COMSOL
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Numerical Simulations of Condensing Moist Air Around Cold Cylinder

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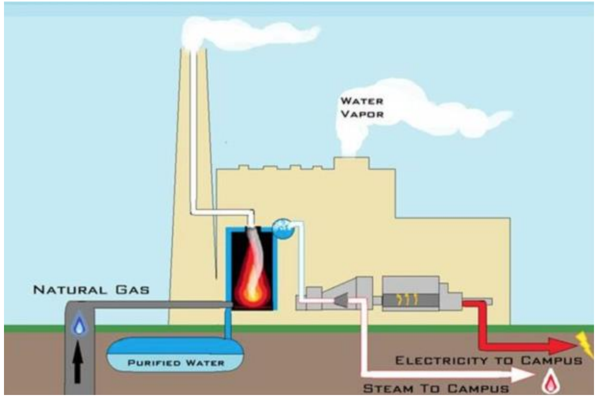
Outline

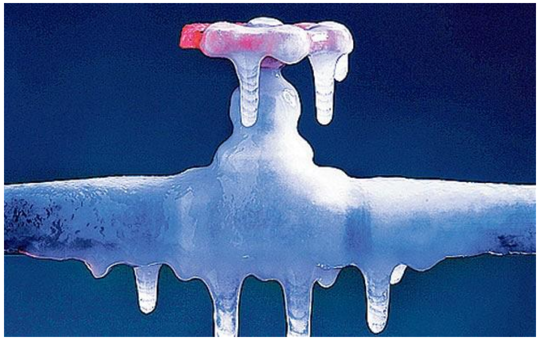
Introduction – Moist Air Flow

- Moist air flow around cold cylinder exist in many industrial applications such as:
  - Oil and gas industry
  - Food processing
  - Thermal energy storage systems
  - Refrigeration system
  - Heat exchangers
  - Refinery products pipelines
  - Power plant steam lines



Introduction – Moist Air Flow

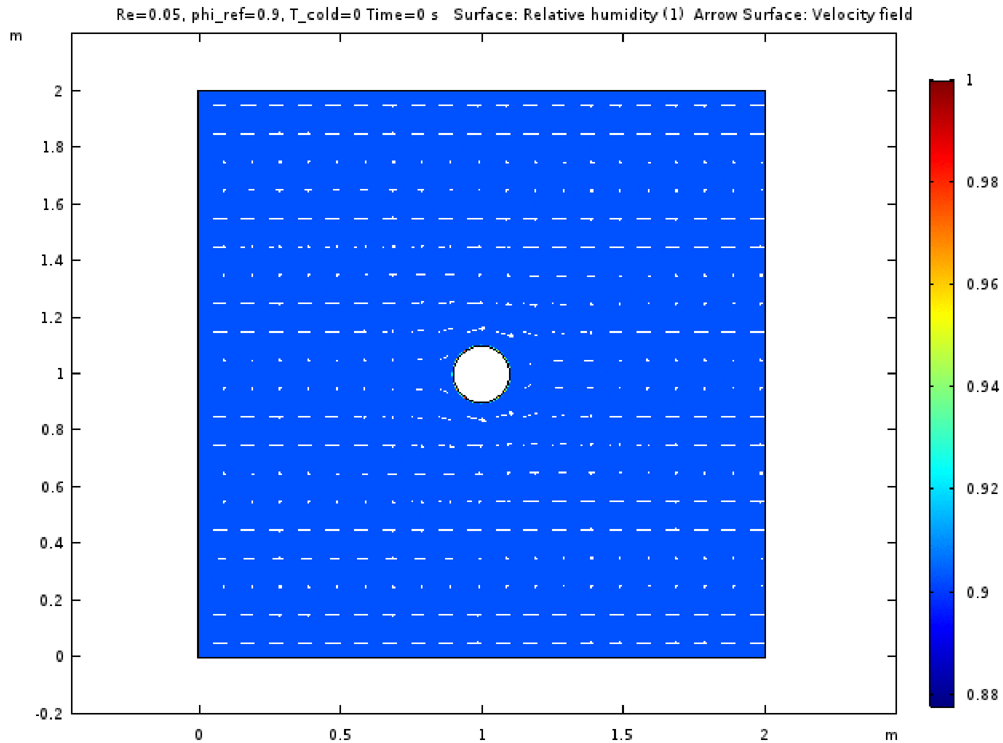
- Condensation of moist air on cold cylinders affects:
  - Air flow around the cylinders
  - Heat transfer into/from the cylinders
  - Build up moisture may lead to freezing pipes
  - Decreases the efficiency of industrial devices
  - Lead to corrosion



Problem Identification

In this problem

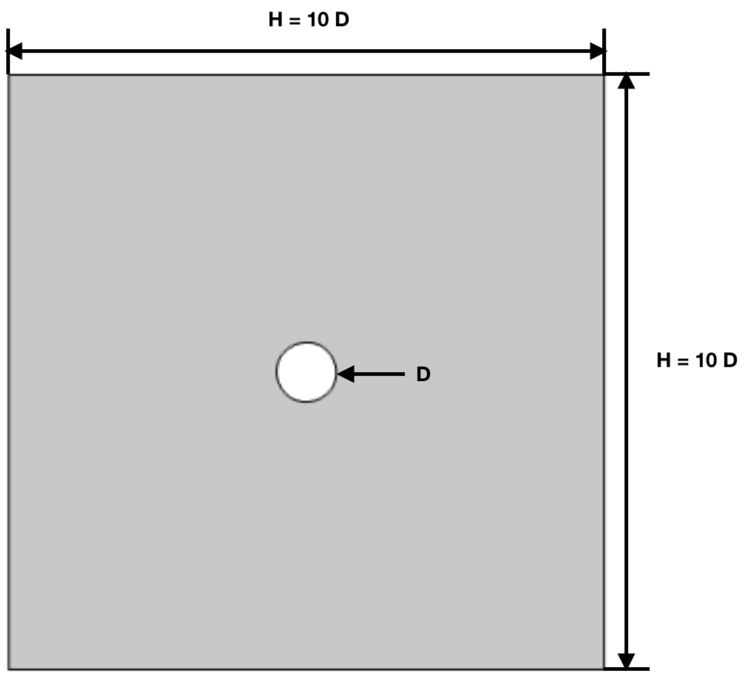
- Simulation for condensing moist air around cold cylinder is investigated
- Effect of environment relative humidity, flow Reynolds number, and cylinder temperature are investigated
- Moister build-up impact on heat transfer and moisture content are reported
- The Numerical simulation focuses on temperature field, flow fields, and concentration of moist air in computational domain.



Problem Identification

- COMSOL Multiphysics is used to solve this problem using Heat Transfer, Laminar Flow and Transport of Diluted Species physics.
- Using time dependent solution.
- Two dimensional model.

Dimensions	Value (m)
D	0.2
H	2



Problem Identification - Assumptions

1. Moist fluid with constant temperature, variable relative humidity, and speed is modeled.
2. No phase change effect considered in moist fluid.
3. Flow is two dimensional, laminar and weakly compressible.
4. Temperature of moist fluid is constant and equal to 33 ^{o}C.
5. Relative humidity for moist fluid range from 0.3 to 0.9.
6. Flow Reynolds number range from 0.001 to 1.
7. Cylinder surface temperature range from 0 to 30 ^{o}C.

