Heat Transfer Workshop 11 - Water Evaporation Introduction

Name ________________________ **Read about simultaneous heat and mass transfer**

The human body uses water evaporation as an important heat transfer mechanism. There are also many industrial processes that utilize water evaporation, especially for air drying of products. Fortunately, convection mass transfer *J* can often be modeled in exactly the same way that convection heat transfer q_c is modeled. In terms of the transfer per area (flux)

$$q"_c = h\,(T_s - T_\infty)$$

$$J" = h_m\,(C_s - C_\infty)$$

Heat flux is in terms of the temperature difference from the surface to the bulk fluid (air) and mass flux is in terms of the concentration difference of water vapor from the surface to the bulk air. These concentrations are equal to the density of water vapor at the saturation temperature of water and can be found from steam tables. The relative humidity relates the actual water vapor concentration in air with this saturation value of water vapor all at the air temperature T_∞.

$$\varphi = {}^{C}/_{C_{sat\ @T_\infty}}$$

The heat transfer coefficient *h* and mass transfer coefficient h_m can be related for the same surface conditions by the Lewis relation

$$h_m = h\,\frac{D}{k}\,Le^{1/3}$$

where *D* is the diffusion coefficient of water vapor in air and *k* is the thermal conductivity of air taken at the average temperature of the air in the boundary layer $T_{av} = (T_s + T_\infty)/2$. The Lewis number *Le* is the ratio of the thermal diffusivity of air *α* to the kinematic viscosity *ν*. For water vapor in air at typical room temperature conditions the Lewis number is nearly a constant value of 0.85.

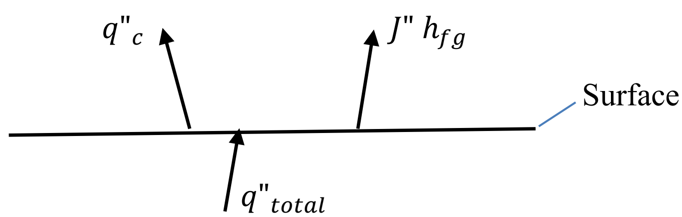
$$Le = {}^{\alpha}/_{D} = 0.85$$

This also provides an easy method to find the diffusion coefficient,

$$D = {}^{\alpha}/_{0.85}$$

The total energy flux from the surface is the combination of the convection heat transfer and the evaporation energy flux of the mass transfer. Because the water changes from liquid to vapor during evaporation, the enthalpy of vaporization h_{fg} must be included.

$$q"_{total} = q"_c + J"\,h_{fg}$$



Heat Transfer Workshop 11 Water Evaporation Results

Name ________________________

In Workshop 8 you measured convective heat transfer from your wrist. Now the challenge is to measure the combination of heat and mass transfer when sweat or water is introduced. First, tape the heat flux sensor to your wrist as before for the dry measurement. Keep the second thermocouple out in the room to record the air temperature. Take about 20 seconds of heat flux and temperature data (until steady) while moving your arm in air. Then place a wet cloth (included in your kit) that has been drenched with water over top of the sensor and repeat. The cloth dries out pretty fast so re-saturate the cloth each time before using it. Plot the heat flux and surface temperature as a function of time for both cases and note the change when the wet cloth is added.

Use the steady-state heat flux and temperature values to calculate the heat transfer coefficient h when the arm is dry before the cloth is added. Neglect the effects of radiation. Assume the h stays the same (but not the surface temperature) when the cloth is added. Use this value with the Lewis Relation to calculate the corresponding mass transfer coefficient, h_m. Record your measured and calculated values in the chart along with the corresponding air properties (at T_{av}) from a property table.

	q'' (W/m^2)	T_s (°C)	T_∞ (°C)	T_{av} (°C)	k (W/m-K)	α (m^2/s)	D (m^2/s)	h (W/m^2-K)	h_m (m/s)
Arm dry				---	---	---	---		---
Arm wet									

Use the temperatures of the sensor and the surrounding air to find the corresponding saturation concentrations of water vapor from a saturated steam property table.

at temperature T_s = (°C), the enthalpy of vaporization h_{fg} = (kJ/kg)
at temperature T_s = (°C), the water vapor density = C_{sat} = C_s = (kg/m^3)

at temperature T_∞ = (°C), the water vapor density = $C_{sat\ @T\infty}$ = (kg/m^3)

Use these properties to fill in the table below. Initially, assume a relative humidity to find the water vapor concentration in the air ($C_\infty = \varphi\ C_{sat\ @T\infty}$). Start with φ = 50%. Then calculate the total heat flux for the wet case using the equations on the first page of the lab. Does it match what was measured? If not, adjust the relative humidity value and repeat the calculations until the total heat flux matches the measurements. If the calculated heat flux is too small, choose a smaller value of relative humidity. If too large, choose a larger φ.

	φ	$C_\infty = \varphi\ C_{sat\ @T\infty}$ (kg/m^3)	J'' (kg/s/m^2)	$J''h_{fg}$ (W/m^2)	q''_c (W/m^2)	q''_{total} (W/m^2)	$J''h_{fg}/q''_{total}$ (Fraction)
1st try	0.50						
2nd try							
3rd try							

1. Although the rate of water evaporation (J'') is small, why is the associated energy transfer ($J''h_{fg}$) so large?

2. Why is the skin temperature much lower in the wet case?

3. Why is sweating such a good mechanism for cooling the body?