Characterizing Convection for Horizontal Cylinders

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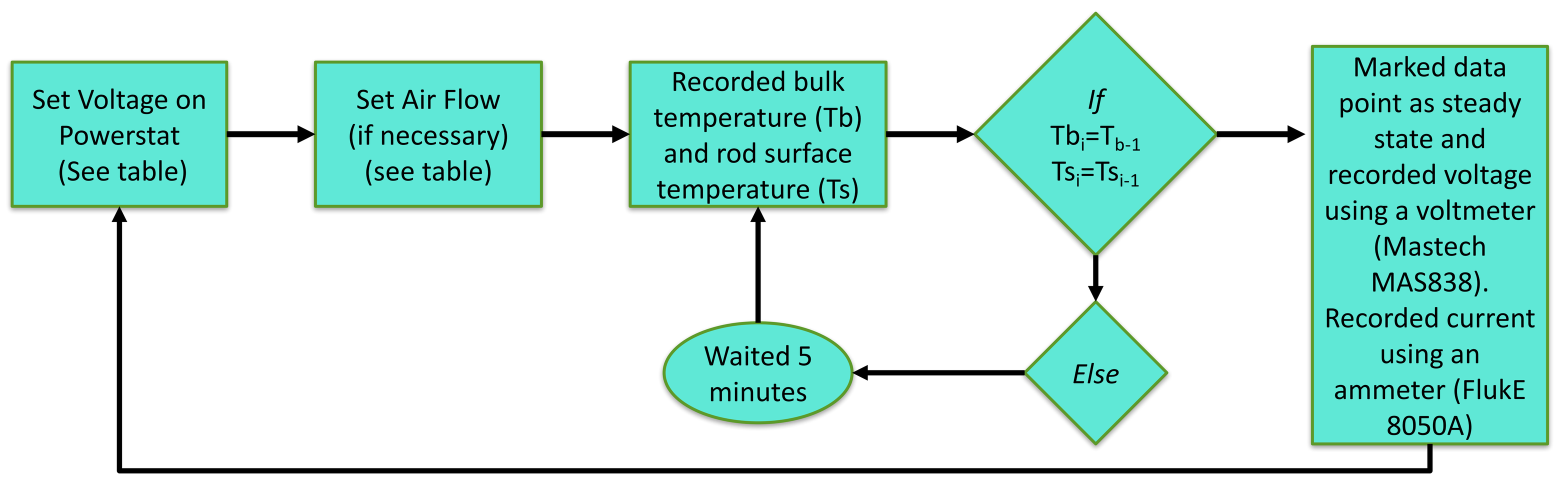
Introduction

- Aimed at the study of natural and forced convection
- Natural is driven by density changes and forced convection occurs to an imposed pressure gradient
- Measured each while studying convective heat transfer around 3 horizontal cylindrical elements
- Horizontal cylinders are symmetric and fairly 2-dimensional when it comes to analysis [3].
- Study will characterize the convective heat transfer around each element by generating the convective heat transfer coefficient as well as correlations between different relevant dimensionless numbers.

Goals

- Determine the heat transfer coefficient *(h)* for each cylindrical element
- Derive correlations between relevant dimensionless numbers for both forced convection and natural convection treatments
- Determine the effect of fluid velocity and diameter on the heat transfer coefficient
- Propose a solution to the design problem with the experimental results

Experimental Methods



For the following diameters: $\{^1/_4{''}, ^3/_8{''}, ^1/_2{''}\}$

Convection	Voltage (V)		Volumetric Flow Rate ($10^{-4} m^3/s$)			
	15	30	0	1.25	3.83	6.75
Natural	√	√	√			
Forced		√		√	√	√

Analytical Methods

- For natural convection, Grashof numbers were computed[3].
- Convection coefficient (h) is computed using *Eqn 1* where voltage (V), current (I), diameter (D), length of rod (L), the temperature of the surface (T_s); the temperature of the bulk air (T_b)

$$h = \frac{VI}{\pi DL(T_s - T_b)} \quad \textit{Eqn. 1}$$

- Using *Eqn. 2*, a relation between *Nu*, *Gr,* and *Pr* can be computed. Unknown constants a and m are found via nonlinear regression [1].

$$Nu = a(GrPr)^m \quad \textit{Eqn. 2}$$

- To calculate *Nu* for forced convection modes, *Eqn. 3*, which relates *Nu, Re,* and *Pr*, is used where *C* and *n* are constants that can be fit using a nonlinear regression

$$Nu = CRe^n Pr^{1/3} \quad \textit{Eqn. 3}$$

Results

Relations between rod diameter, air velocity, and heat transfer coefficients for natural and forced convection are investigated in *figure 1* and *2*. An actual versus predicted plot is used a measure of fit for theoretical *h* values.