Problem Identification - Governing Equations

- Mass conservation (Weakly Compressible)

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

- Momentum conservation

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot \left[-p\mathbf{I} + \mu\left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right) - \frac{2}{3}\mu(\nabla \cdot \mathbf{u})\mathbf{I} \right] + \mathbf{F} + \rho \mathbf{g}$$

- Energy conservation

$$d_z \rho C_p \frac{\partial T}{\partial t} + d_z \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = d_z Q + q_0 + d_z Q_p + d_z Q_{vd}$$

$$\mathbf{q} = -d_z k \nabla T$$

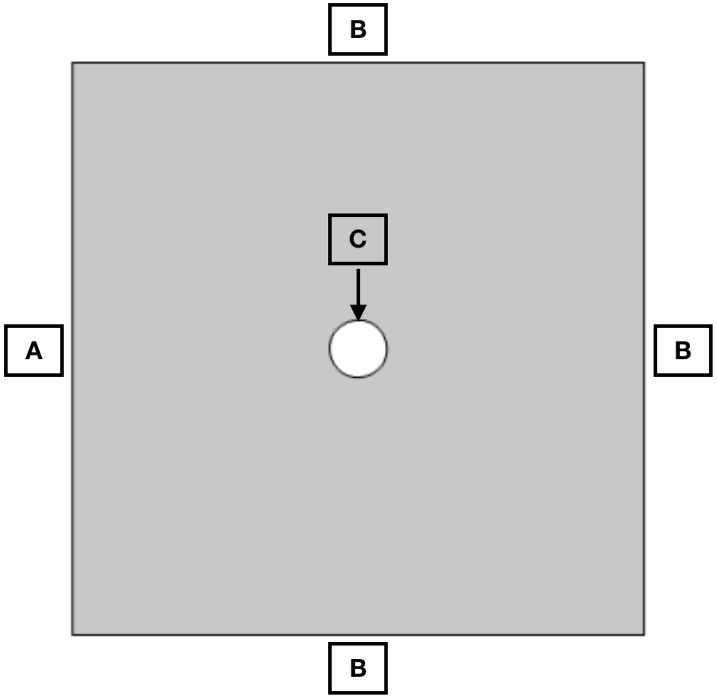
- Species transport

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (-D_i \nabla c_i) + \mathbf{u} \cdot \nabla c_i = R_i$$

$$\mathbf{N}_i = -D_i \nabla c_i + \mathbf{u} c_i$$

Problem Identification - Boundary Conditions

- Laminar Flow Physics:
  - Boundary A : Flow inlet.
  - Boundary B : Open boundary.
  - Boundary C : Wall.
- Heat Transfer Physics:
  - Boundary A : Open boundary.
  - Boundary B : Open boundary.
  - Boundary C : Temperature.
- Transport of Diluted Species Physics:
  - Boundary A : Open boundary.
  - Boundary B : Open boundary.
  - Boundary C : No Flux.



Base Cases Description

- This case is used to show the effect of study parameters (Reynolds number, cold cylinder surface temperature, and environment relative humidity) on the results (Total heat flux, and moisture content).

- Environment Temperature remains 33 ^{o}C in all cases including this base case.

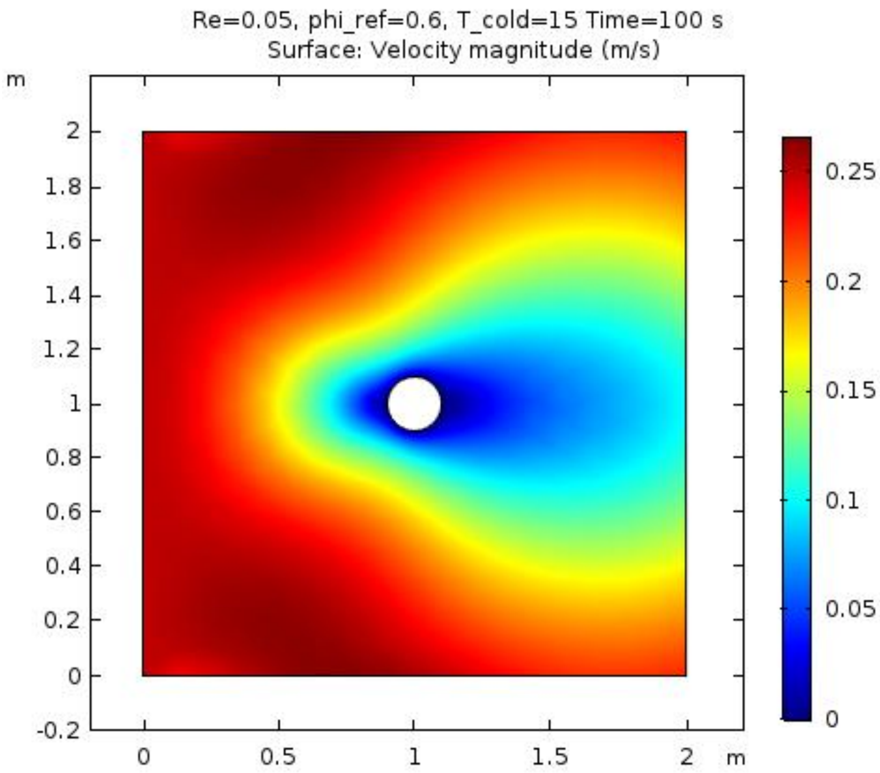
- In this base case:

