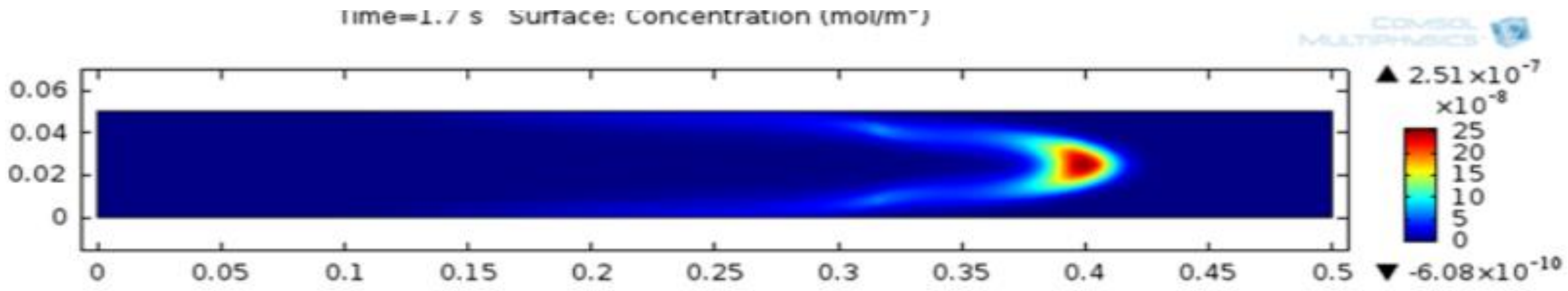
Modeling of Humidification in Comsol Multiphysics 4.4



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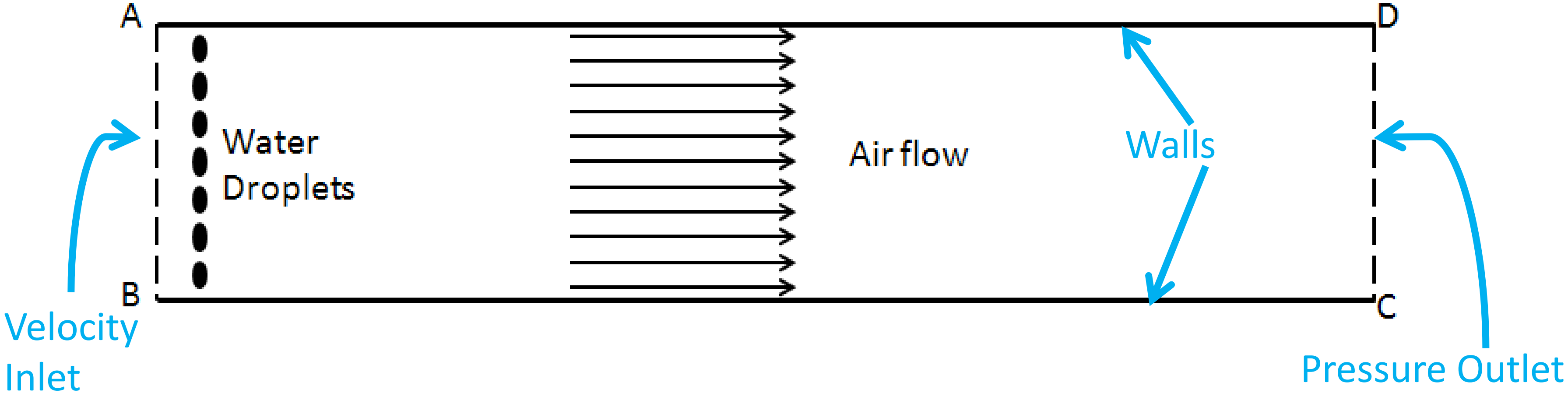
What is Humidification???

- Humidification is the process of increasing the moisture content of air and thereby the Relative Humidity.
- One of the methods to humidify air is evaporation of water droplets suspended in air.
- From the point of view of CFD, this presents a complex problem consisting of multiphase flow, heat transfer and mass transfer phenomenon all coupled

Simulation domain

- As a precursor to actual humidifier modeling we conducted a simplified simulation of evaporation of water droplets in a straight air channel
- Particle Tracing Module was coupled with CFD module in Comsol Multiphysics



Governing Equations

- The air flow is governed by the Navier Stokes Equations with source terms added to Continuity and Energy equations to account for the water droplet evaporation.