A nonlinear regression using *Excel* 2016 was carried out to determine coefficients given by *Eqn. 2* and *Eqn. 3*. The resulting equations were 3-dimensional and are thus given by contour plots (developed in *MatLab 2016*), *figure 3*.

Natural Convection

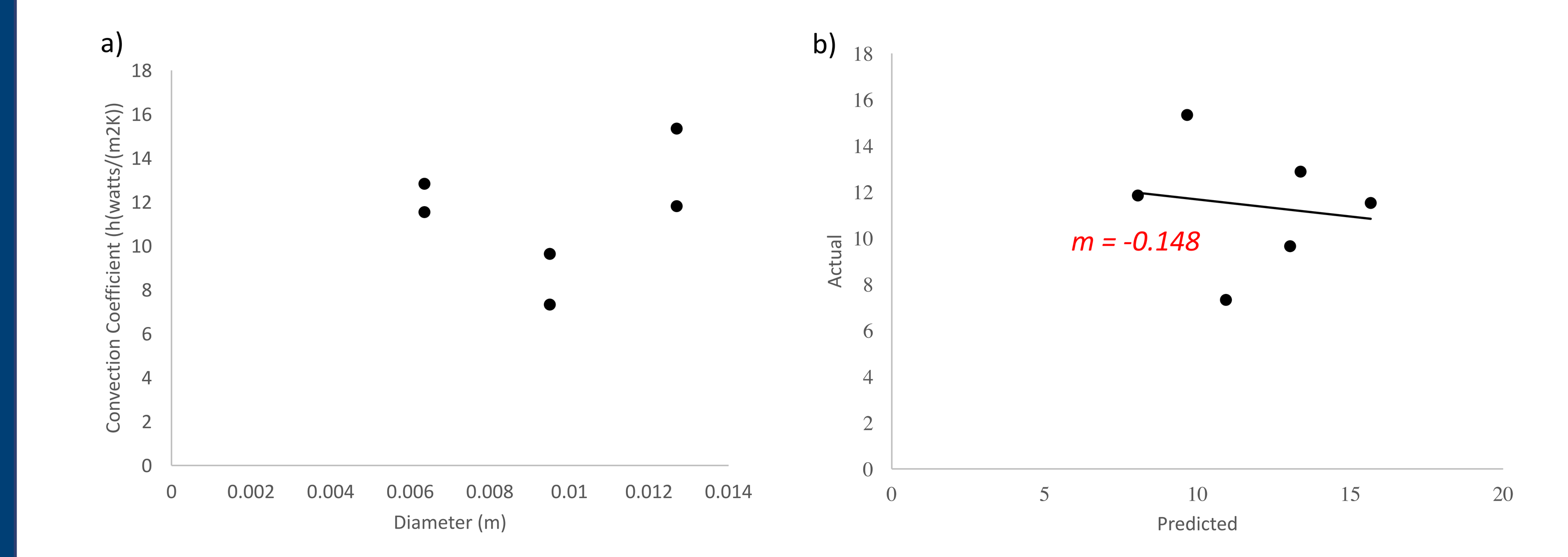
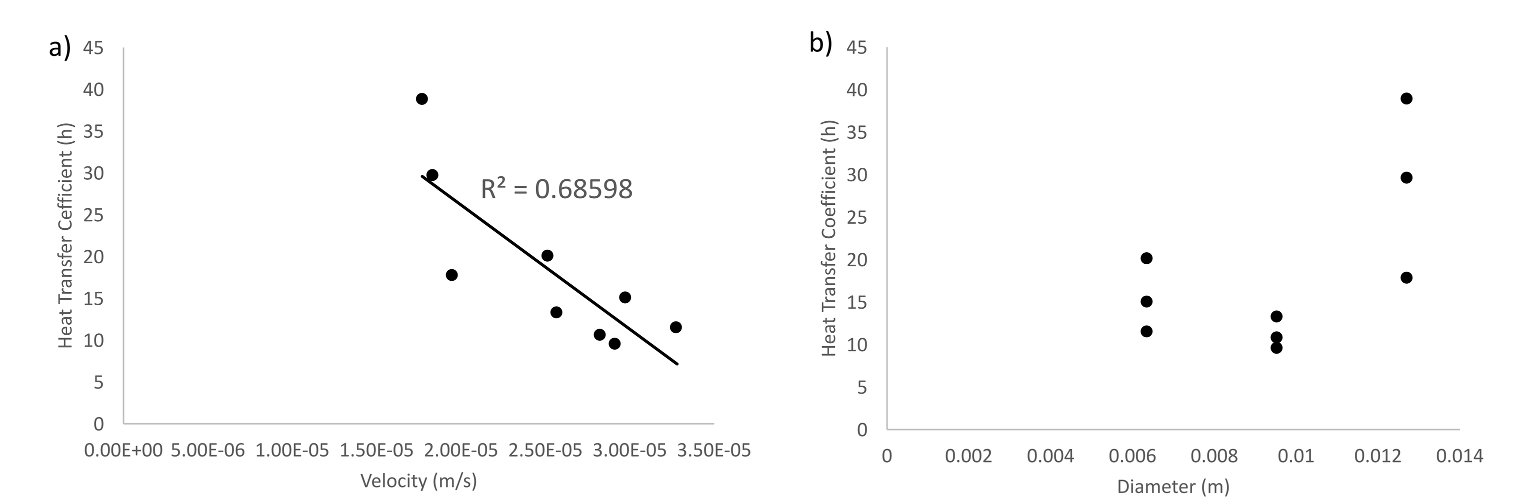


