Contribution to the numerical modelling for heat exchange in the steam generator of a small modular reactor (SMR)

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Context :

The steam generator (SG) plays an important role in the transmission of energy between the primary circuit and the secondary circuit of the reactor

Objective :

Develop a numerical model to simulate heat exchange in the steam generator to model the secondary domain temperature in small modular reactor SMR

General context

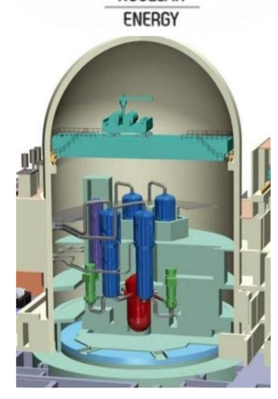
Problematic

How to allow developing countries to access nuclear energy at a controlled cost ?

PHYSOR Project

Objectives

Predesigning a SMR-type reactor and to develop tools and skills in correlation with their design by enhancing the core design of a nuclear reactor, predicting thermo-mechanical constraints applied to a SMR and improving their passive safety.



Study context

- In this work we are interesting to study the heat exchanges in SMR steam generator
- To simplify the heat exchanges we consider an exchanger made up of two coaxial tubes
- The hot fluid which will be cooled enters the internal pipe at an inlet temperature $T_{C\ inlet}$ and leaves with an outlet temperature $T_{C\ outlet}$
- The cold fluid enters the pipe with a tubular section at an inlet temperature $T_{F\ inlet}$ and leaves with an outlet temperature $T_{C\ outlet}$

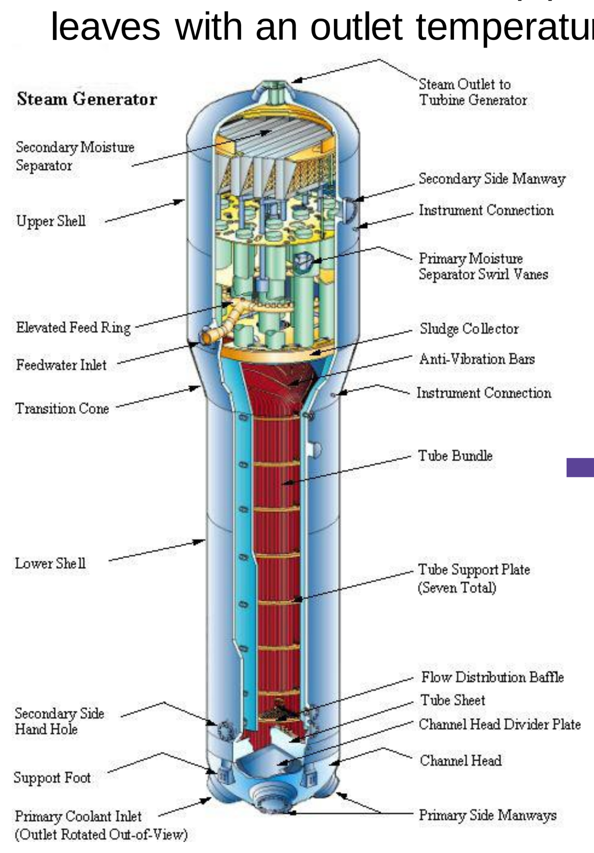


Fig.1 Steam generator [1]

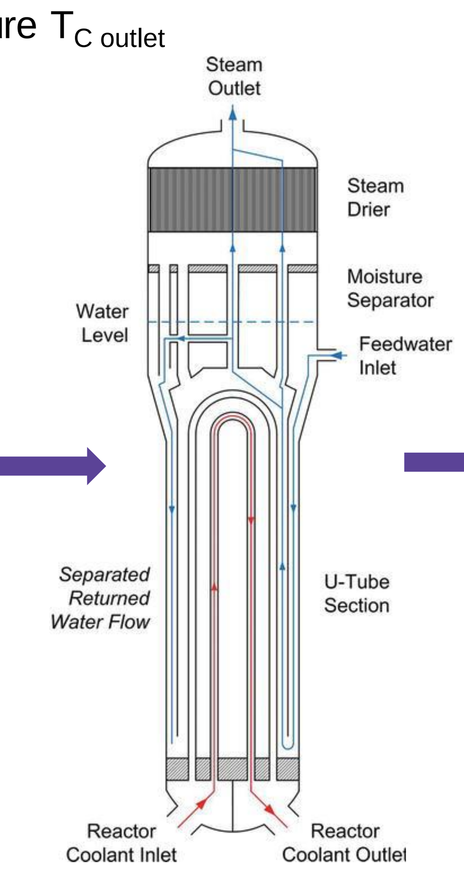


Fig.2 Simplified Recirculating steam generator flow paths [2]