$$\frac{\partial \rho}{\partial t} + \nabla .(\rho u) = \Gamma(T_p)\dot{m} \qquad \text{(Continuity Equation)}$$

$$\frac{\partial(\rho u)}{\partial t} + \nabla .(\rho u u) = -\nabla P + \nabla .(\mu(\nabla u + \nabla u^T)) + F_{Body} \qquad \text{(Momentum Equation)}$$

$$\frac{\partial(\rho C_p T)}{\partial t} + \nabla .(\rho C_p T u) = \nabla .(k \nabla T) - \Gamma(T_p)(\nabla .(D(\nabla c)) M_w h_i + \dot{m} H_e) \qquad \text{(Energy Equation)}$$

$$\frac{\partial (c)}{\partial t} + \nabla .(cu) = \nabla .(D(\nabla c)) + \Gamma (T_p) \frac{\dot{m}}{M_w}$$

(Transport Equation for vapor)

$$\frac{\partial v_p}{\partial t} = F_D (u - v_p)$$

(Momentum Equation for particle)

$$m_p \tilde{C}_p \frac{\partial (T_p)}{\partial t} = hA_p (T_\infty - T_p) + \varepsilon_p A_p \sigma (T_\infty^4 - T_p^4) + \Gamma (T_p) \dot{m} H_e Volume_{cell}$$

(Energy Equation for particle)

Implementation in Comsol Multiphysics

- Comsol Multiphysics 4.4 did not allow the exchange of variables between Lagrangian frame (particles) and Eulerian frame (air flow).

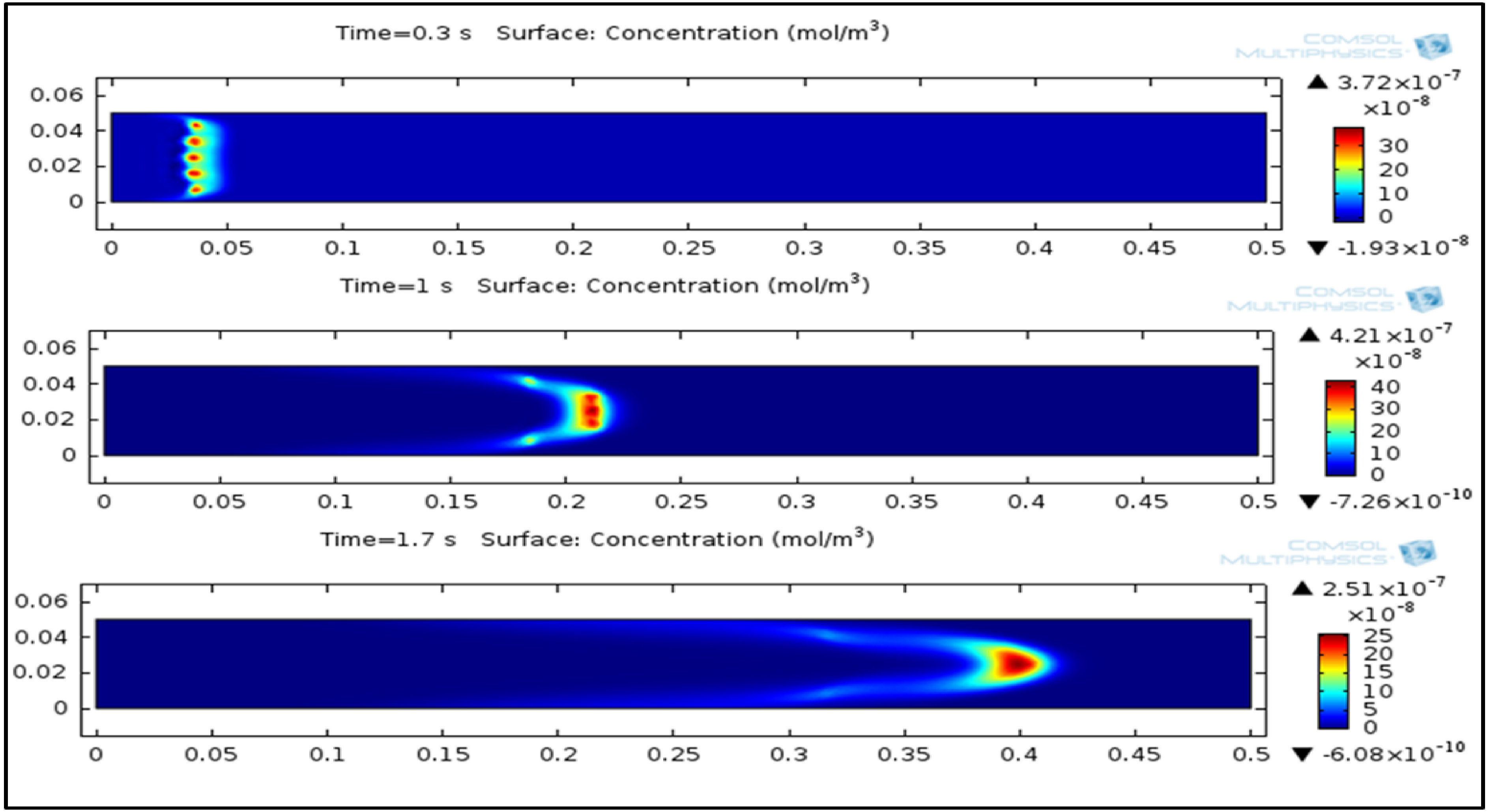
- Hence a system of PDE's was defined as:

