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Thermal-hydraulic post-test analysis of the transition from forced to natural circulation in ICE test section

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Lavoro svolto in esecuzione della linea progettuale LP3 punto B2 parte II
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Abstract

This report, carried out at the DIMNP of the University of Pisa, in collaboration with ENEA Brasimone Research Centre, illustrates the thermo-fluidynamic results of the analysis, performed by the RELAP5 system code, of an experimental test recently carried out at ENEA on CIRCE facility.

In particular, the so-called Test D of the last experimental campaign performed with the ICE test section was considered. This test simulates an Unprotected Loss Of Flow (ULOF) accident transient of interest for the safety of HLM reactors. The aim of this test was to investigate the transition from forced to natural circulation in the primary system.

The RELAP5/Mod3.3 code, modified in order to take into account the LBE fluid properties, was employed to reproduce the phenomena occurring during the test transient and to assess the capability and limits of the code by comparing the numerical results with experimental data.

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Nomenclature

Abbreviations

c_p	Specific heat at constant pressure [$J \cdot kg^{-1} \cdot K^{-1}$]
D	Diameter [m]
g	Acceleration of gravity [$m \cdot s^{-2}$]
HTC	Heat Transfer Coefficient [$W \cdot m^{-2} \cdot K^{-1}$]
$\dot{m}$	Mass flow rate [$kg \cdot s^{-1}$]
Nu	Nusselt number
Pe	Peclet number
Re	Reynolds number
H_r	Riser height [m]
ΔP	Pressure difference [mbar]
ΔP_{DF}	Driving force [mbar]
$\dot{Q}$	Power [kW]
ΔT	Temperature difference [K]
p	Pitch [m]
x	Pitch to diameter ratio (*p/D*)
$\bar{\rho}_{LBE}$	LBE mean density [$kg \cdot m^{-3}$]
$\bar{\rho}_g$	Gas mean density [$kg \cdot m^{-3}$]
$\rho_{r,TP}$	Riser two phase flow mean density [$kg \cdot m^{-3}$]
$\bar{\alpha}$	Average void fraction

Acronyms

CIRCE	CIRCulation Experiment
DEMETRA	DEvelopment and assessment of structural materials and heavy liquid MEtal technology for TRAnsmutation systems
DIMNP	Dipartimento di Ingegneria Meccanica Nucleare e della Produzione
ENEA	Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo sostenibile

HLM	Heavy Liquid Metal
HS	Heat Section
HX	Heat Exchanger
ICE	Integral Circulation Experiment
LBE	Lead-Bismuth Eutectic
RELAP5	Reactor Excursion and Leak Analysis Program
SS	Stainless steel
ULOF	Unprotected Loss Of Flow

