Heat, mass and momentum transport in wet mineral-wool insulation: Experiment and simulations

Ojectives and methods: To test the performance of wet mineral-wool insulation, a water submersion setup is used to monitor its heat transfer sequentially through dry, submerged, and drainage-drying periods. This is shown in Figure 1. A cylindrical-shell insulation is wrapped around a pipe carrying a preheated (over 100^{o}C) oil stream. The temperature at various locations is monitored, and after a few hours in each period, steady state conditions are reached. Numerical 2-D (with gravity) simulations are also performed, with the control of the insulation hydrophobicity through the insulation surface liquid saturation. The predicted 2-D liquid saturation, Figure 2, shows that gravity and capillary pressure play significant roles in the liquid distribution and the insulation hydrophobicity changes with temperature due to the dissolution of the hydrophobic fiber coating. The presence of a gap between the pipe and insulation plays a significant role in heat transfer during the submerged period, as it allows for continuous direct liquid contact with the pipe. During the drying period, the evaporation rate continuously decreases (with a decrease in the average liquid saturation), governed by the increasing resistances to the heat and liquid flow.

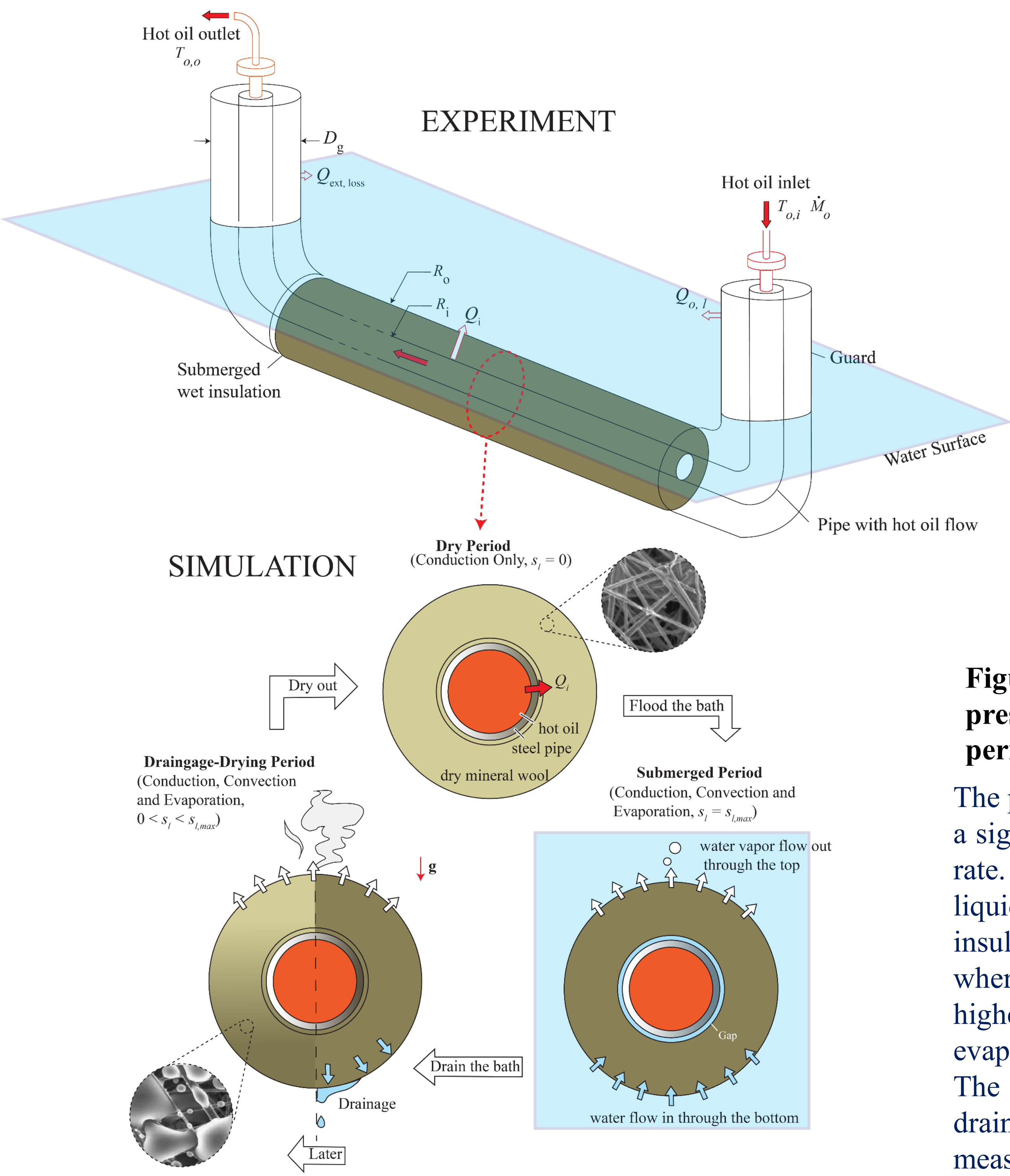

Figure 1. Wet insulation experiment and simulations.

