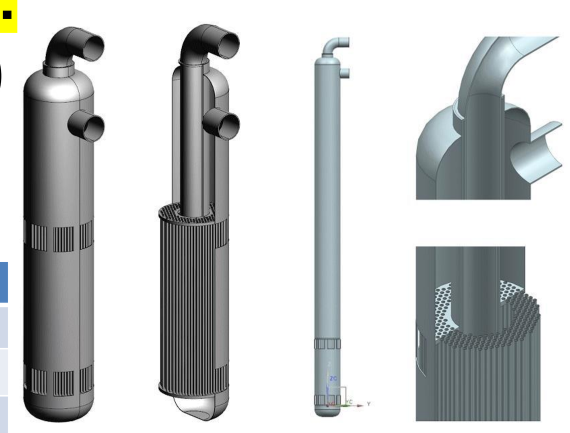


Fig. Schematics of SALUS DHX

Parameter	IHX	DHX
Number of Units	4	4
Heat Removal Capacity per Unit	97.8 MW_t	1.67 MW_t
Number of Tubes per Unit	1050	114
Total Tube Length	4.85 m	2.13 m
Active Tube Length	3.8 m	1.73 m
Shroud Inner Diameter	1.311 m	0.576 m
Shell-side Inlet Temp.	510 ºC	360 ºC
Shell-side Outlet Temp.	357.7 ºC	251.1 ºC
Shell-side Sodium Flowrate	341.4 kg/s	11.74 kg/s
Heating Tube Outer Diameter	17.9 mm	21.7 mm
Pitch-to-Diameter Ratio	1.5	1.5
Heat Transfer Tube Material	9Cr-1Mo-V	9Cr-1Mo-V
Number of Tube Support Plate	5	2

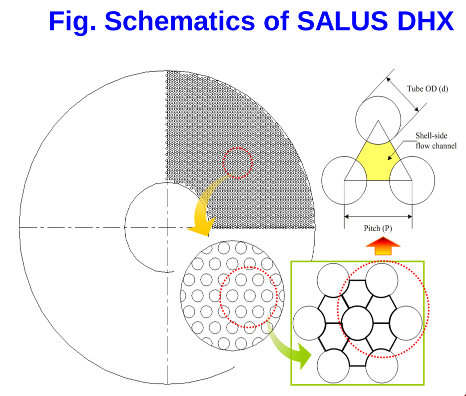


Fig. SALUS IHX tube Array

Hydraulic Resistance (HR) Model for CFD

Conventional Correlations:

- Axial Pressure Drop along Straight Tune Bundles (Darcy Friction Factor Correlation)

$$\Delta P_{axial} = f_z \frac{L}{D_h} \cdot \frac{1}{2}\rho u_{axial}^2, \text{ with } f_z = \begin{cases} \dfrac{64}{Re} & \text{for } Re < 2{,}000 \\ \dfrac{1}{\left[1.8\log(Re) - 1.64\right]^2} & \text{for } Re > 4{,}000 \end{cases}$$

- Pressure Drop across a Support(Grid) Plate (Idelchik's Handbook Diagram 3-12)

$$\Delta P_{Grid} = K_i \frac{1}{2}\rho u^2 + \xi_{fr}, \text{ with } K_i = \frac{\Delta P}{\rho u_0^2/2} = \left(1.707 - \bar{f}\right)^2 \cdot \frac{1}{\bar{f}^2}$$

ξ_{fr} = potential friction loss

$\bar{f}$ = (actual flow area)/(frontal flow area)

Newly Developed Correlation:

$$\Delta P_{Total} = \Delta P_{axial} + F \cdot \Delta P_{Grid} = \Delta P_{Measured}$$

Correction Factor (to be obtained)

- Extended applicability
- Depending on power level (as a function of Re number)

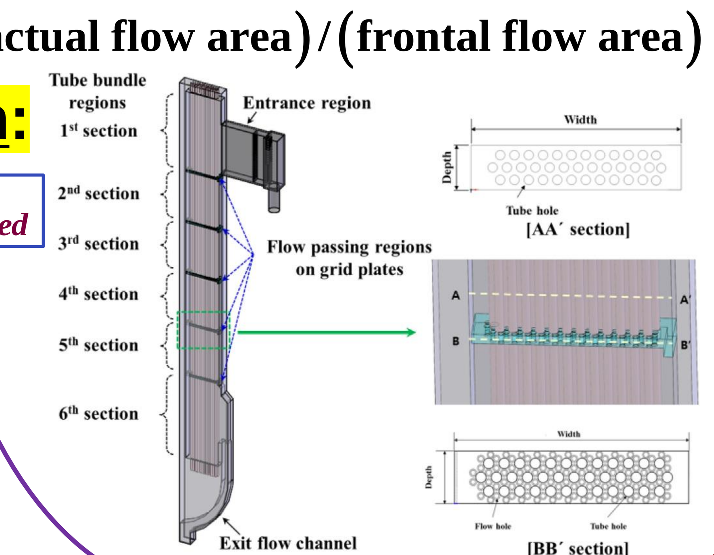


Fig. iHELP Experiment

Correction Factor, *F*

Obtained Correction Factor:

