Mitteilung

Projektgruppe/Fachkreis: Technische Strömungen

Development of an experimental set-up to investigate heat transport in convective air flows with phase transition

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The heat transfer in mixed convective air flows with phase transition is a phenomenon which occurs in nature and a plethora of technical applications. When condensing materials form droplets, condensation leads to an increased heat transfer rate and therefore is advantageous in heat exchangers [1], whereas in other technical applications condensation is oftentimes undesirable. For instance, fogging on the windshield or headlights of motor vehicles leads to restrictions when driving and a reduction of optical transparency influences road safety. In addition, a considerable amount of thermal energy is required for defogging, which can have a negative effect on the range of electric cars [2]. The design and modification of these components with regard to optimizing dehumidification or preventing misting is often based on experience and intuition. Despite the enormous progress of numerical methods in recent years, there is still a lack of reliable and applicable models for the numerical simulation of condensation in general, and in particular of droplet condensation on surfaces. Due to the complexity of the physical processes that determine the heat transport and thus the fogging on the panes, reliable simulations are expensive and time-consuming, and therefore not suitable for industrial applications. Thus, the objective of the present study is to develop a model, using dimensionless numbers, which allows the prediction of the condensation behavior on panes based on a reduced parameter space. In such a configuration the mass transport of the vapor by phase transition, the resulting latent and the sensible heat transfer are determined by the physical processes of convection and diffusion, the boundary conditions and the material properties of the surfaces. In addition, the mass transfer of water vapor changes even with the smallest changes in the boundary conditions. A major challenge of this study is therefore to design and construct an experimental setup with the appropriate measurement technology, which meets the requirements of ensuring defined boundary conditions, reproducibility of the experiments and measurement accuracy. The setup corresponds to a generic replica of a vehicle headlamp.
The air flow inside automotive headlights is the result of the superposition of forced and natural convection. The former is characterized by the Reynolds number $Re = UL/\nu$ and origins from ventilation holes at the rear wall of the cavity. The latter is a result of the heat emission from the internal light sources on the headlight's back. This can be expressed using the Grashof number $Gr = L^3 g \Delta T \beta/\nu$. β, g, ν are thermal expansion coefficient, gravitational acceleration and the kinematic viscosity of the working fluid air with respect to the current laboratory condition. The characteristic velocity U is equal to the mean inlet velocity and L is a characteristic system length, i.e. the ratio between the system volume and the inlet's cross section. ΔT is the temperature difference between the mean temperature of the heating and the cooling plate. If the temperature of the windscreen T_c falls below the dew point T_{dp}, a vapor mass flow $\dot{M}_v$ occurs due to phase transition. Fogging of the pane thus depends on the flow velocity U, the air temperature T_a, the pane temperature T_c, the heat emission of the lamps $\dot{Q}_l$ as well as on their temperature T_h and the dew point temperature T_{dp}. The challenge is to provide an experimental setup that does not only exactly determine all these variables, but also controls them with high precision. For this purpose we have designed, developed and constructed an experimental setup that meets these requirements. The structure consists of a rectangular cavity that is heated at the rear and cooled at the front. To compensate pressure changes caused by temperature shifts, automotive headlights are designed as open systems to allow air exchange with the engine compartment. Hence, the configuration is equipped with an air inlet and an air outlet. This configuration maps all physical processes that determine the fogging of headlamp windshields. The dimensions of the sample are: length $L = 0.5$ m, width $W = 0.5$ m and height $H = 0.25$ m. The air inlet and outlet extend over the entire cell height and have an aspect ratio of 0.1. Both are aligned parallel to the sample's side walls. A sketch of the configuration is depicted in Fig. 1. The control setup shown in Fig. 2 consists of three control loops. The first loop is connected to the air inlet and splits up into a humidity and a temperature control cycle. The second closed loop cycle sets the temperature of the cooling plate. The transparency of the cooling plate is achieved by using paraffin oil which flows between two parallel glass walls. The third loop controls the air temperature of the housing around the condensation cell. The temperature is kept at the mean cavity temperature of

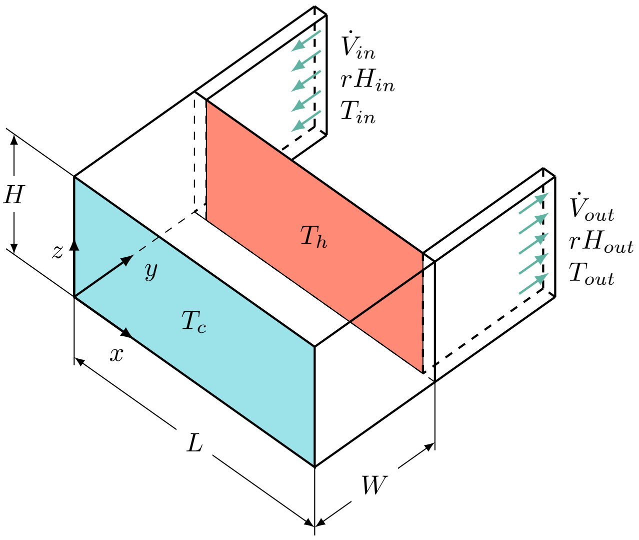

Fig. 1: Schematic setup of the condensation cell: The cooling plate is colored in blue (temperature T_c) and the heating plate is colored in red (temperature T_h). Transparent areas are kept at mean cavity temperature. Inlet and outlet conditions are characterized by means of humidity rH, temperature T_{in} and volume flow $\dot{V}$.

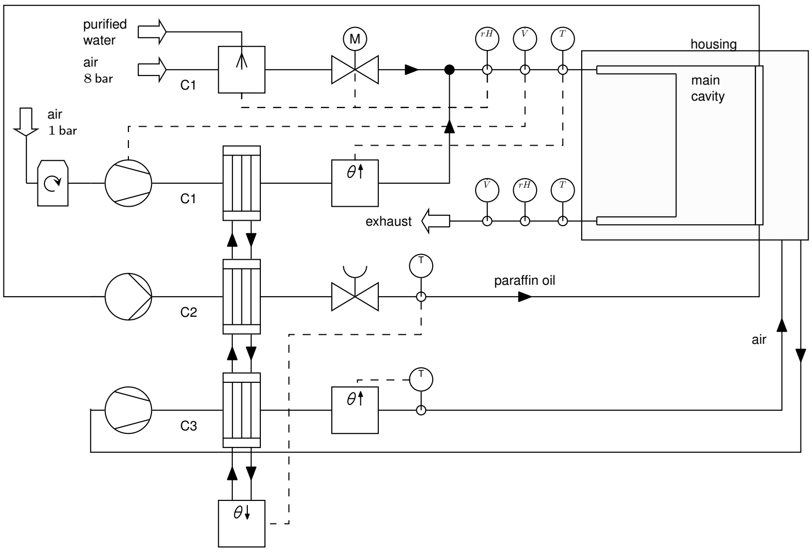

Fig. 2: Three loops control the inlet temperature, humidity and volume flow of the inlet (C1), the cooling plate temperature (C2) and the ambient temperature of the condensation cell (C3).

the sample to minimize heat transfer through the glass sidewalls of the volume. Optical accessibility will pave the way for the future application of measurement techniques like PIV, laser-Doppler anemometry (LDA) and methods for image-based distribution analysis of condensate, i.e. performed by Zheng et al. [3]. Kim et al. [4] studied the flow in a consumer headlight by means of stereoscopic particle image velocimetry (PIV). In their work they report on the superposition of thermal and forced convection and resulting three-dimensional structures. To investigate if these structures are present in the generic setup as well, we will provide results of Tomo-PIV measurements.

References

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