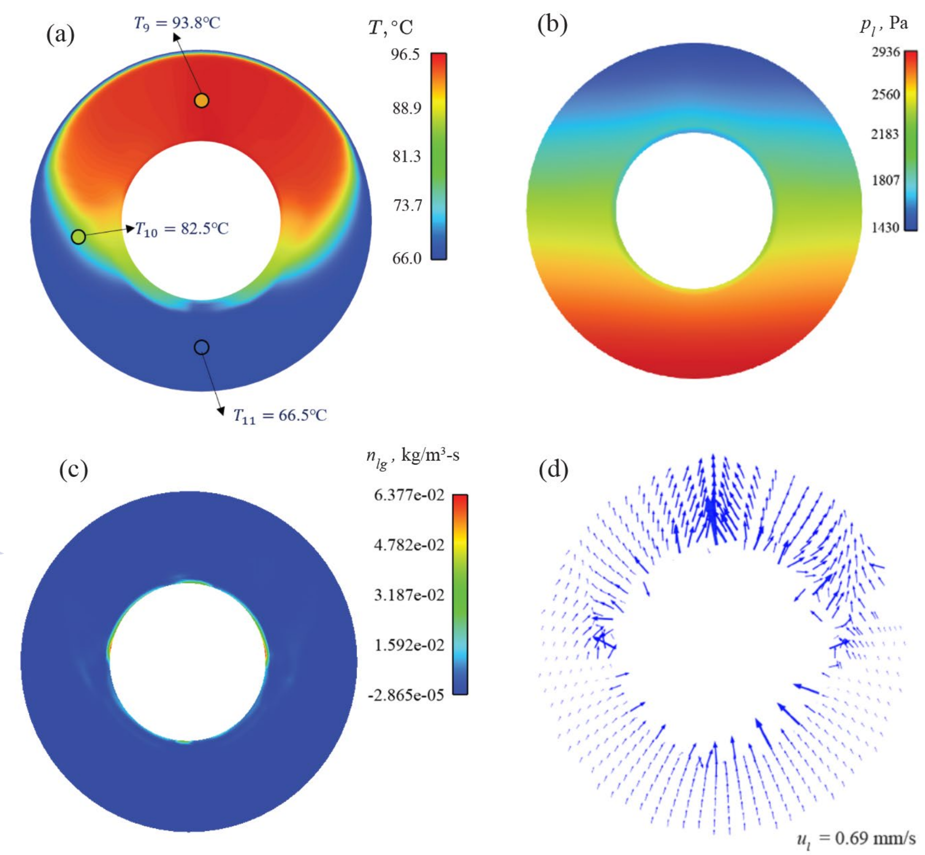

Figure 2. The predicted steady-state (a) temperature, (b) pressure, (c) evaporation rate distributions submerged period, and (d) velocity vector plot

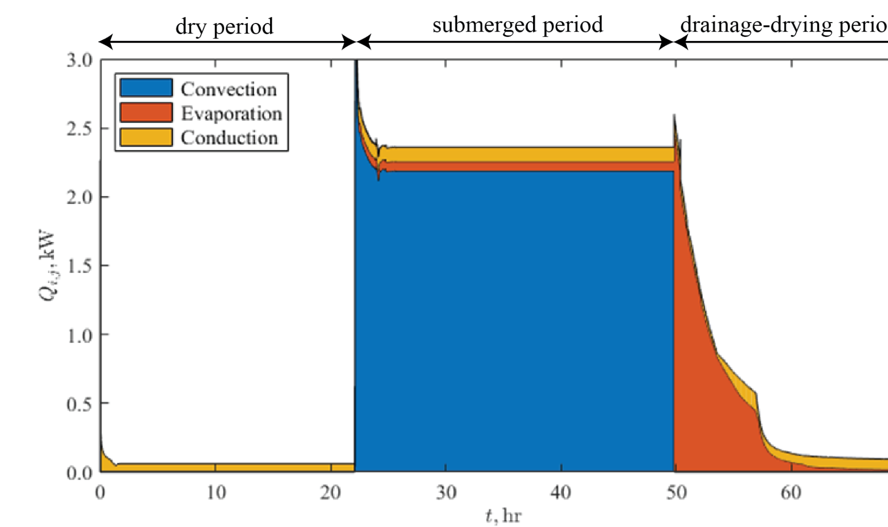

Figure 3. Division of heat transfer through the wet insulation into conduction (k), convection (u), and evaporation (lg) by simulations.

Results and take aways: In Figure 3, it is clear that the liquid motion (convection) has a significant effect on the heat transfer rate. In the submerged period, water reaches the unavoidable small gap between the pipe and the insulation, causing a significant drop in the insulation temperature in that region.

The presence of the gap, and the liquid within it, keeps the pipe surface temperature close to the boiling temperature, i.e., a significant temperature drop (about 70°C) from the end of the dry period, and this evaporation increases the heat loss rate. In addition to the liquid saturation and capillary pressure, both gravity and hydrostatic pressure influence affect the liquid motion and heat transfer, with liquid flowing in from the lower and leaving from the upper surface of the insulation. The highest heat transfer rate occurs during the submerged period, followed by the drainage-drying period where it gradually falls back to the dry period rate. The predicted evaporation rate in the submerged period is not the highest. During the drying period, since the water vapor is able to flow more readily due to low liquid saturation, evaporation (phase change) dominates the heat transfer.

The heat transfer during dry period is dominated by conduction, the submerged period by liquid convection, and the drainage-drying period is dominated by evaporation. Good agreement (within a maximum of 20%) is found between the measurements and the predictions. In the predictions, the van Genuchten capillary pressure model is found to be the most suitable for the high liquid hold up observed in the experiments.