Proceedings of the 8th World Congress on Momentum, Heat and Mass Transfer (MHMT'23)
Lisbon, Portugal – March 26 – 28, 2023
Paper No. ICMFHT 114
DOI: 10.11159/icmfht23.114

Dynamic, Semi-Empirical Modelling and Experimental Validation of Pressure Drop in Capillary Tubes

Janina Deichl[1], Christian Hoffmann[1], Jens-Uwe Repke[1], Tommy Grunert[2]
[1]Technische Universität Berlin, Process Dynamics and Operations Group, Sekr. KWT 9
Straße des 17. Juni 135, 10623 Berlin, Germany
janina.deichl@tu-berlin.de; c.hoffmann@tu-berlin.de; j.repke@tu-berlin.de
[2]BSH Hausgeräte GmbH
Wohlrabedamm 15, 13629 Berlin, Germany
tommy.grunert@bshg.com

Extended Abstract

With the introduction of the new EU energy label in 2023, the requirements for energy-efficient operation of household appliances will tighten. For household tumble dryers, in particular, the energy consumption must be strongly reduced for them to comply with the updated regulations. Therefore, a model which can predict the performance of the heat pump cycle, as well as the overall performance of the heat pump tumble dryer, is needed. This requires dynamic modelling the individual components of the heat pump cycle. Especially, for an investigation on overall energy consumption, the start-up, shut-down process as well as the drying process itself is of vital importance. This can only be done by means of a dynamic model.

The focus of this contribution is on the dynamic modelling of the static throttling device, a capillary tube. The pressure drop through the capillary tube strongly affects the behaviour of the heat pump and is in turn influenced by the roughness of the tube, the internal diameter, and the length of the capillary as well as the properties of the refrigerant. In addition, the influence of the phase change inside the capillary also has an impact on the pressure drop.

For a systematic investigation on this pressure drop in the capillary, a dynamic model is formulated within MATLAB/SIMSCAPE assuming an adiabatic and non-isenthalpic state change. Moreover, our previous work [1] has shown a hysteresis effect during the capillary operation at different subcooled conditions at constant mass flow and pressure at the capillary inlet, which we could confirm in our own test-rig [2]. This is due to the wetted surface of the capillary, which reduces the roughness of the capillary. As the hysteresis influences the pressure drop through the capillary, it cannot be neglected in the dynamic model. A stable hysteresis is implemented which means that the wetted fraction of the capillary persists with decreasing subcooled temperature over the entire simulation time and will not subside. The time dependency of the hysteresis has not been considered yet which means that the wetting of the capillary collapses after a time and is not stable. One approach may be to reset the stable hysteresis after a certain time based on a resetting mechanism, another may be to consider a memory variable based on time-dependent experimental data.

The experimental data for the refrigerants R290 and refrigerant mixture R436B for the validation of the model is obtained on a customized test-rig for the determination of the pressure drop over the length of the capillary. In this contribution, we use the own formulated dynamic model to describe the dynamic process behaviour of the capillary during operation. In these studies, we compare the results obtained for several correlations with our own parameterized correlation for R290 and the prediction for the refrigerant mixture R436B. The presented simulation studies and experimental data allow an assessment of the predictability of our proposed capillary model for other refrigerants, which were not considered during the development of the correlation. The predictability of the capillary model as well as of other components of the heat pump tumble dryer allows an analysis of the possible energy saving potentials of the overall process.

References

[1] Gabrisch, X., and Repke, J. (2020), Modelling the two-phase flow of propane in a capillary tube: Determination of the two-phase viscosity based on detailed experiments. International Journal of Refrigeration, 118: 427-442. https://doi.org/10.1016/j.ijrefrig.2020.05.018.

[2] Deichl, J., Weigert, J., Hoffmann, C., Repke, J. and Grunert, T. (2022), Semi-Empirical and Data-Driven Modelling of Two-Phase Flow in Capillary Tubes. Chemie Ingenieur Technik, 94: 1216-1216. https://doi.org/10.1002/cite.202255285.