- A Fitting Curve was generated by using the Origin software.

$$F = Y_0 + A_1 \exp(-Re/T_1) + A_2 \exp(-Re/T_2)$$

Where Y_0 = 0.28461, A_1 = 0.12876, A_2 = 4971.3016, T_1 = 8895.01778 and T_2 = 80.68048

Verification of the Correlation:

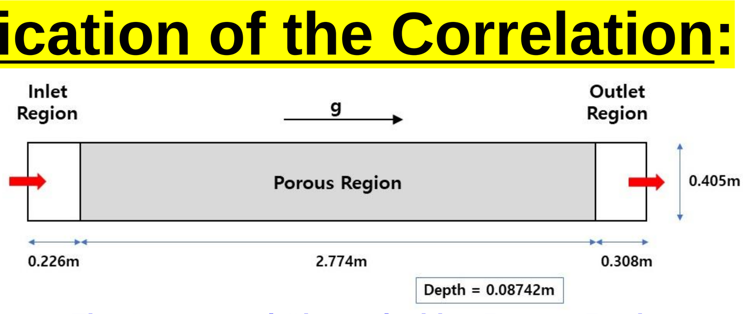
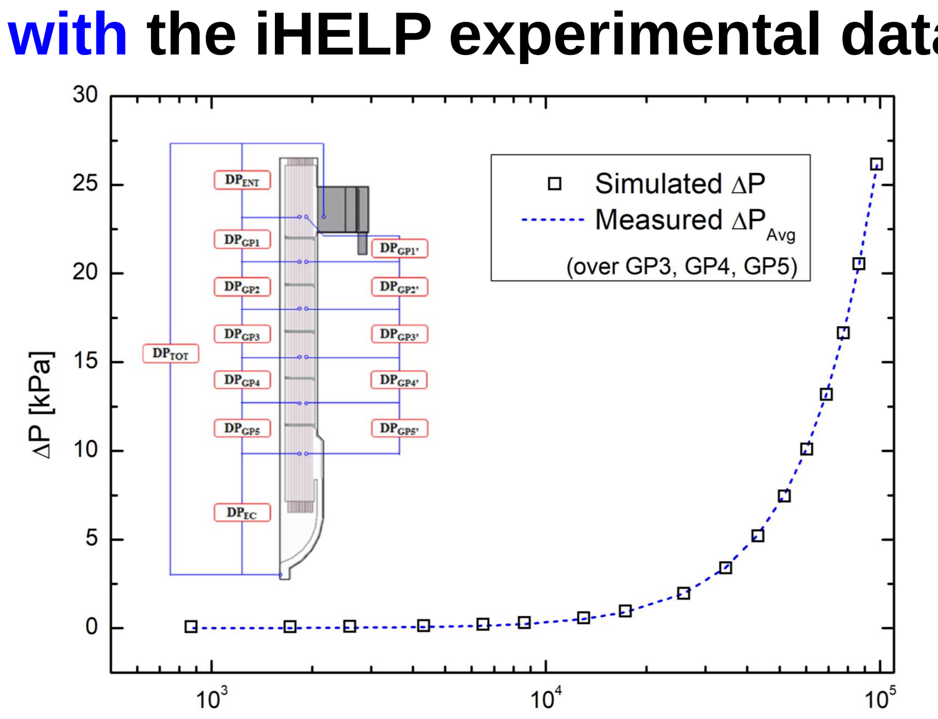


Fig. Conceptual Channel with a Porous Region

- Simulated pressure drops of the conceptual channel agree well with the iHELP experimental data.



Checking the Design Requirement of a SALUS DHX

Design Requirements:

- Design parameters for operating (stand-by) condition

Design Parameter	PDHRS (Passive)	ADHRS (Active)
Number of Units	2	2
Heat Removal Rate per Unit	1.67 MW_t	1.67 MW_t
Shell-side Sodium Flow Rate	11.73 kg/s	11.73 kg/s
Shell-side Inlet/Outlet Temp	360.0/251.1 ºC	360.0/251.1 ºC

Validation:

- A sodium pool with a DHX unit was designed for validation.
- Check the sodium mass flow rate, resulted from the given heat removal rate.

