Numerical Analysis of Mist-Cooled High Power Components in Cabinets

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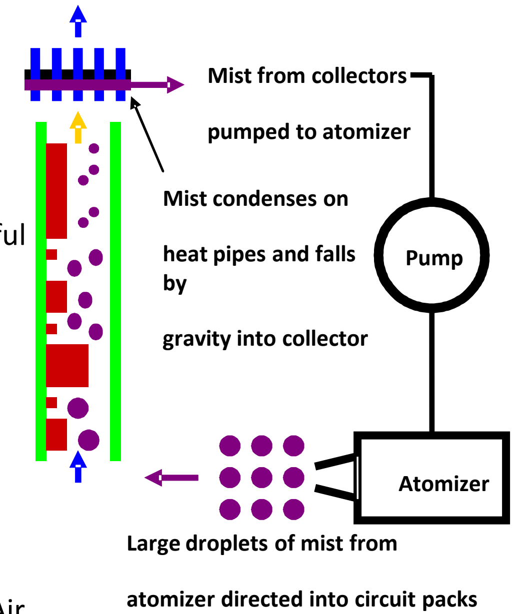
Objective

The present work quantifies the potential for thermal management of a sealed cabinet using an evaporating mist introduced upstream of the high-power electronic components. The effect of droplet size and the mist loading fraction on the heat sink temperature reduction is computed and parametrically analyzed.

Impact

- Elimination of hot/cold aisles
- Reduced operating expenditure by avoiding wasteful cooling of room air and pumping air over long distances
- Ergonomic benefits (reduced acoustic noise)
- Increased thermal densities through shelf-level cooling and increased fan speeds
- Prevention of pollutants and dust from entering racks



Approach

Continuous phase

$$\frac{\partial}{\partial x_i}(\rho u_i) = S_m$$

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + F_i$$

$$\frac{\partial}{\partial x_i}(\rho c_p u_i T) = \frac{\partial}{\partial x_i}\left(k_i \frac{\partial T}{\partial x_i}\right) + \dot{q}'''$$

$$\frac{\partial}{\partial x_i}(\rho u_i m_v) = \frac{\partial}{\partial x_i}\left(\rho D_{AB} \frac{\partial m_v}{\partial x_i}\right) + S_m$$

$$\mathrm{Re}_D = \frac{\rho D_P |u_P - u|}{\mu}$$

Disperse phase

$$\frac{dm_P}{dt} = -h_m(\rho_{v,s} - \rho_v)A_P$$

$$\frac{du_P}{dt} = \frac{18\mu}{\rho_p D_p^2}\frac{C_D \mathrm{Re}_D}{24} + F_{other}$$

$$m_P c_{p,P}\frac{dT_P}{dt} = hA_P(T - T_P) + h_{fg}\frac{dm_P}{dt}$$

$$Sh = \frac{h_m D_P}{D_{AB}} = 2.0 + 0.6\mathrm{Re}_D^{0.5}\, Sc^{1/3}$$

$$Nu = \frac{hD_P}{k} = 2.0 + 0.6\mathrm{Re}_D^{0.5}\,\mathrm{Pr}^{1/3}$$

Discrete Phase Model (DPM) in FluentAir is treated like continuum phase, droplets as the dispersed phase. The interactions between the two phase is accounted by mass, momentum and heat exchange (source/sink terms in Navier-Stokes equations for air flow)

Interactions between two phases

$$F_i = \sum\left(\frac{18\mu C_D \mathrm{Re}_D}{24\rho_p D_p^2}(u_{P,i} - u_i) + F_{other,i}\right)\dot{m}_P \Delta t$$

$$S_m = \frac{\Delta m_P}{m_{P0}}\frac{\dot{m}_{P0}}{dV}$$

$$\dot{q}''' = \left[\frac{\bar{m}_P}{m_{P0}} c_{p,P}\Delta T_P + \frac{\Delta m_P}{m_{P0}}\left(-h_{fg} + \int_{T_{ref}}^{T_p} c_{p,v}\,dT\right)\right]\frac{\dot{m}_{P0}}{dV}$$