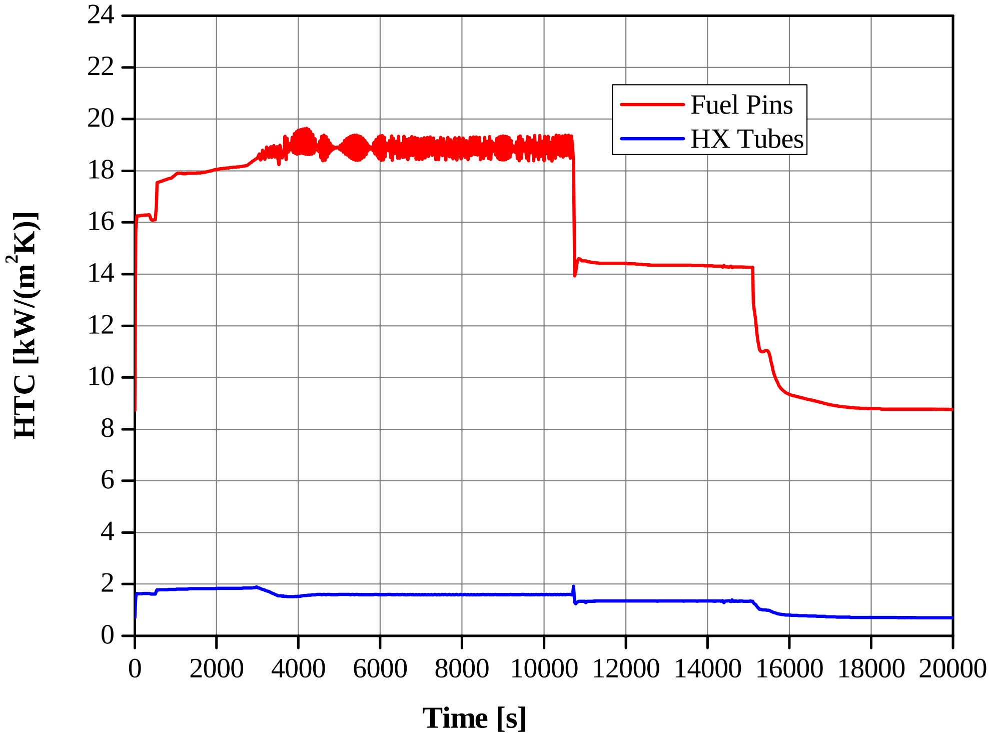

Figure 17. Convective heat transfer calculated by RELAP5, for heat section and heat exchanger.

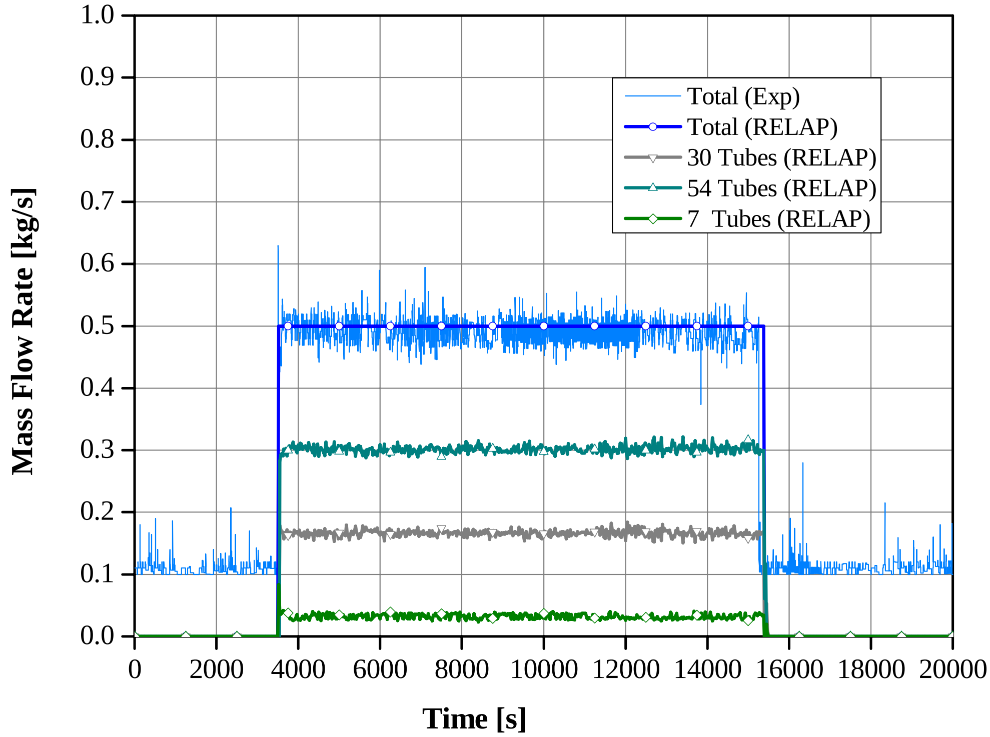

Figure18. Secondary side water mass flow rate.

Figure 18 plots the RELAP5 total secondary mass flow rate (imposed by TMDPJUN 801 to a value of 0.5 kg/s) compared with experimental data and its repartition through the, 30, 54 and 7, sector tubes.