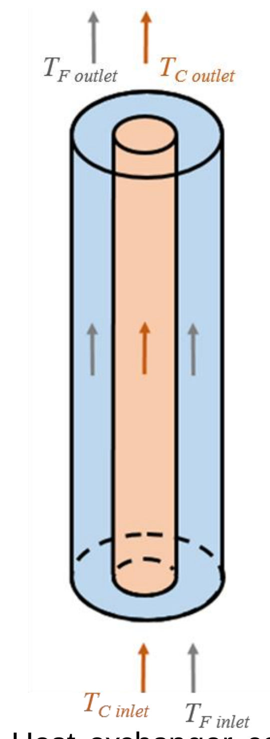


Fig.3 Heat exchanger consisting of two coaxial tubes

Numerical modeling

- The simulation are carried out using the coupling of two software OpenModelica and ANSYS CFX primary domain (Figure 4)

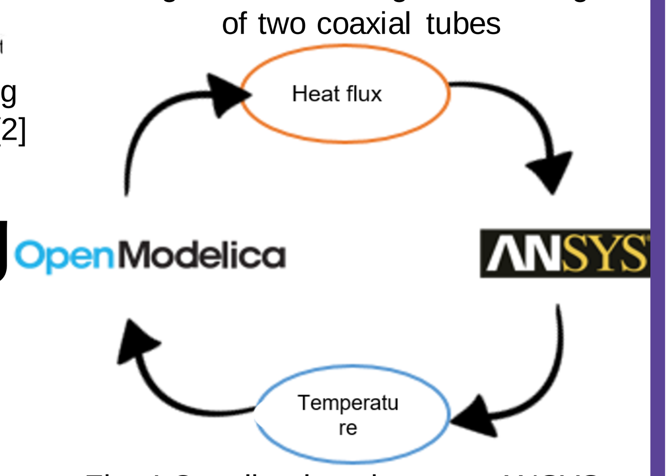


Fig. 4 Coupling loop between ANSYS CFX and OpenModelica

- The calculation domain is divided into two parts: primary domain corresponding to the hot source and a cold secondary domain corresponding to the cooling fluid in the secondary circuit (Figure 5)
- T_C and T_F represent the temperatures of the hotter and colder fluid. T_{SI} and T_{SE} are the temperatures of the internal and external surface of the solid medium separating the flows (Figure 6)
- The T_{SE} temperature imposed on the exterior surface corresponds to that of the second domain, calculated by ANSYS CFX (Figure 7)
- The internal fluid temperatures T_{SI} is calculated using OpenModelica (Figure 7)

