Figure 23 illustrates the water average temperatures at two heights of the tanks: at the free water surface (T_{top}) and at the sparger holes ($T_{sparger}$). The average value is calculated for a radial distance of 2 m (equal to the ETT radius). Figure 23 shows that at the end of transient, the temperature difference is equal to about 4 °C for ETT while it is about 15° C for the ITER tank.

The influence of the length of steam jet on the axial difference of temperature is shown in Figure 24. A greater length of steam jet produces a smaller axial difference of temperature (about 8 °C) which remains almost constant in all the transients. A shorter length of steam jet produces a greater axial difference of temperature although at the end of transient the temperature difference is almost equal.

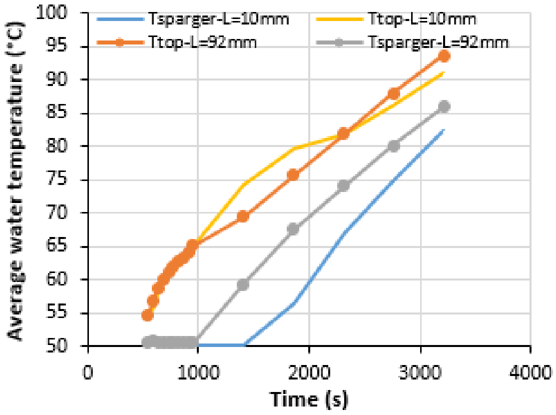

Figure 24. Water average temperatures vs time at different heights of the reduced scale tank (ETT) (different lengths of steam jet: L=10mm-L=92mm)

6. CONCLUSIONS

This paper illustrates the results of experimental tests, analytical model and CDF simulations concerning the steam direct condensation in water at sub-atmospheric pressure.

The tests have been performed in a reduced scale experimental rig simulating the ITER safety system called VVPSS. A similitude analysis has been developed in order to extrapolate the results obtained with the reduced scale experimental rig to the full scale system.

The CFD analyses permitted to assess the scale laws and demonstrate the capability of a large-scale condensation tank to simulate very well the physical phenomena which occur in the actual full scale Vapor Suppression Tank even if the Diameter/Height ratio is different. This different D/H ratio determines a different temperature difference along the height of the tanks.

The heat transfer occurs preferably in the axial direction in the longer ETT and in radial direction in the ITER tank. All the water, in both the tanks, is involved in the condensation process. Therefore, the water average temperature and the downstream pressure (in front of the sparger holes) are equal, resulting in the same condensation regimes.

The analytical model, developed based on the experimental results, seemed to describe well the global process of steam condensation at sub-atmospheric pressure. In addition, it permitted to determine the different condensation regimes depending on the transient of the steam mass flow rate due to accidental events and the water average temperature and downstream pressure in the condensation tank.

DISCLAIMER

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

REFERENCES

[1] Mazed D, Lo Frano R, Aquaro D, Del Serra D, Sekachev I, Olcese M. (2018). Experimental investigation of steam condensation in water tank at sub-atmospheric pressure. Nuclear Engineering and Design 335(15): 241-254. https://doi.org/10.1016/j.nucengdes.2018.05.025

[2] Mazed D, Lo Frano R, Aquaro D, Del Serra D, Sekachev I, Orlandi F. (2016). Experimental study of steam pressure suppression by condensation in a water tank at sub-atmospheric pressure. Proceedings ICONE24, Charlotte, North Carolina (USA), pp. V002T06A003. https://doi.org/10.1115/ICONE24-60029

[3] Lo Frano R, Mazed D, Aquaro D, Del Serra D, Sekachev I, Giambartolomei G. (2017). Methodology to investigate vibration phenomena caused by the steam condensation at sub-atmospheric condition. Proceedings of 25th International Conference on Nuclear Engineering, Shanghai (China), pp. V005T05A042. https://doi.org/10.1115/ICONE25-67448

[4] Lo Frano R, Mazed D, Aquaro D, Del Serra D, Orlandi F. (2017). Experimental investigation of functional performance of a vacuum vessel pressure suppression system of ITER. Fusion Engineering and Design 122: 42-46. https://doi.org/10.1016/j.fusengdes.2017.09.010

[5] Lo Frano R, Mazed D, Olcese M, Aquaro D, Del Serra D, Sekachev I, Giambartolomei G. (2018). Investigation of vibrations caused by the steam condensation at sub-atmospheric condition in VVPSS. Fusion Engineering and Design 136(B): 1433-1437. https://doi.org/10.1016/j.fusengdes.2018.05.031

[6] Lo Frano R, Aquaro D, Olivi N. (2016). Fluid dynamics analysis of loss of vacuum accident of ITER cryostat. Fusion Engineering and Design 109-111(B): 1302–1307. https://doi.org/10.1016/j.fusengdes.2015.12.038

[7] Shibata M, Takase K, Watanabe H, Akimoto H. (2002). Experimental results of functional performance of a vacuum vessel pressure suppression system in ITER. Fusion Engineering and Design 63-64: 217-222. https://doi.org/10.1016/S0920-3796(02)00242-9

[8] Takase K, Ose Y, Kunugi T. (2002). Numerical study on direct-contact condensation of vapor in cold water. Fusion Engineering and Design 63-64: 421-428. https://doi.org/10.1016/S0920-3796(02)00269-7

[9] Aquaro D. (2015). Experimental study of steam pressure suppression by condensation in a water tank at sub-atmospheric pressure. FDR Meeting, Cadarache, France.

[10] ANSYS FLUENT rel.19.2 – 2018 Ansys©Inc