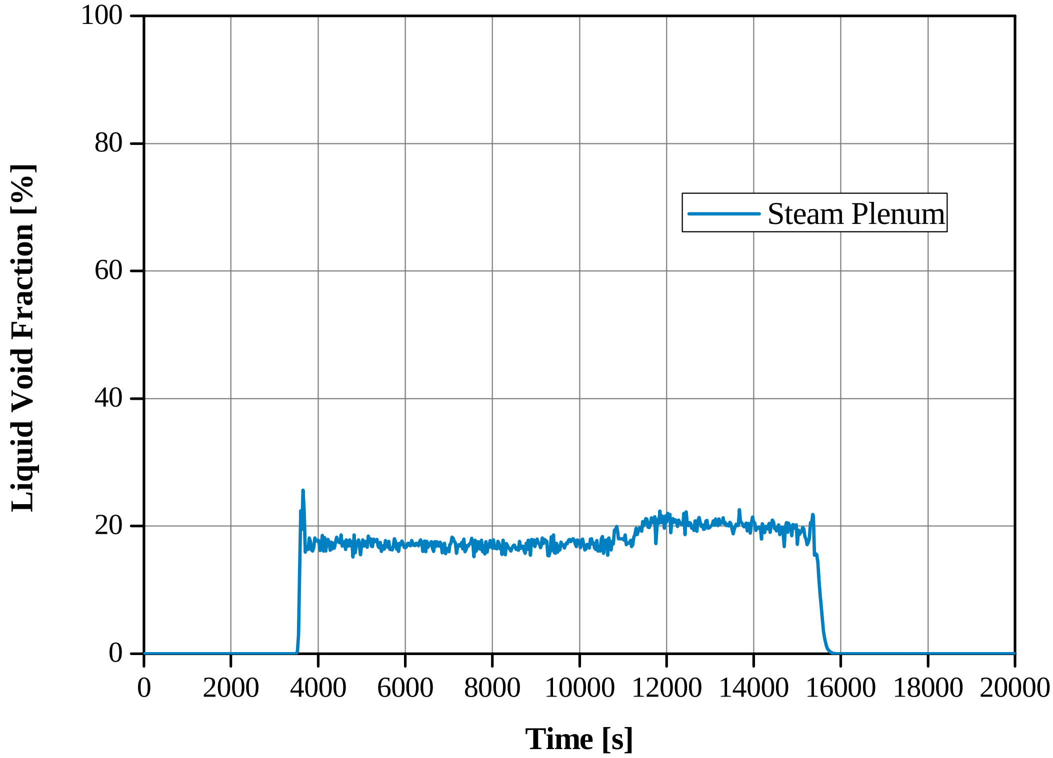

Figure19. Liquid void fraction inside the steam plenum.

The liquid void fraction in the Steam plenum volume (BRANCH 700) has been requested to RELAP5. Figure 19 shows a value around 20 % fraction of liquid during the HX water flowing phase, due to the condensation of water-steam mixture caused by the descending cold water penetration crossing the steam plenum.

4. Conclusions

The RELAP5 code adequately reproduces the total LBE mass flow rate during the forced circulation phase, while an overestimation of the simulated value is observed during the natural circulation phase; consequently the simulated heat section velocity trend shows analogous behaviour. Concerning riser mean void fraction obtained from RELAP5, a value of about 12 % is found, resulting higher than the experimental value of 8 % (obtained through an empirical method); hence from the comparison of the numerical and experimental driving force, a proportional discrepancy is found: 450 mbar and 280 mbar for RELAP5 and experimental data, respectively.

LBE bypass phenomenon crossing the separator barrier was simulated introducing a time dependent junction that forced a fraction of the mass flow rate, exceeding the separator level, directly into the downcomer. This quantity (20 kg/s) was estimated from experimental data power unbalance associated to HS and HX. Introducing the LBE bypass, the code reproduces suitably the HS and HX temperature profile in the assisted circulation phase, while some discrepancies are observed during the following ULOF transient. The same considerations are valid for the power balance.

The main discrepancies observed with experimental data may be imputed to RELAP5 inability to take into account the phenomenon of axial conduction. This phenomenon appears to be relevant in a vertical pool facility such CIRCE, where a huge amount of the total LBE (mainly within the downcomer zone) is in stagnant or very low velocity conditions (some mm/s). Furthermore, a possible inappropriate use of the heat coefficient correlations in LBE stagnant conditions may be an additional source of error. Therefore, an improved model able to overcome these code limitations must be used in future work in order to more accurately reproduce experimental thermal behaviour during the transient phase.

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