Figure 1: a) Heat transfer coefficient $(W * m^{-2} * K^{-1})$ versus diameter. There is a quadratic trend.
b) Actual values of *h* versus predicted values of *h* due to the Churchill and Chu correlation. The slope or the trend line is shown in red. Perfect fit of predicted to actual values is given by a slope of 1.

Forced Convection



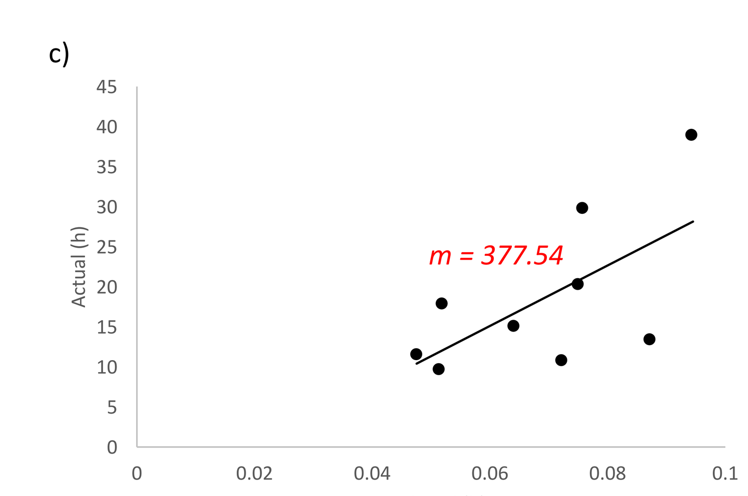


Figure 2: a) Heat transfer coefficient versus air velocity is plotted. The relation is roughly linear with a negative slope.
b) Heat transfer coefficient versus diameter is plotted. The relation is roughly quadratic with the minimum occurring for the 3/8"
c) Much like relationship seen in *figure 1.b*, actual values of *h* are plotted against theoretical ones. While this slope is positive, it is still very far from 1.