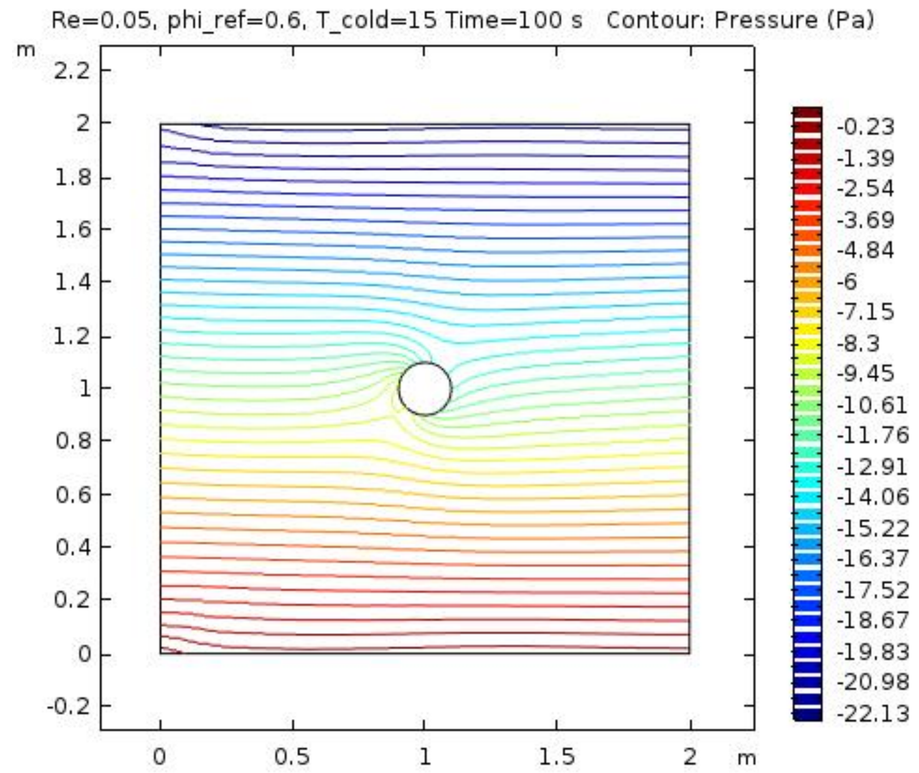
  Reynolds number set to 0.05

  Cold cylinder temperature = 15 ^{o}C

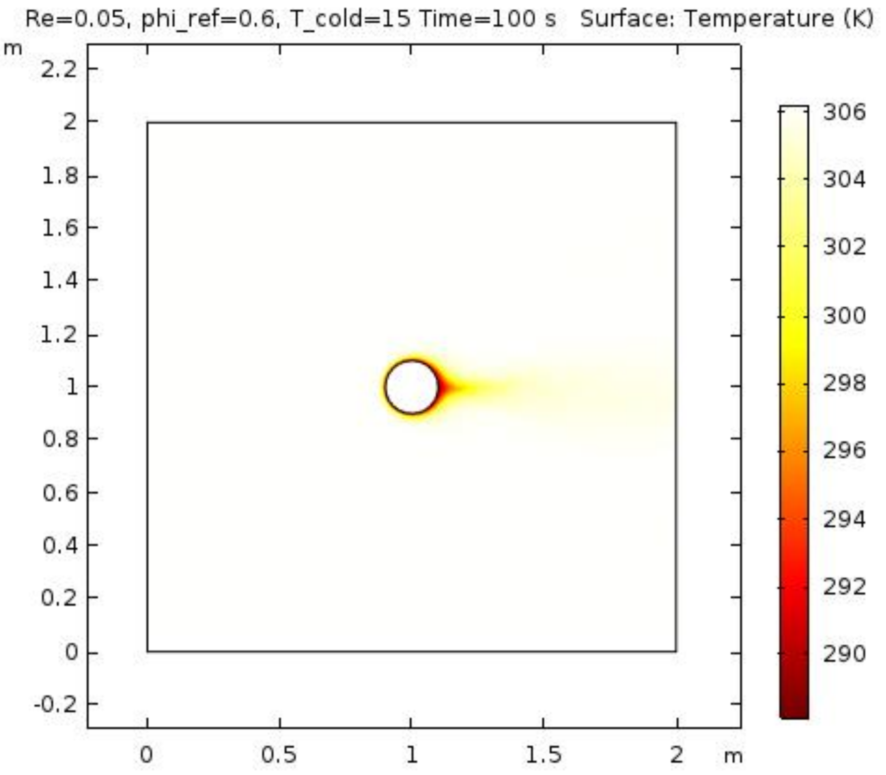
  Environment Relative Humidity = 60 %

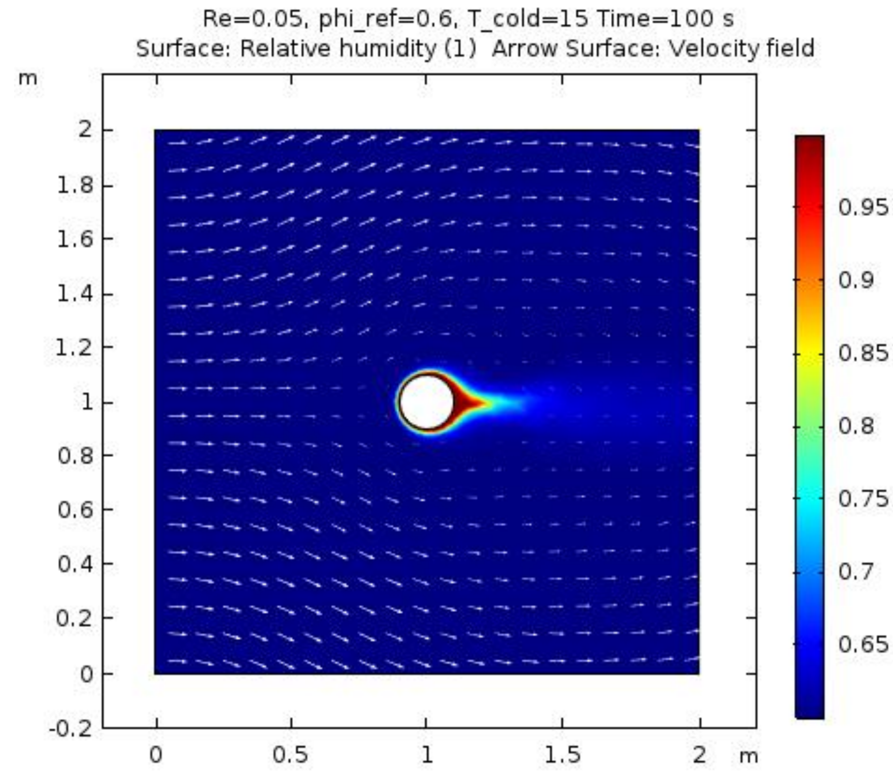
Base Case Results





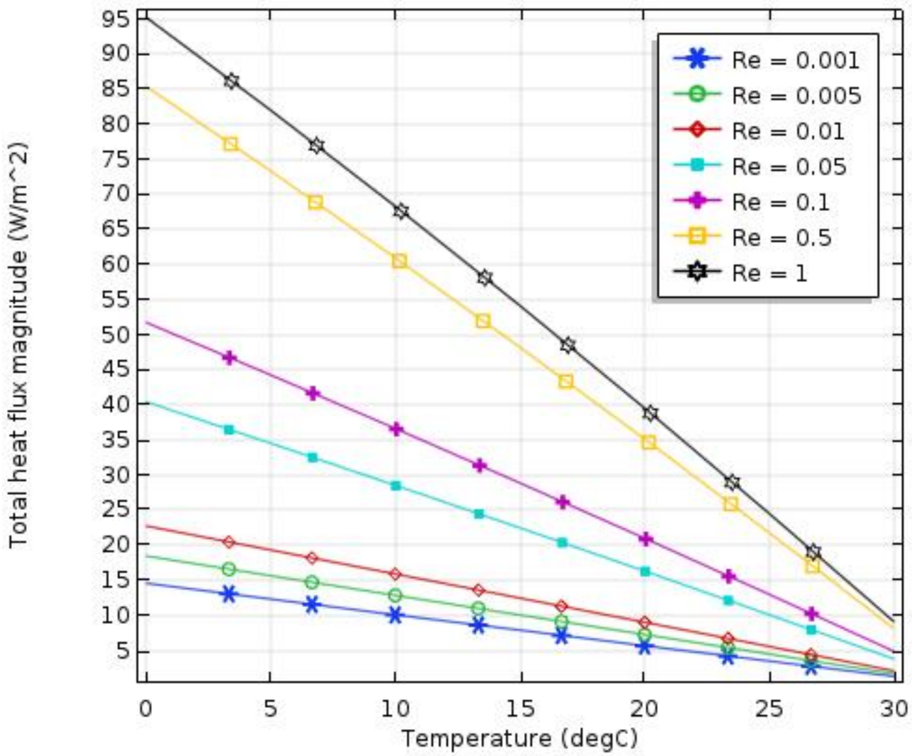