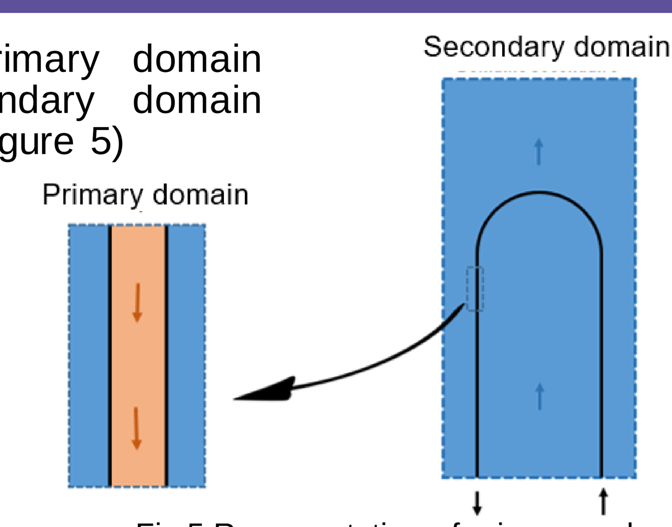


Fig.5 Representation of primary and secondary domains

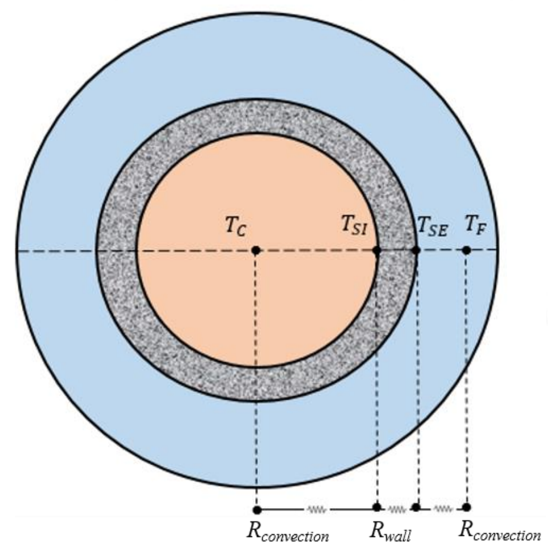


Fig. 6 Cross section of the exchanger

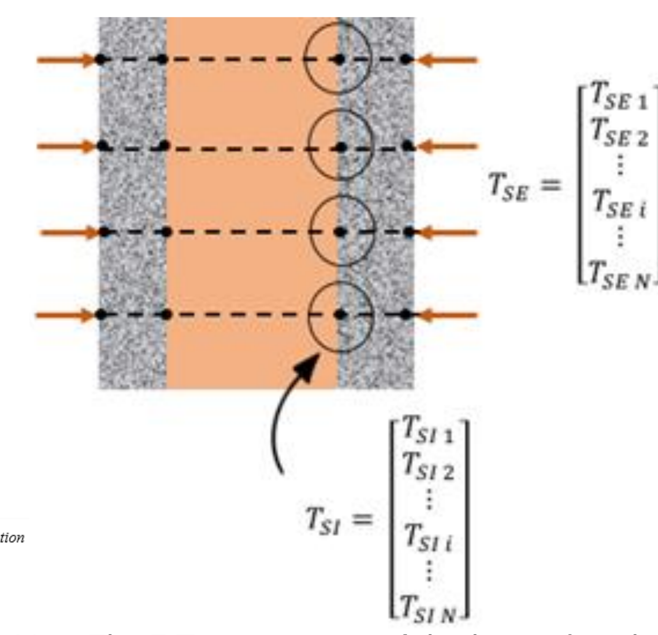


Fig. 7 Temperatures of the internal and external surface of the primary domain

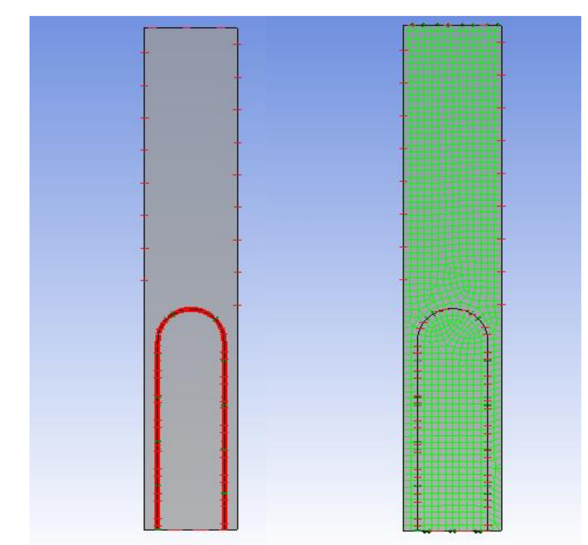


Fig. 8 Geometry of compute domain and computational mesh used

- To link the two modules, we have developed a programming script in Python 2.7 language, Figure 9 show the description of the algorithm used. This script is important to set up:
  - Tool initialization
  - The module iteration loop
  - The end of the tool with respect for the convergence criterion
  - Data management and visualization of an interactive interface
- The k-ε model was used for modeling gas phase turbulence
- Inlet conditions

Flow inlet conditions	
$T_{C\ inlet}$	$353\ K$
$\dot{m}_C$	$1\ kg/s$
$T_{F\ inlet}$	$283\ K$
$\dot{m}_F$	$1\ kg/s$
INTERNAL TUBE PROPERTIES	
Thermal conductivity λ	$52{,}0\ W/mK$
the thickness of the tubes e	$0{,}005\ m$