$$e_a \frac{\partial^2}{\partial t^2}\left[\frac{u1}{v1}\right] + d_a \frac{\partial}{\partial t}\left[\frac{u1}{v1}\right] + \nabla .\psi = \left[\frac{S1}{S2}\right]$$

Set to zero

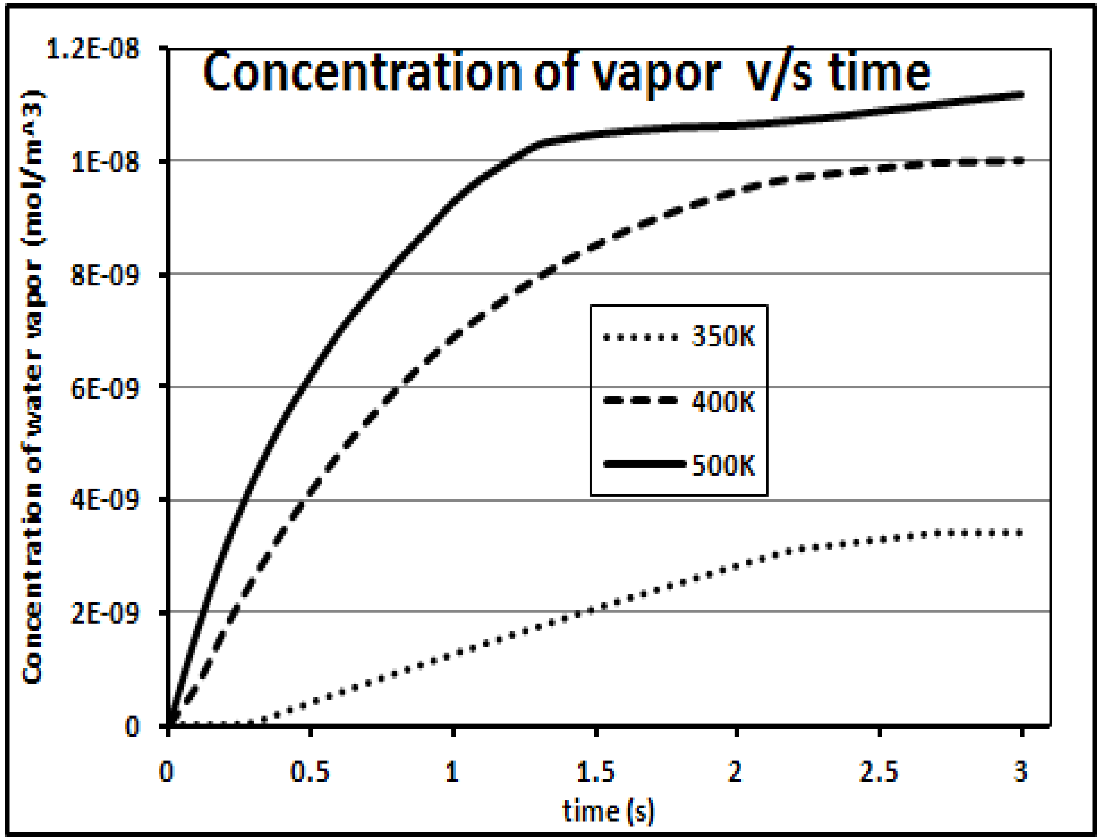
Source terms from particles

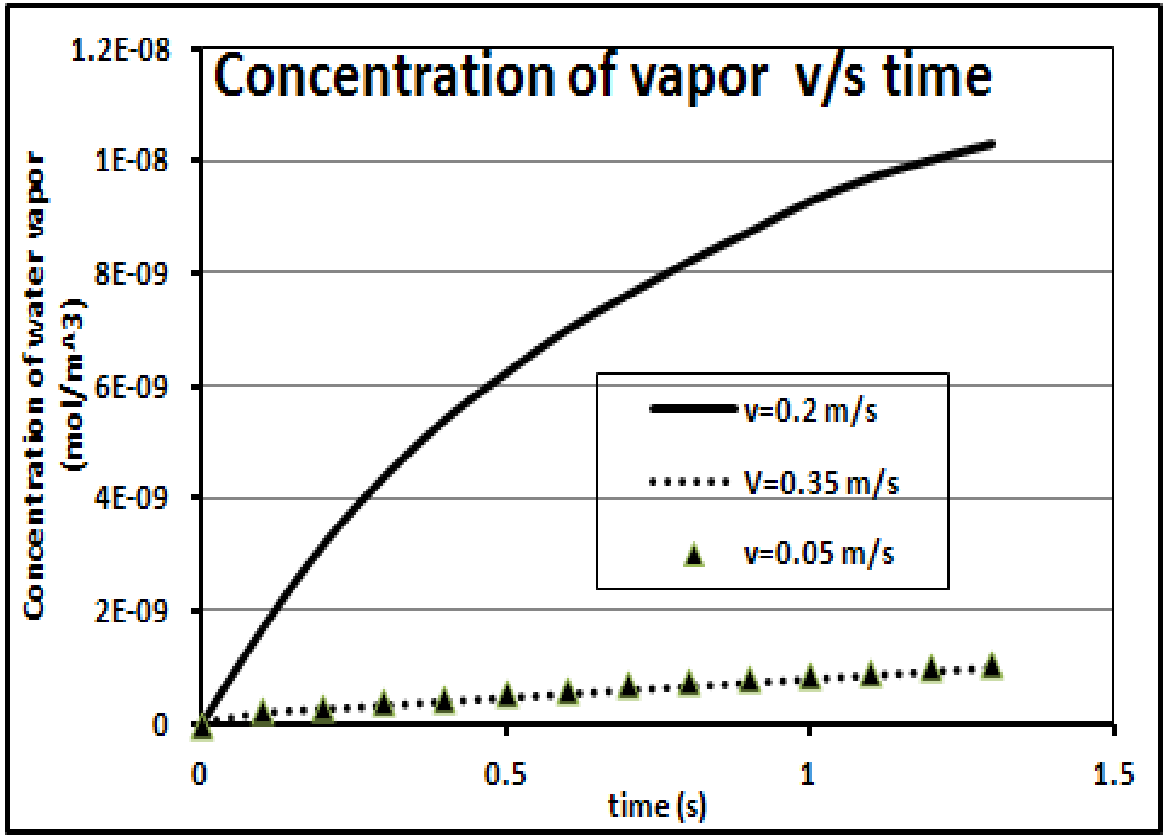
Results:



Time=0.3 s Surface: Concentration (mol/m³)
0.06
0.04
0.02
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
▲ 3.72×10⁻⁷
×10⁻⁸
30
20
10
0
▼ -1.93×10⁻⁸
Time=1 s Surface: Concentration (mol/m³)
▲ 4.21×10⁻⁷
×10⁻⁸
40
30
20
10
0
▼ -7.26×10⁻¹⁰
Time=1.7 s Surface: Concentration (mol/m³)
▲ 2.51×10⁻⁷
×10⁻⁸
25
20
15
10
5
0
▼ -6.08×10⁻¹⁰
COMSOL MULTIPHYSICS

Effect of inlet air temperature and velocity on evaporation





Evaporation initiation length for various inlet air temperatures:

Temperature (K)	**Evaporation initiation length (m)**
350	0.03
400	0.00115
500	0.001

Conclusions:

- Complex phenomenon of coupled Multiphase flow with heat and mass transfer was modeled with Comsol Multiphysics 4.4 .
- The contours of vapor concentration depict that the phenomenon has been captured well.