Base Case Results



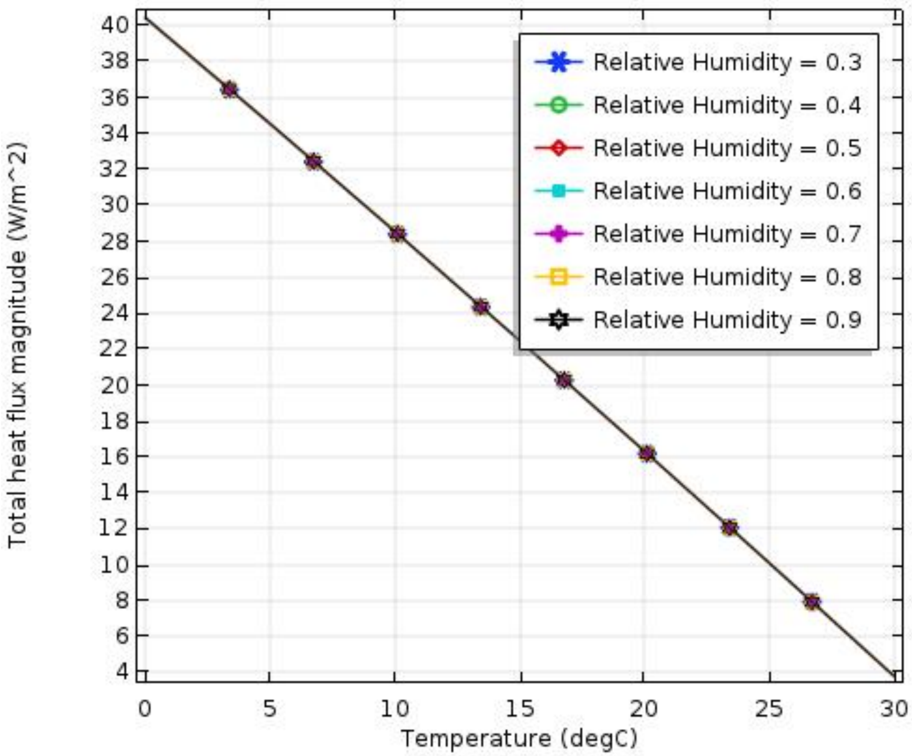


Results - Effect of Cold Cylinder Surface Temperature

Relative Humidity = 0.6

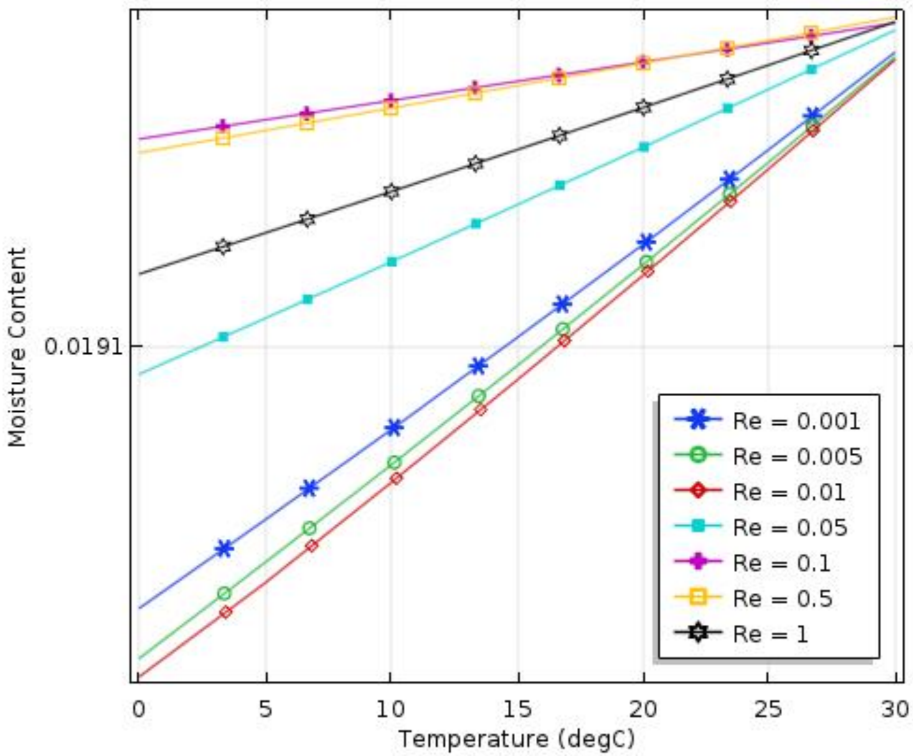


Re = 0.05

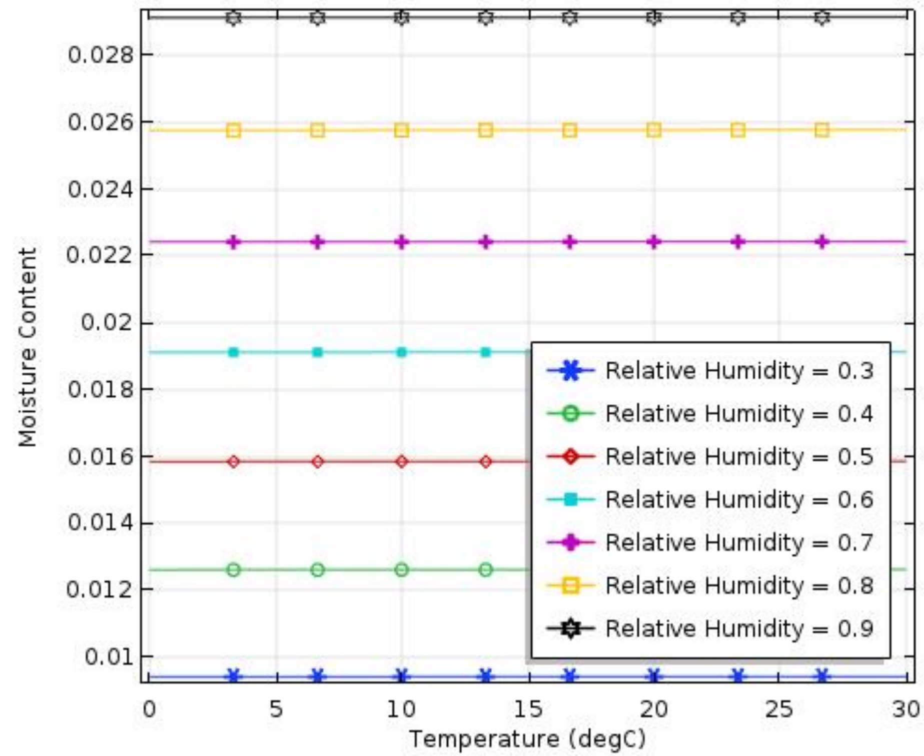


Results - Effect of Cold Cylinder Surface Temperature