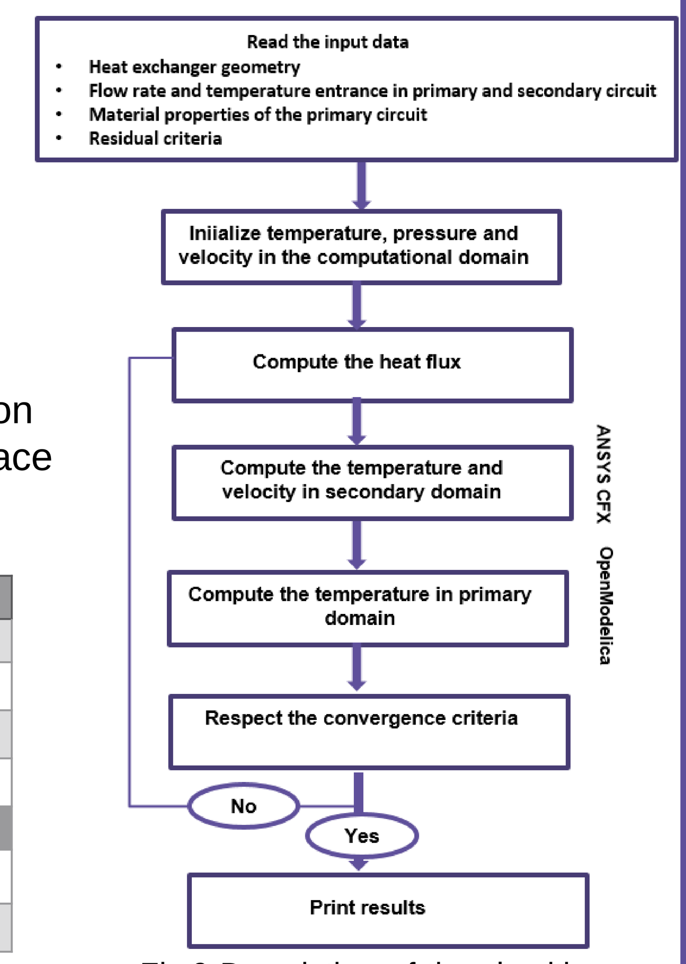


Fig.9 Description of the algorithm

[1] IAEA, editor. Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Steam Generators. Technical Reports Series no. IAEATECDOC-1668: ed. Vienna: International Atomic Energy Agency; 2011. 273 p

[2] Siniša Šadek and Davor Grgić "Operation and Performance Analysis of Steam Generators in Nuclear Power Plants" Chapter 8, Heat Exchangers - Advanced Features and Applications. Edited by S M Sohel Murshed and Manuel Matos Lopes. DOI: 10.5772/66962

Results and discussion

Figure 10 and Figure 11 show the secondary domain results respectively of axial velocity and temperature contours at the first global iteration. Its shown that the cold fluid is not yet heated and remains at its inlet temperature $T_{F\ inlet}$

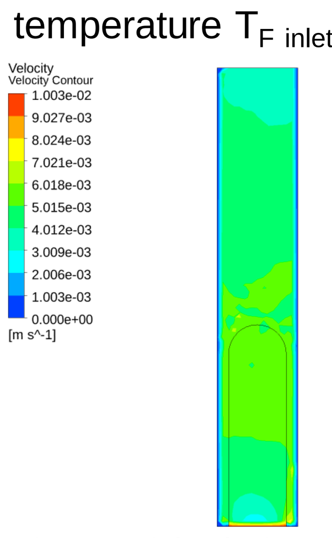


Fig. 10 Axial velocity contour

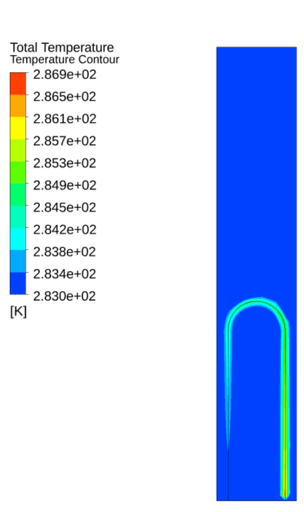


Fig.11 Gas temperature contour

Figure 12 present the simulation residuals of all calculation. The convergence of the system is obtained after 16 iterations, the criterion defined is thus respected.

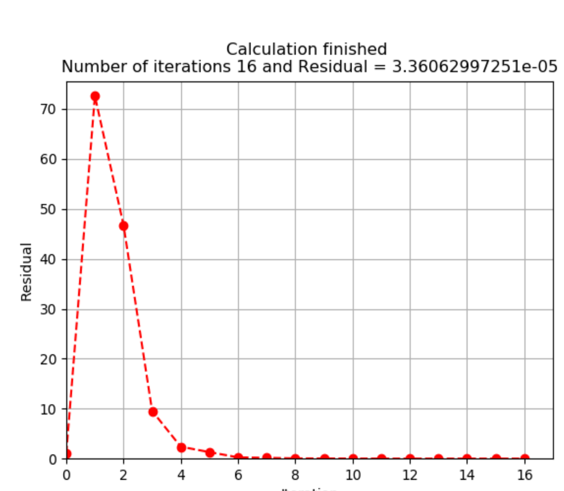


Fig.12 Simulation residuals

The fluid in secondary domain (Fig. 13 and Fug. 14) is heated and the temperature becomes uniform after meeting the tube. The hotter parts have a higher speed and pressure, consequently the direction of flow is changed as showed in Figure 15.