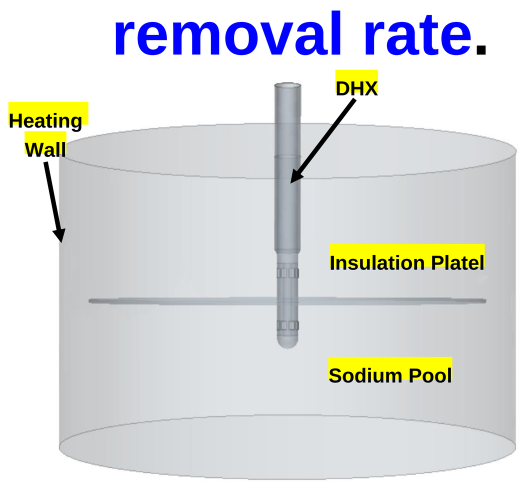


Fig. Sodium Pool Geometry

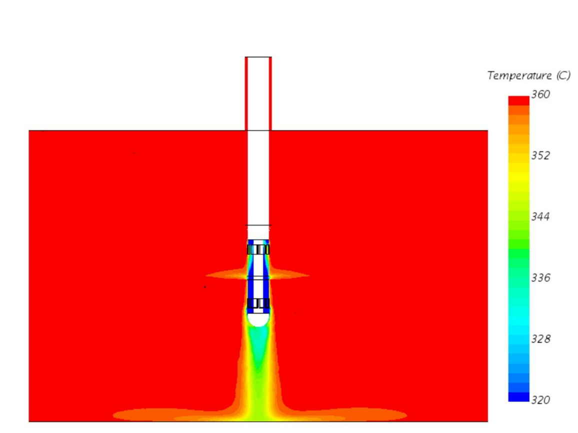


Fig. Resultant Temp. Field

- Resultant sodium mass flow rate = 11.468 ~ 11.484 kg/s (validated !)

Applications & Future Works

Applications:

- Current design of SALUS DHX shows DHX inlet surrounded by narrow guide cylinder.
- Advanced HR correlation can be applied for studying guide cylinder effect on DHX inlet flows.

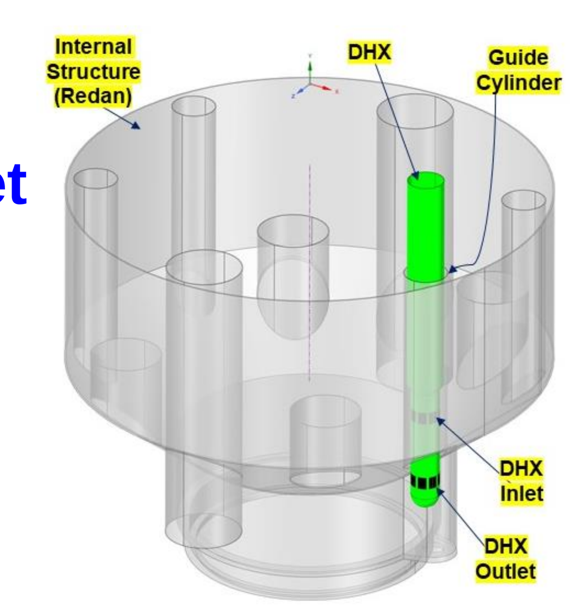


Fig. Location of SALUS DHX inlets and Guide Cylinder

Future Works:

1) Establishing ¼ SALUS PHTS CFD Model
2) CFD simulation of various DHX elevation cases
3) Improving SALUS design with proper DHX elevation

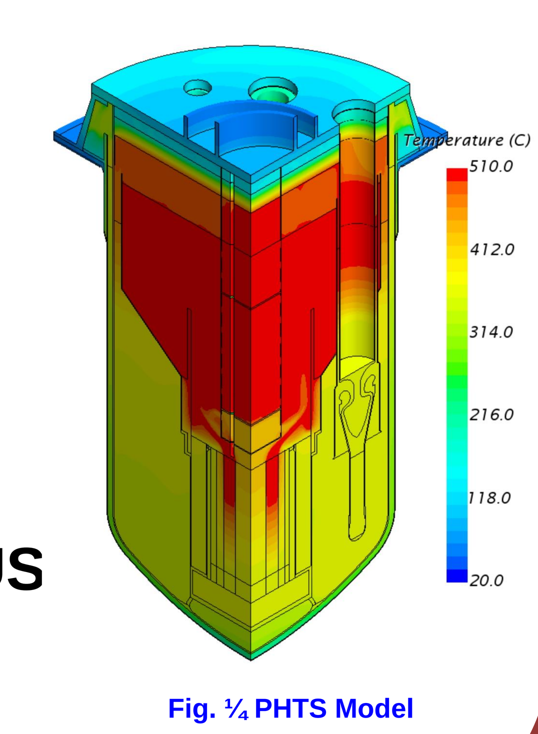


Fig. ¼ PHTS Model