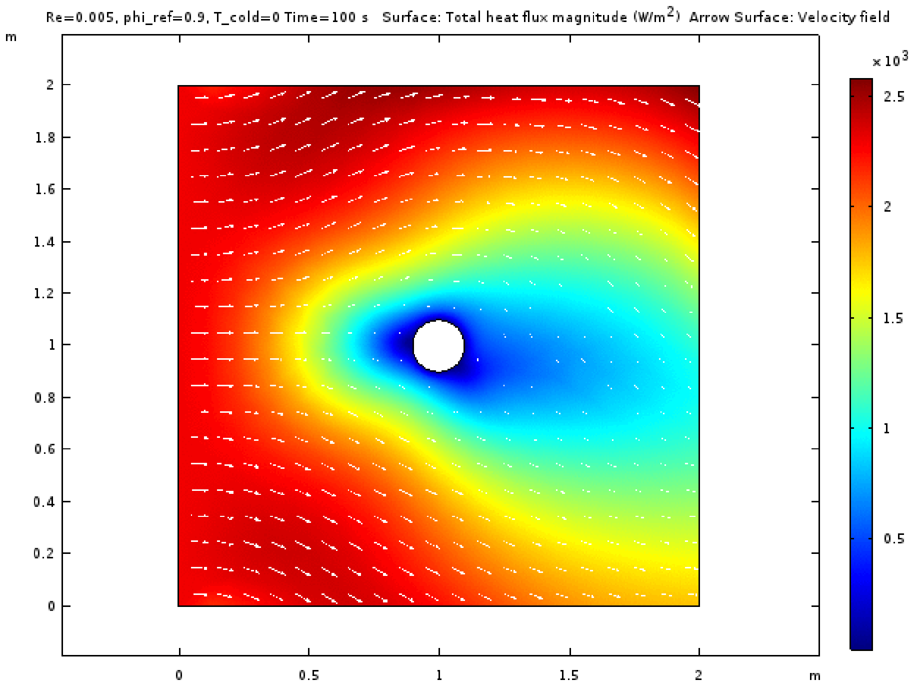
Relative Humidity = 0.6

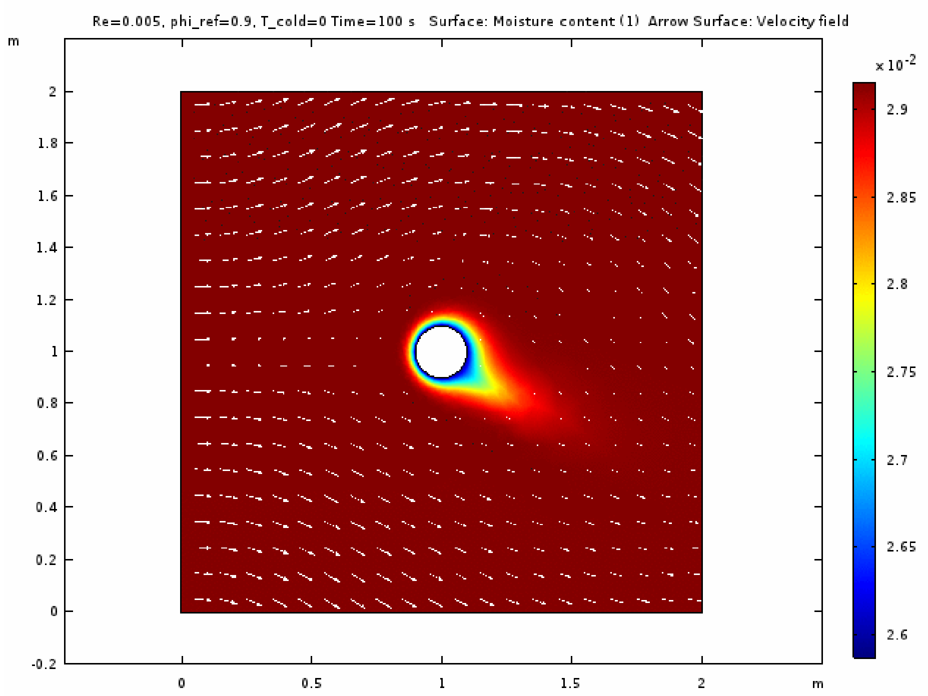


Re = 0.05



Results - Effect of Cold Cylinder Surface Temperature

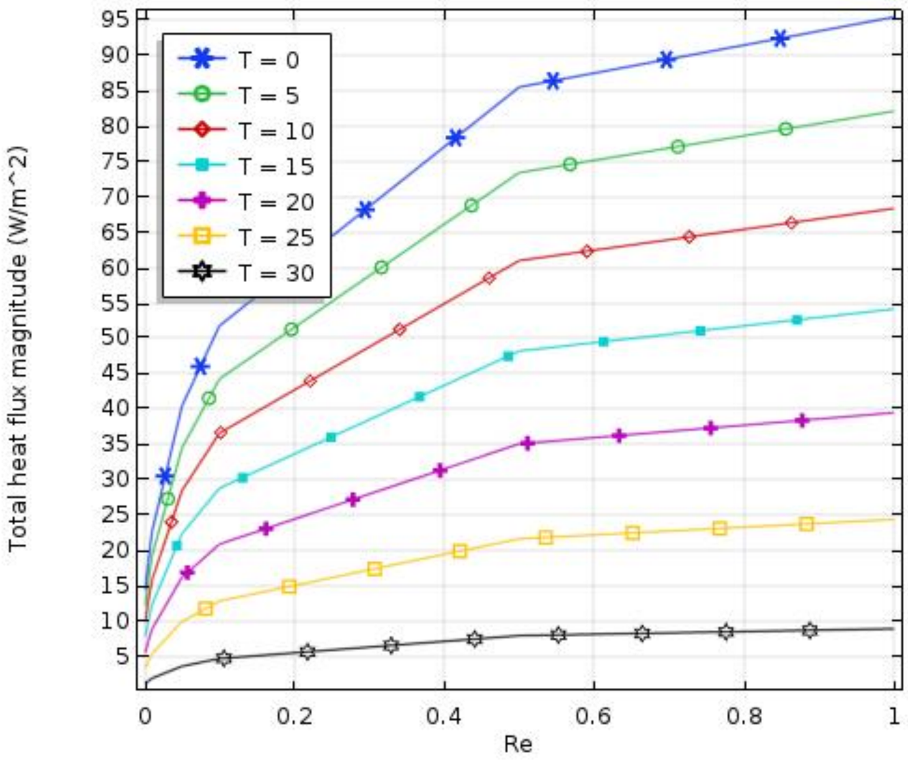




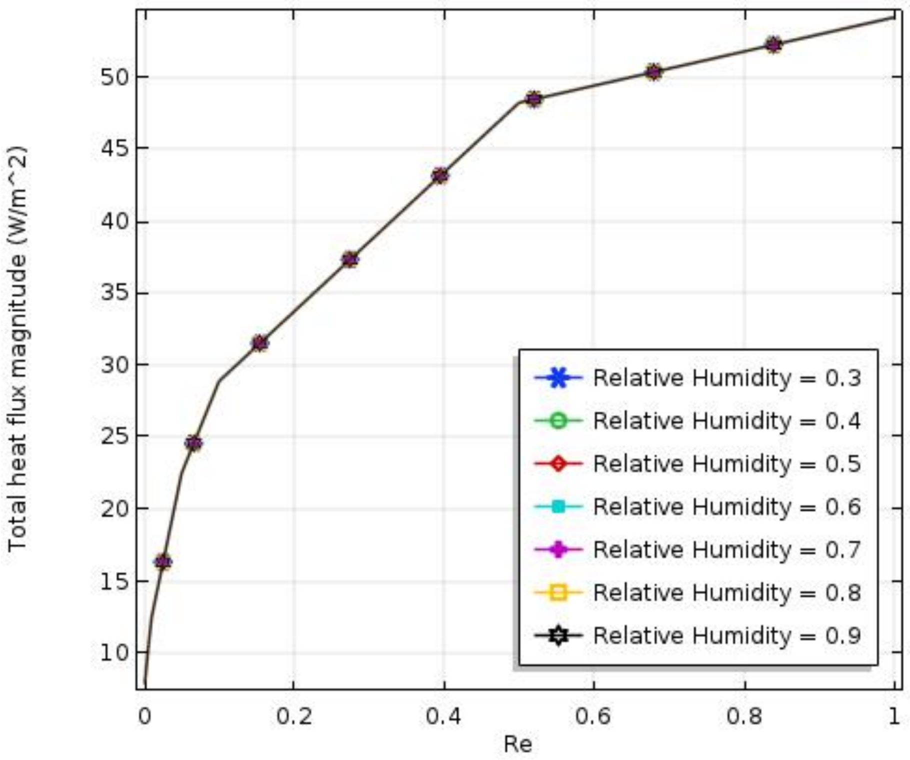
Increasing Cold Cylinder Surface Temperature