- As expected the evaporation increased with increasing temperature of inlet air and evaporation initiation length reduced.
- There is an optimum velocity of inlet air for maximum evaporation.

Thank You

Appendix

- Drag Coefficient and particle Reynold's number:

$$F_D = \frac{18\mu}{\rho_p d_p^2} \frac{C_d \operatorname{Re}_d}{24}; \operatorname{Re}_d = \frac{\rho |u - v_p| d_p}{\mu}$$

- Calculation of heat transfer coefficient ,h for particles:

$$Nu = \frac{hd_p}{k_{air}} = 2.0 + 0.6 \operatorname{Re}_d^{1/2} \operatorname{Pr}^{1/3}$$

- Updating the particle diameter:

$$d_p^{new} = d_p^{old} - \frac{\dot{m}\, d_p^{old}}{3 m_{old}}$$

- Rate of mass transfer:

$$\dot{m} = \frac{N_i A_p M_{vapor}}{Volume_{element}} \; where \;, Ni = k_c (c_s - c)$$

cs is concentration of vapor at droplet surface assuming pressure to be equal to saturation

pressure, while kc is calculated as :

$$Sh = \frac{k_c d_p}{D} = 2.0 + 0.6 \, \mathrm{Re}_d^{1/2} \, Sc^{1/3} , where \;, Sc = \frac{\mu_{air}}{\rho_{air} D}$$