Figure 16 show a decrease in T_{SI} until last node and T_{SE} has an increase at the ends and has a constant temperature between these two parts correspond to the saturation state. this results is in agreement with the literature data [3].

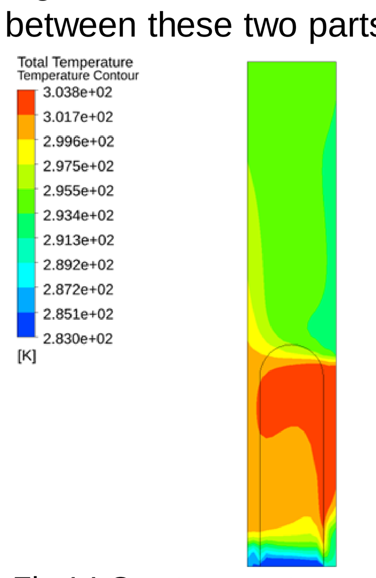


Fig.14 Gas temperature contour

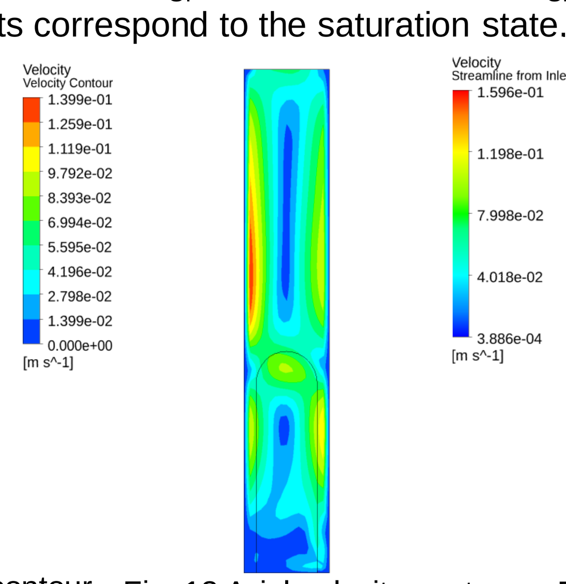


Fig. 13 Axial velocity contour

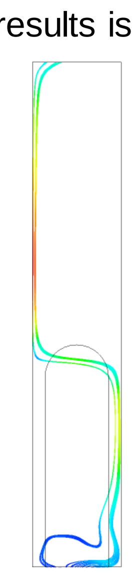


Fig.15 Pathlines contour

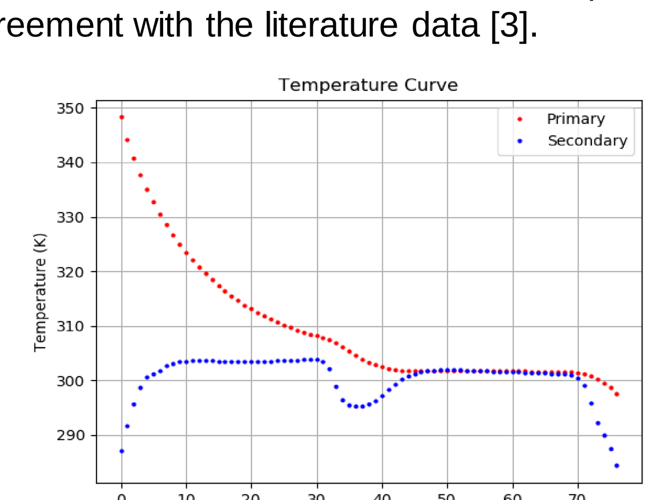


Fig.16 T_{SI} and T_{SE} profiles

[3] https://www.wikiwand.com/fr/G%C3%A9n%C3%A9rateur_de_vapeur

Conclusion

Simplified model to predict the heat exchanges in steam generator of SMR was developed using a coupling model between ANSYS CFX and OpenModelica software.

- Physical behavior of the primary and the secondary circuit are modelled separately
- Ansys CFX and OpenModelica software are used to model respectively secondary and primary domain
- Simulation results seem to be qualitatively in a good agreement with the physical behavior of the equipment
- The presented approach features an acceptable compromise between the accuracy of the thermal and the fluidic field and calculation time which is very reduced comparing to detailed model

Perspective

- Finalize the qualification of the developed tool
- Modeled several internal tubes
- Model the secondary domain in two-phase

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