Internal Condensing Flows inside a Vertical Pipe: Experimental/Computational Investigations of the Effects of Specified and Unspecified (Free) Conditions at Exit

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Reported experimental and computational results confirm that both the flow features and heat-transfer rates inside a condenser depend on the specification of inlet, wall, and exit conditions. The results show that the commonly occurring condensing flows’ special sensitivity to changes in exit conditions (i.e., changes in exit pressure) arises from the ease with which these changes alter the vapor flow field in the interior. When, at a fixed steady mass flow rate, the exit pressure is changed from one steady value to another, the changes required of the interior vapor flow toward achieving a new steady duct flow are such that they do not demand a removal of the new exit pressure imposition back to the original steady value—as is the case for incompressible single phase duct flows with an original and “required” exit pressure. Instead, new steady flows may be achieved through appropriate changes in the vapor/liquid interfacial configurations and associated changes in interfacial mass, heat-transfer rates (both local and overall), and other flow variables. This special feature of these flows has been investigated here for the commonly occurring large heat sink situations, for which the condensing surface temperature (not heat flux) remains approximately the same for any given set of inlet conditions while the exit-condition changes. In this paper’s context of flows of a pure vapor that experience film condensation on the inside walls of a vertical tube, the reported results provide an important quantitative and qualitative understanding and support an exit-condition based categorization of the flows. Experimental results and selected relevant computational results that are presented here reinforce the fact that there exist multiple steady solutions (with different heat-transfer rates) for multiple steady prescriptions of the exit condition—even though the other boundary conditions do not change. However, for some situations that do not fix any specific value for the exit condition
(say, exit pressure) but allow the flow the freedom to choose any exit pressure value within a certain range, experiments confirm the computational results that, given enough time, there typically exists, under normal gravity conditions, a self-selected “natural” steady flow with a natural exit condition. This happens if the vapor flow is seeking (or is attracted to) a specific exit condition and the conditions downstream of the condenser allow the vapor flow a range of exit conditions that includes the specific natural exit condition of choice. However, for some unspecified exit-condition cases involving partial condensation, even if computations predict that a natural exit-condition choice exists, the experimental arrangement employed here does not allow the flow to approach its steady natural exit condition value. Instead, it only allows oscillatory exit conditions leading to an oscillatory flow. For the reported experiments, these oscillatory pressures are induced and imposed by the instabilities in the system components downstream of the condenser.