Dimensionless relations

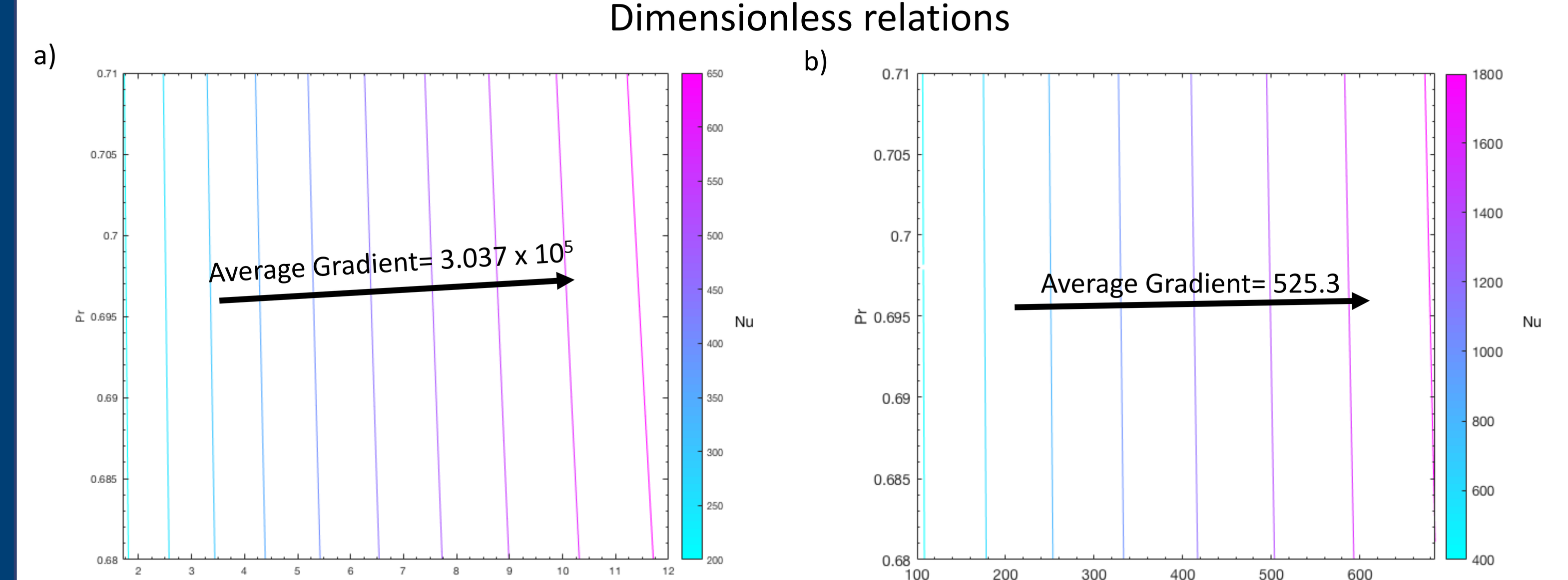


Figure 3: a) A contour plot *Eqn. 2* where *a*=0.00673 and *m*=0.63092 and equipotentials of *Nu* are given as colored lines that correspond to the colorbar at the right. The average gradient (or how steep the plane is perpendicular to the contour lines) is given by the arrow. The average gradient was computed by taking average of the value of the gradient at the four corners of the range.
b) Much like *a)* a contour plot with a similarly computed gradient is shown, but the relation used is *Eqn. 3* where *C*=9.9857 and *n*=0.81514