Results - Effect of Flow Reynolds Number

Relative Humidity = 0.6

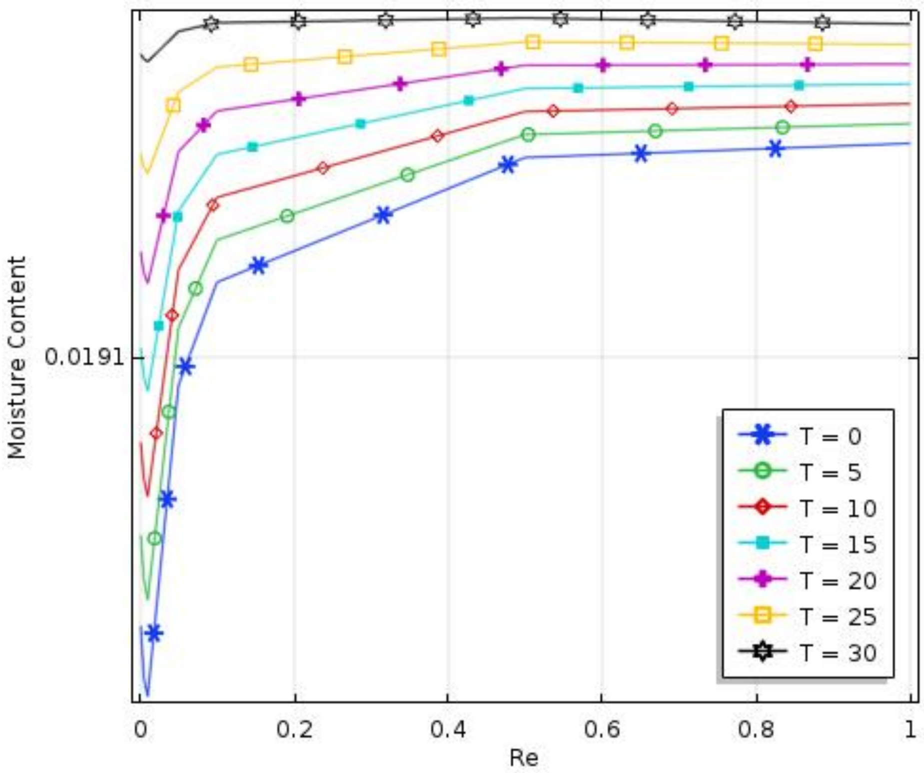


Temperature = 15 ^oC

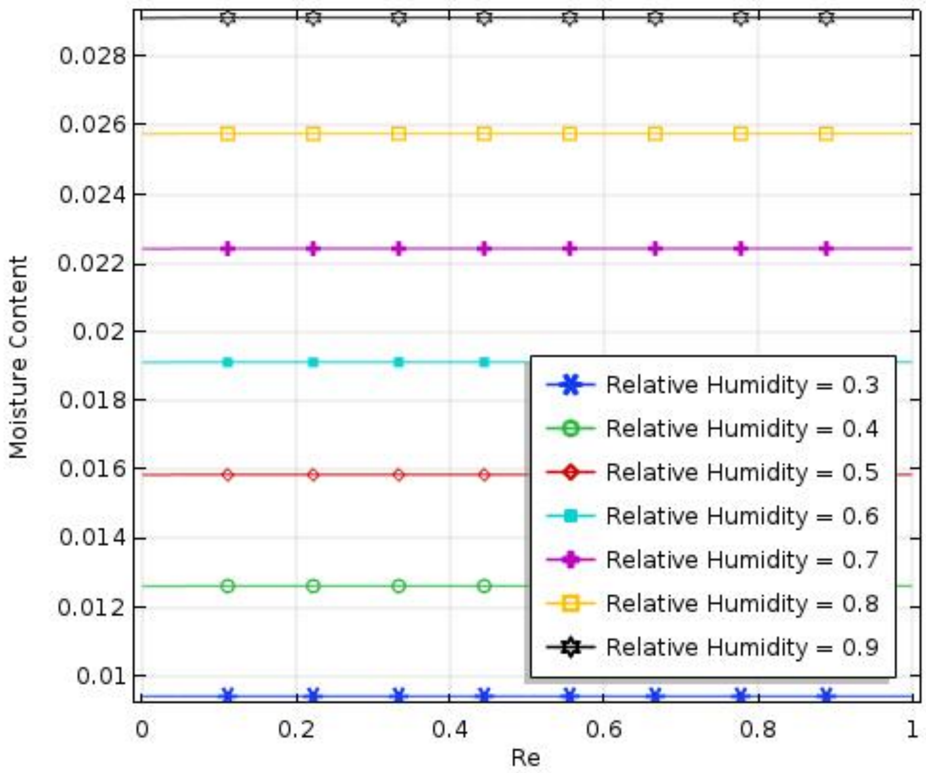


Results - Effect of Flow Reynolds Number

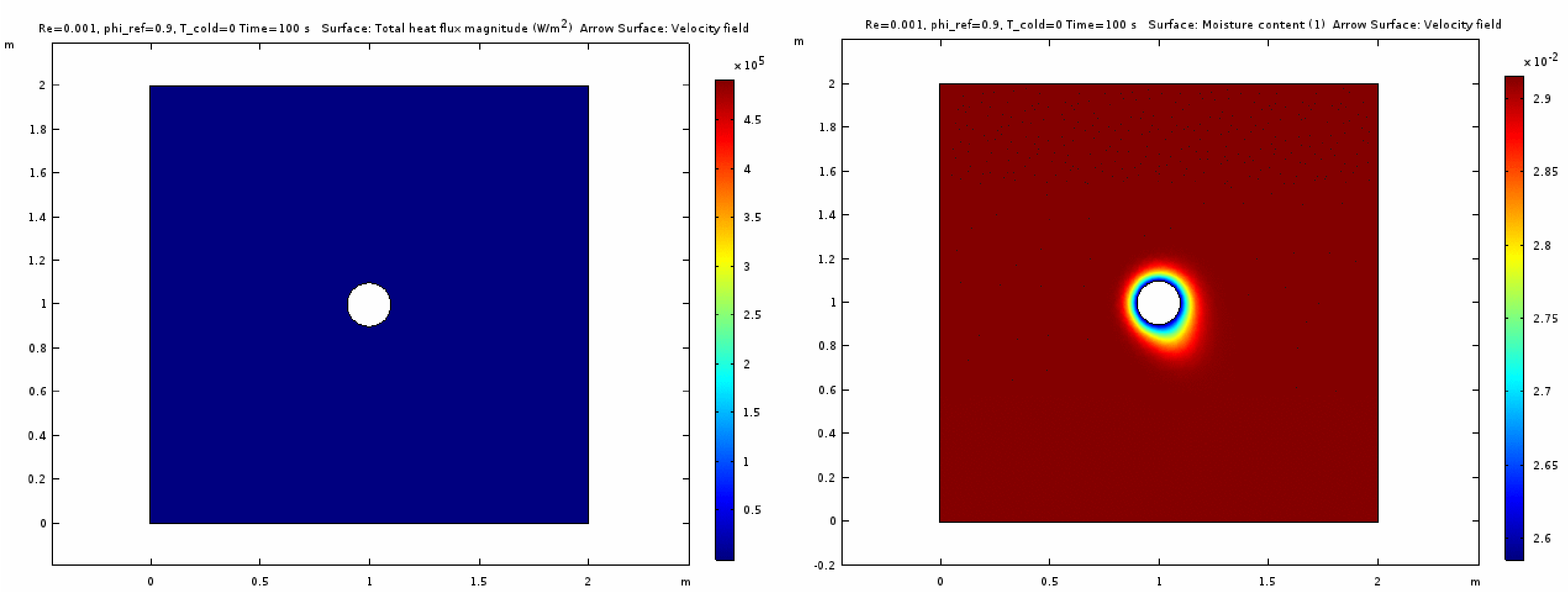
Relative Humidity = 0.6



Temperature = 15 °C



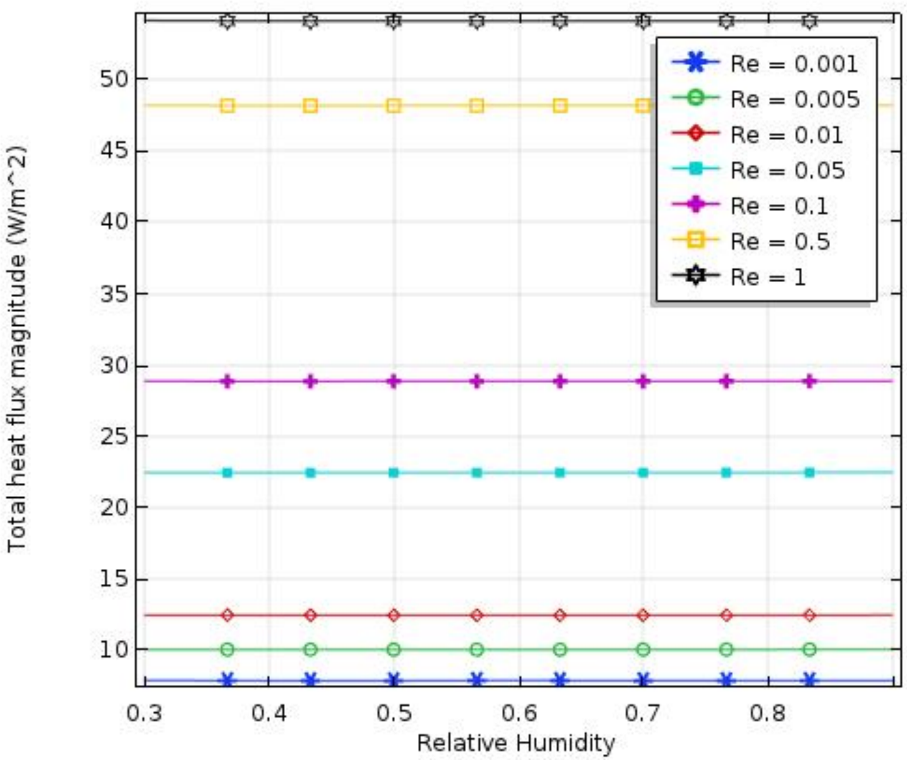
Results - Effect of Flow Reynolds Number



