We report measurements of turbulent heat transport in cylindrical samples of ethane ($\text{C}_2\text{H}_6$) with diameter equal to height and heated from below while the applied temperature difference $\Delta T = T_b - T_t$ straddled the liquid-vapor coexistence curve $T_\phi(P)$. Starting in the vapor phase, the sample mean temperature $T_m = (T_t + T_b)/2$ was decreased in small steps and at constant pressure. As the top temperature $T_t$ decreased below $T_\phi$, droplet condensation occurred in a thin thermal boundary layer just below the top plate. This is shown by the shadowgraph images in Fig. 1. The left image is in the single-phase vapor region where $T_t > T_\phi$, and shows refractive-index variations associated with plumes and thermal fluctuations. For the middle and right images the sample is still nearly completely filled with vapor, but small circular black regions appeared which correspond to liquid droplets.

Fig. 1. Shadowgraph images at different mean temperatures with, from left to right, $\phi = 1.01, 0.92, \text{ and } 0.85$ where $\phi$ is the temperature fraction $0.5 + (T_m - T_\phi(P))/\Delta T$. For this experiment $P = 41.37$ bars and $\Delta T = 0.50K$.

In the single-phase regions where the temperature fraction $\phi = [0.5 + (T_m - T_\phi(P))/\Delta T]$ is greater than 1 (vapor) or less than 0 (liquid), the effective conductivity $\lambda_{eff}$ at constant $\Delta T = 1K$ corresponded to a Nusselt number $Nu = \lambda_{eff}/\lambda$ ($\lambda$ is the conductivity in the absence of convection) that was
typically near 200. When droplets formed, the latent heat of vaporization $H$ provided an additional heat-transport mechanism. $\lambda_{\text{eff}}$ increased linearly with decreasing $T_m$ and $T_t$ (see Fig. 2a), and reached a maximum value $\lambda_{\text{eff}}^*$ at $\phi^* \simeq 0.45$ that was an order of magnitude larger than the single-phase $\lambda_{\text{eff}}$. The initial slope of the heat-transport enhancement was proportional to $1/\Delta T$, and $\lambda_{\text{eff}}^*$ varied only mildly with $\Delta T$. As shown in Fig. 2b, this implies that data for $\lambda_{\text{eff}}$ taken with different $\Delta T$ fall onto a unique straight line when plotted as a function of $\phi$. Except for the droplets, the sample remained filled with vapor in the range $\phi > \phi^*$ and the measurements were reproducible and independent of whether $T_m$ was increased or decreased.

Interestingly, the onset of enhancement occurred at $\phi = \phi_{\text{on}} \simeq 0.95 < 1$, where a thin meta-stable vapor layer of finite thickness $l_c$ already existed below the top plate. The fact that $\phi_{\text{on}}$ is independent of $\Delta T$ implies that $l_c$ is also independent of $\Delta T$ even though the thermal gradient just below the top plate depends strongly on $\Delta T$. For the example of Fig. 2 one can estimate that the thermal boundary-layer thickness is given by $l_{BL} \simeq L/(2Nu) \simeq 200 \mu m$ where $L \simeq 8$ cm is the sample height. For $l_c$ one has $l_c \simeq (1-\phi_{\text{on}})l_{BL} \simeq 20 \mu m$.

As $P$ approached the critical pressure, $\lambda_{\text{eff}}^*$ increased dramatically even though $H$ vanished. We attribute this phenomenon to an enhanced droplet-nucleation rate as the critical point is approached.

For $\phi < \phi^*$ the sample filled with liquid, heat-transport enhancement was by boiling, and the data were irreproducible and depended on past history.

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