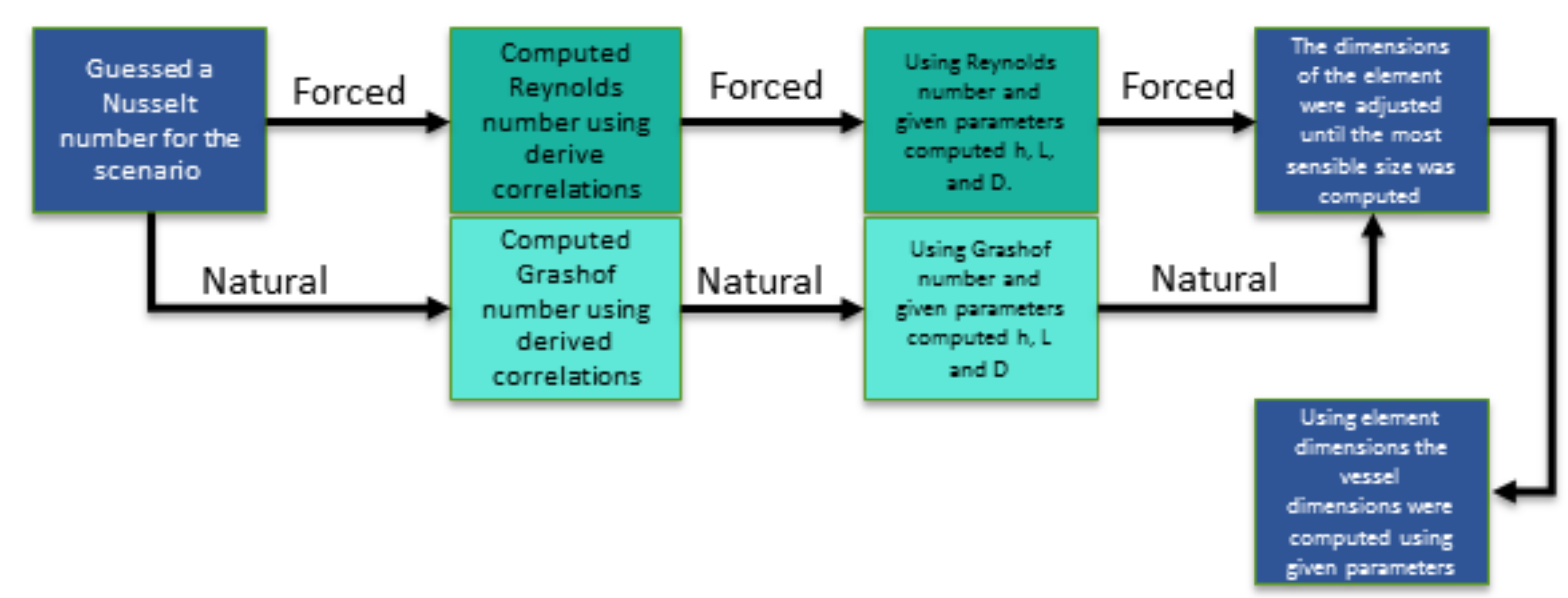
Conclusions

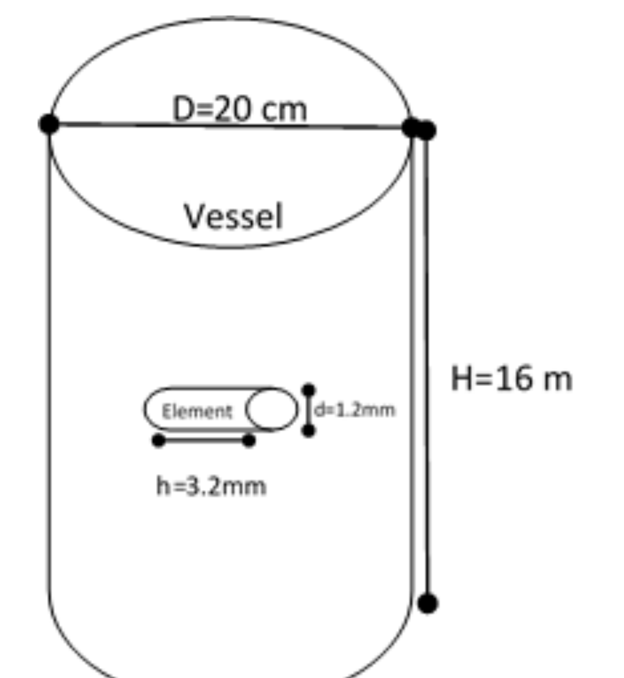
- For this experiment, analytical methods of determining *h* (such as the Churchill and Chu correlation) were highly erroneous in predicting *h* (*figure 1.b* and *figure 2.c*.
- As a result, the *h* values for forced convection were larger than the natural convection *h* values.
- Diameter did not correspond linearly with *h*; more tests with more diameters should be carried out to characterize this nonlinearity.
- Air velocity is negatively correlated with *h* linearly with an R^2 value of 0.6860; perhaps a nonlinear fit would characterize the behavior better.
- For both methods of convections, high dimensionless numbers (*Re*, *Gr*, *Pr*) yield high *Nu* which yields high convection coefficients.
- In general, for the setup used, forced convection has larger heat convection coefficients.

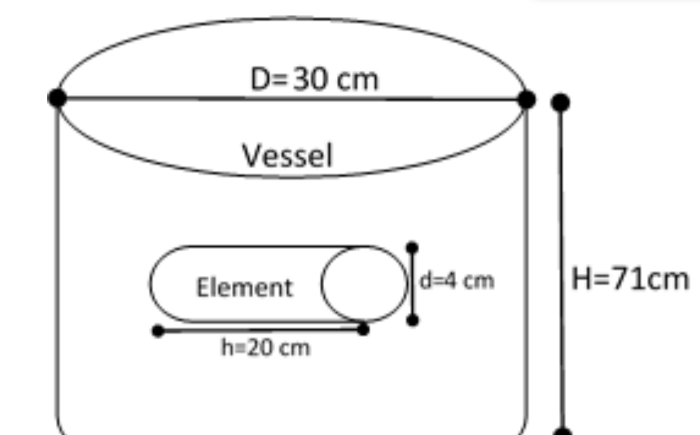
Design Problem Solution

Parameters:

Velocity of Air	25 m/s	Volumetric Flow Rate	0.5 m^3/s
Surface Temperature of the Rod(T_s)	80^{oC}	Air Temperature (T_b)	30^{oC}
	Power	1.6667 watts	







Natural convection solution

Forced convection solution

References

[1] F. P. Incropera, D. P. Dewitt, T. L. Bergman, and A. S. Lavine, "Principles of Heat and Mass Transfer," vol. 7, 2015.
[2] C. J. Geankoplis, "Transport Processes and Separation Process Principles," vol. 4, 2016.
[3] S. K. S. Boetcher, "Natural Convection from Circular Cylinders," Springer, 2014.

Acknowledgements

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