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MOIST RAYLEIGH-BENARD CONVECTION

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Abstract We report the observations from turbulent thermal Rayleigh-Benard convection experiment with a two-phase liquid-vapor binary mixture. Evaporation/condensation processes in a turbulent convection are accompanied by the formation of cloud like structures above the liquid-vapor interface. We also found that a liquid film condensation on the underside of the top plate results in regular hexagonal patterns of falling droplets.

Keywords: Rayleigh-Benard convection, clouds, moist convection, multi-phase flow

Clouds play an important role in climate change and weather prediction. According to the Inter-governmental Panel on Climate Change clouds are one of the least understood domains in the field of climate sciences and are "listed as one of the most urgent problems requiring scientific attention" [1, 2]. Cloud physics involves turbulence, phase transition and interactions with radiation. These complexities have restricted the number of laboratory experiments and so most research in clouds are dependent on field measurements. With the progress of high performance computing the attempts to understand the moist convection system through large eddy simulation [3] and direct numerical simulation [4] have been performed. In this paper we present the results from a laboratory scale moist convection experiment involving liquid-vapor phase transition in a turbulent Rayleigh-Benard convection (RBC) system.

The earth's atmosphere consists of water vapor that can undergo phase change, and other gases that exist only in the gaseous state. The binary mixture used in the experiment is composed of sulfur hexafluoride (SF_6) and helium (He). The experimental conditions are set such that SF_6 exists in both liquid and vapor phase (similar to water vapor in earth's atmosphere) and helium acts like a carrier gas (present only in the gas phase). A schematic representation of the phenomenon observed inside the convection cell is shown in figure 1. Above the bottom plate SF_6 is present in the liquid phase, and the gas phase above this layer consists of SF_6 and He. When the bottom plate heater is switched on a turbulent thermal convection sets in. The dark region in figure 2 represents the cloud like patterns formed above the liquid-vapor interface. These structures highlight the sheet like plumes found close to the boundary in a turbulent RBC [5] thus indicating that these patterns are located close to the boundary layer above the liquid-vapor interface.

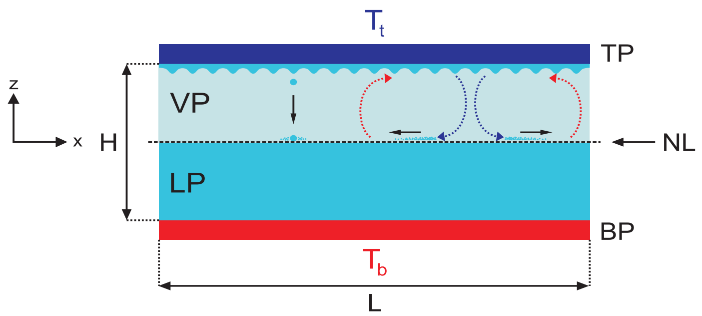

Figure 1. Schematic diagram of the flow pattern inside the convection cell [6].
LP-liquid phase, VP-vapor phase, BP-bottom plate, TP-top plate, NL-nucleation layer.
Cell height H=2.16 cm, lateral size L=6.51 cm, aspect ratio $L/H \approx 3$.

Convection is also accompanied by the condensation of thin layer of liquid SF_6 on the underside of the top plate that results in the formation of hexagonal droplet patterns as shown in figure 2. These droplets grow in size, detach from the top plate and fall back into the liquid pool of SF_6. The film condensation was also observed in the absence of helium in the working fluid but no cloud like structures were observed in this case above the liquid-vapor interface. To obtain the cloud like patterns above the liquid-vapor interface a non-condensable gas (helium in our case) is required. Further experiments are required to understand the behavior of the cloud like structures in the system and to capture the exact nature of the instability in the liquid layer on the underside of the top plate.

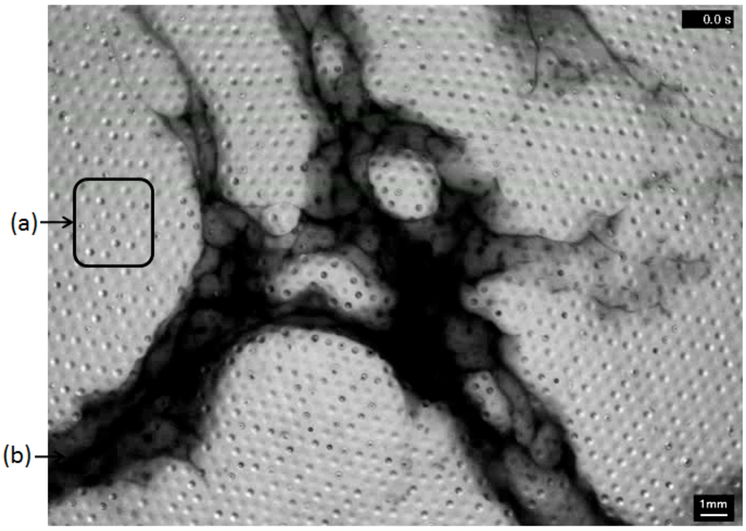

Figure 2. Top view of convection cell: (a) droplet condensation on the underside of the top plate, (b) cloud like structures. Experimental conditions: pressure 54 bars, mean temperature 317.65 K, temperature difference 0.5 K.

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