Heat Transfer - Homework 7

Rose Gebhardt, Hannah Quirk, and Harris Paspuleti

April 18, 2020

Applications of Nusselt Numbers: Wind Chill Effect

The weather channel reports a temperature outside of 20°C, but 'Real Feel' of 5°C. What is the 'Real Feel' reporting?

1 MATLAB Function

Problem Statement Write MATLAB code that takes a input parameters D (outer diameter), wind speed V, and fluid properties ($k, \rho, c_p,$ and μ) and uses Nusselt number correlations to return the convection coefficient for convection across a cylinder.

In order to find the convection coefficient for convection across a cylinder, one needs to define the diameter of the cylinder, the velocity of the fluid, the temperature of the cylinder, the ambient temperature, the fluid's thermal conductivity, the fluid's density, the fluid's specific heat capacity, the fluid's dynamic viscosity, the fluid's coefficient of expansion, and whether the convection is forced or natural. For each case, these parameters are defined and entered into the function.

The function then uses these values to compute the Reynolds Number, Prandtl Number, Grashof Number, and Rayleigh Number. It should be noted that for forced convection, the Grashof Number and Rayleigh Number are not used. Additionally, since the ambient temperature is not needed to compute the convection coefficient for forced convection, a 'NaN' is passed into the function for this value.

Once these non-dimensional parameters are found, the Nusselt Number for each case is found by searching for tabulated values. Using the Nusselt Number, the convection coefficient is then calculated and returned.

To see code for the full function, refer to Section 3.

2 Results Table

Problem Statement Complete the results table below to compare different conditions. Assume that the exposed skin temperature is 32°C (for natural convection). Use $D = 0.02$ m for a finger and $D = 0.080$ m for a forearm.

Scenario	Fluid	Free Stream Fluid Velocity	T_∞	Convection Coefficient ($W/m^2/K$)
Exposed finger on a cold day with no wind	Air	0	0^oC (= 32^oF)	**8.7159**
Exposed finger on a *really* cold day with no wind	Air	0	-15^oC (=4.4^oF)	**9.5950**
Exposed finger on a cold day with a light wind (1 mph)	Air	0.447 m/s	NA	**15.365**
Exposed finger on a cold windy day (10 mph)	Air	4.47 m/s	NA	**47.540**
Exposed forearm on a cold day with no wind	Air	0	0^oC	**6.1630**
Exposed forearm on a cold windy day (10 mph)	Air	4.47 m/s	NA	**27.994**
Exposed finger dipped in ice/water	$H2O_{(L)}$	0	0^oC	**694.45**
Exposed finger under running water	$H2O_{(L)}$	1.0 m/s	NA	**5039.8**
Exposed forearm dipped in ice/water	$H2O_{(L)}$	0	0^oC	**599.48**
Exposed forearm under running water	$H2O_{(L)}$	1.0 m/s	NA	**3377.8**

Convection Coefficients for Each Case

Final Results

- The convection coefficients are higher when the convective fluid is water than when it is air.
- The convective coefficients are higher for forced convection than for natural convection.

Concluding Statements

This problem shows how convective coefficients can be computed for external flows given the geometry of the system, properties of the convection fluid used, and the temperature difference between the object the surrounding area. It shows how non-dimensional parameters are used, how natural convection and forced convection coefficients are computed differently, and how tabulated values can be found in an automated way using code.

3 MATLAB Function to Find Convection Coefficient

```
function h = find_convection(entries)

    % Define Each Entry
    D = entries(1); V = entries(2); T_skin = entries(3); T_inf = entries(4);
    k = entries(5); rho = entries(6); c_p = entries(7); mu = entries(8);
    beta = entries(9); f_n = entries(10);

    % Compute Non-Dimensional Parameters
    Re = (rho*V*D)/mu;
    Pr = (mu*c_p)/k;
    Gr = (9.81*beta*abs(T_skin-T_inf)*(rho^2)*(D^3))/(mu^2);
    Ra = Gr*Pr;

    % f_n == 0 --> forced convection
    % f_n == 1 --> natural convection

    % Forced Convection
    if f_n == 0

        % Possible Error Statements
        if Re < 0.4 || Re > 400000
            error('reynolds number is out of forced convection range!!! :(')
        end
        if Pr < 0.5 || Pr > 50
            error('prandtl number is out of forced convection range!!! :(')
        end

        % Coefficients for Each Case
        if Re >= 0.4 && Re < 4
            C = 0.989; n = 0.330;
        end
        if Re >= 4 && Re < 35
            C = 0.911; n = 0.385;
        end
        if Re >= 35 && Re < 4083
            C = 0.683; n = 0.466;
        end
        if Re >= 4083 && Re < 40045
            C = 0.193; n = 0.618;
        end
        if Re >= 40045 && Re <= 400000
            C = 0.0266; n = 0.805;
        end
```

```
        % Compute Nusselt Number
        Nu = C*(Re^n)*(Pr^(1/3));

    end

    % Natural Convection
    if f_n == 1

        % Possible Error Statements
        if Ra < 10^4 || Ra > 10^12
            error('rayleigh number is out of natural convection range!!! :(')
        end

        % Coefficients for Each Case
        if Ra >= 10^4 && Ra < 2.12*(10^7)
            C = 0.53; n = 0.25;
        end
        if Ra >= 2.12*(10^7) && Ra <= 10^12
            C = 0.13; n = 0.3333;
        end

        % Compute Nusselt Number
        Nu = C*(Ra^n);
    end

    h = Nu*k/D;

end
```

4 MATLAB Code - Define System and Find Convection Coefficients

Contents

Wind Chill Effect - Results Table

```
clear all; close all; clc;
```

Tabulate Cases

```
% Fluid Properties of Air
air_k = 0.0257; % W/mK
air_rho = 1.205; % kg/m^3
air_cp = 1009; % J/kgK
air_mu = 1.82*(10^-5); % kg/ms
air_beta = 3.41*(10^-3); % 1/K
air = [air_k,air_rho,air_cp,air_mu,air_beta];

% Fluid Properties of Water
water_k = 0.6; % W/mK
water_rho = 1000; % kg/m^3
water_cp = 4200; % J/kgK
water_mu = 10^-3; % kg/ms
water_beta = 2.07*(10^-4); % 1/K
water = [water_k,water_rho,water_cp,water_mu,water_beta];

% Diameter For Each Case
D = [0.02;0.02;0.02;0.02;0.08;0.08;0.02;0.02;0.08;0.08]; % m

% Velocity For Each Case
V = [0;0;0.447;4.47;0;4.47;0;1;0;1]; % m/s

% Skin Temperature
T_skin = (32+273.15)*ones(10,1); % K

% Ambient Temperature (only needed for natural convection)
T_inf = [0;-15;NaN;NaN;0;NaN;0;NaN;0;NaN] + 273.15; % K

% Forced/Natural Covection
f_n = [1;1;0;0;1;0;1;0;1;0];

% Table of All Values Needed
```

```
table = zeros(10);
table(:,1) = D; table(:,2) = V; table(:,3) = T_skin; table(:,4) = T_inf;
table(:,5:9) = [air;air;air;air;air;air;water;water;water;water];
table(:,10) = f_n;
```

Find Convection Coefficients Using Function

```
% Initialize Values
h = zeros(10,1);

% Apply Function to Each Case
for index = 1:10
    h(index) = find_convection(table(index,:));
end
```