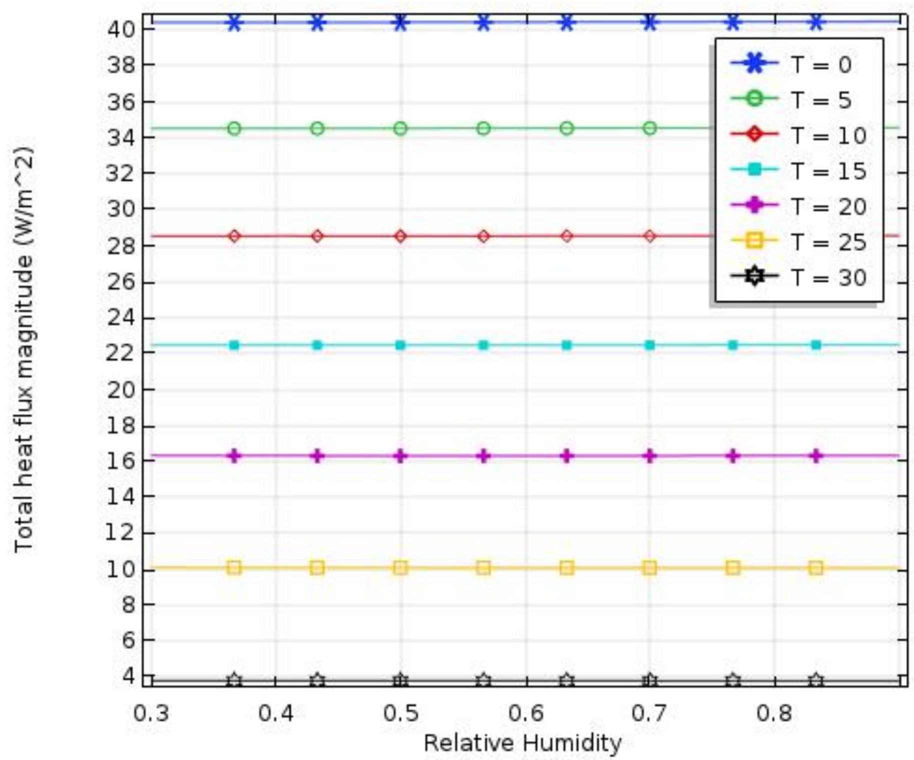
Increasing Flow Reynolds Number

Results - Effect of Flow Relative Humidity

Temperature = 15 °C

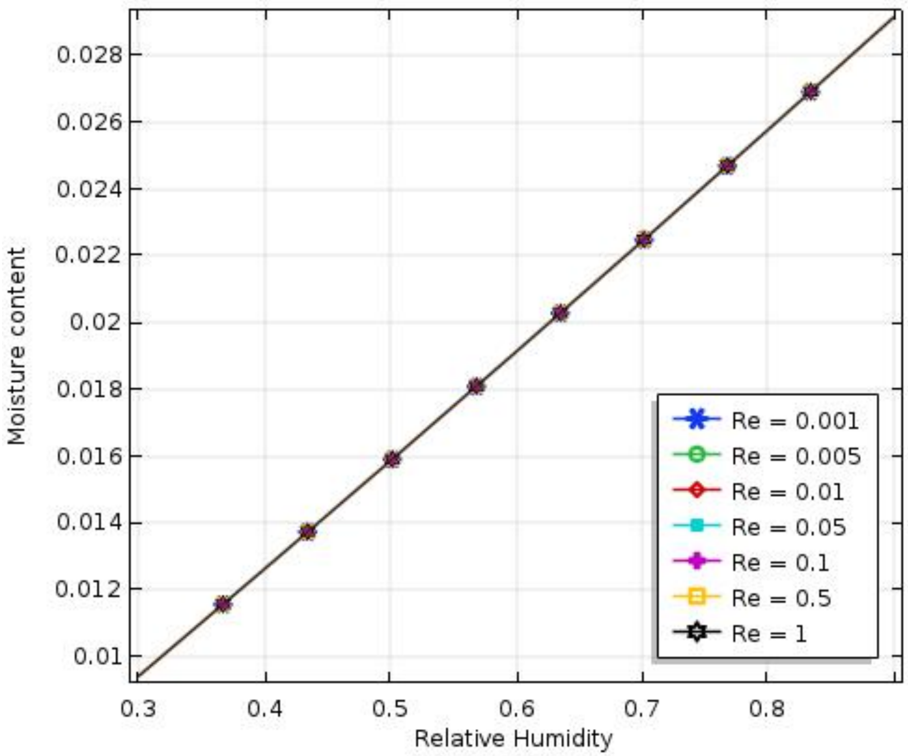


Re = 0.05

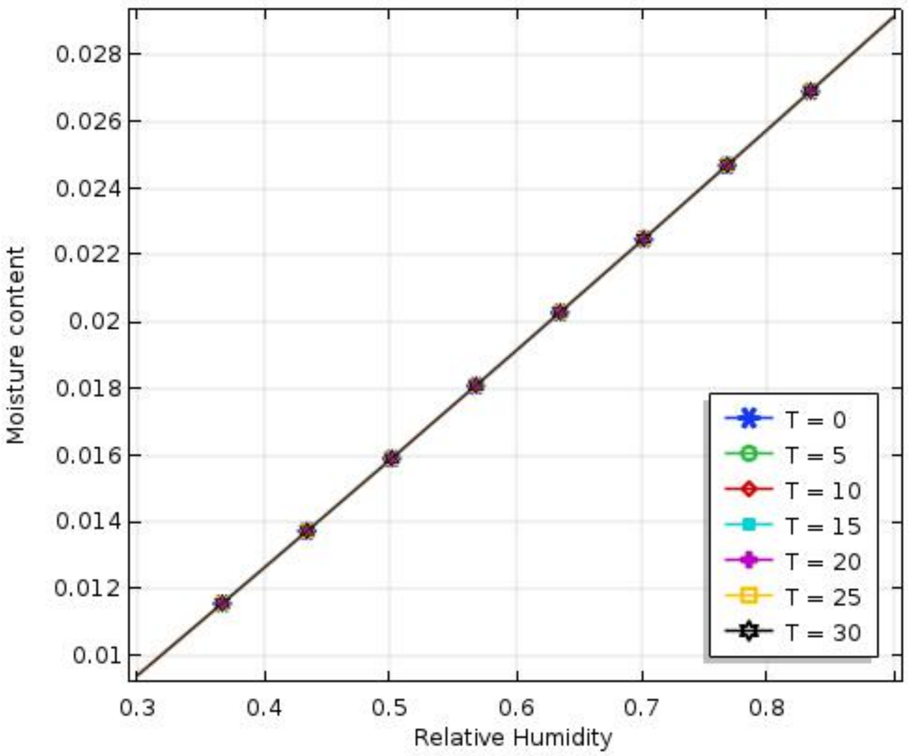


Results - Effect of Flow Relative Humidity

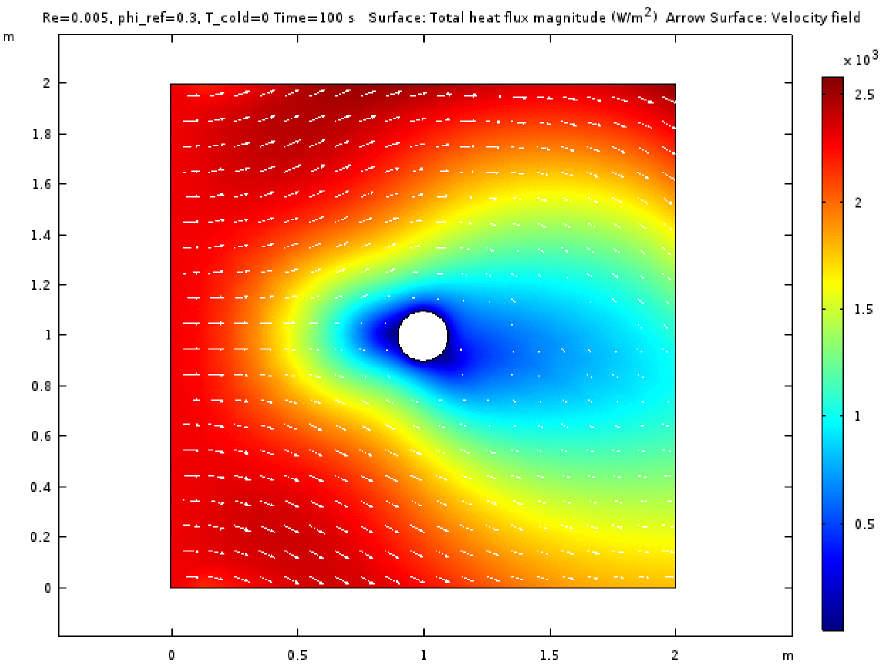
Temperature = 15 ºC

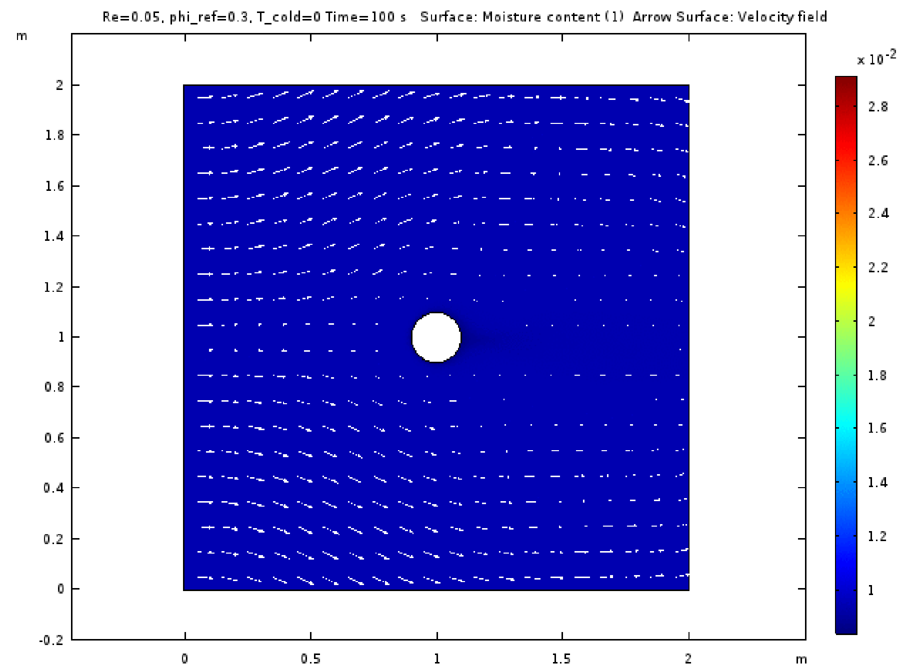


Re = 0.05



Results - Effect of Flow Relative Humidity





Increasing Environment Relative Humidity

Conclusions

- Numerical model for moist air flow around cold cylinder was done successfully.
- The effects of flow Reynolds number, environment relative humidity, and surface temperature of the cold cylinder, on heat flux and moisture content were investigated.
- The cold cylinder surface temperature affect significantly the heat flux especially at high Reynolds number.
- Increasing cylinder surface temperature will reduce the heat flux.
- As the cold cylinder surface temperature increases the moisture content slightly increases.
- Increasing flow Reynolds number will increase the heat flux especially at low temperature.
- Moisture content are affected slightly by flow speed especially at low Reynolds number and low temperature.

Conclusions

- Changing environment relative humidity will not affect the heat flux.
- The moisture content will increase significantly as environment relative humidity increases.
- Neither the speed of the flow nor the cold cylinder surface temperature affect moisture content in the computational domain.

Future Work

Because of computer resources limitation, data availability, and model complexity, some ideas are not implemented in this study and are suggested to be future recommendations to this work, as follows:

- Implementing actual ambient data to reflect actual conditions for the simulation period instead of constant properties for the environment data.
- Consider two-phase flow situation especially in the region where the moist air totally condense.
- Implementing phase change for the condense Air in the computational domain.
- Modeling the problem in three-dimensional domain and studying the operating conditions and flow inside the cylinder.
- Performing a parametric study for the geometry and location.
- Including radiation effect and realistic wind speed changes on the surface of the cylinder.

THANK YOU