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EXPERIMENTAL DETERMINATION OF HEAT TRANSFER COEFFICIENTS IN A LABORATORY OF TRANSPORT PHENOMENA

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ABSTRACT

In the laboratory of transport phenomena of the Faculty of Chemistry at the UNAM located in Mexico, the undergraduate students obtained experimentally heat transfer coefficients, which helps them to understand the concept of heat transfer. In that and in other practices are evaluated the skills used by the students.

KEY WORDS: *Coefficients, heat transfer phenomena, competences.*

1. INTRODUCTION

The heat transfer coefficients are very important for the design of many equipments, including heat exchangers. In the laboratory of transport phenomena of the Faculty of Chemistry at the Universidad Nacional Autónoma de Mexico (UNAM) located in Mexico City, the undergraduate students obtained experimentally a heat transfer coefficient. During the experiment, the students observed the phenomenon, made measurements and made the necessary assumptions for the development of the mathematical models that represent the phenomenon under study. An important role for the experimental work is to promote interactivity and the participation of students, so that they not only acquire knowledge, but skills, habits and attitudes. During the practice, the behavior of students is observed to discuss the competencies that they are using. [6]

1.1 Heat transfer coefficients.

Forced convective heat transfer is due to the movement of fluids. In forced convection the current is usually produced by means of a pump, a stirrer, a compressor or a fan. Most of the equipment used in heat transfer use the forced convection, including boilers, condensers, heat exchangers, etc. Fluids move within devices and may travel along the inside or outside of tubes, plates or also on banks of tubes. As a result, in the calculation of heat transfer it is necessary to take into account the velocity of the fluid, the geometry of the systems and the physical properties of the fluids. The heat transferred by convection is usually expressed by means of the so-called equation of Newton.

$$Q = h\,As\,(Ts - Tf) \ldots\ldots (1)$$

Where, Q is the heat transferred per unit time, h is the heat transfer coefficient of forced convection or film coefficient, As is the area of the object, Ts is the object's surface temperature and Tf is the fluid temperature. There are several methods to evaluate the coefficients of heat transfer by convection such as: dimensional analysis combined with experimentation, exact mathematical solutions of the equations of layer limit, the analogy between heat transfer and mass transfer, numerical analysis, etc. In general, the heat transfer coefficients are obtained by correlations and are in function of dimensionless numbers. In heat transfer, the dimensionless numbers used are the Nusselt, the Reynolds, the Prandtl, the Grashof, the Stanton and the Peclet.

1.2. Cooling of a bar by a stream of air that flows perpendicularly on its surface.

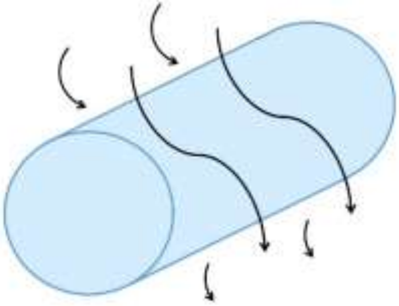


Fig. 1 - Stream of the air flowing perpendicularly on bar surface.

In this case, the cylinder loses heat and the amount lost can be calculated using the equation: [7], [8]

$$Q = m\,(Ts - Tf)\,Cp \ldots\ldots (2)$$

Or in differential form:

$$Q = m\,Cp\,(dTs/d\theta) \ldots\ldots (3)$$

The amount of heat lost through the bar is transferred to air by convection,

$$Q = h\,As\,(Ts - Tf) \ldots\ldots (4)$$

Matching equations (3) and (4):

$$-mCp\frac{dTs}{d\theta} = h\,As\,(Ts - Tf) \ldots\ldots (5)$$

Integrating:

$$\int \frac{dTs}{Ts - Tf} = -\frac{hAs}{mCp}\int d\theta \ \ldots\ldots (6) \quad ; \quad ln(Ts - Tf) = -\frac{hAs}{mCp}\theta + C \ldots\ldots (7)$$

Initial conditions:

$$\theta = 0;\ \text{When, } Ts = To,$$

Therefore,

$$ln\,(To - Tf) = C \ \ldots\ldots (8)$$

Introducing (8) into equation (7):

$$\ln\,(Ts - Tf) = -\frac{hAs}{mCp}\theta + \ln(To - Tf) \ \ldots\ldots (9)$$

The equation (9) is a straight line of the form: y = ax + b.

If we draw the equation (9) as in the graph of Fig. 2, it can be obtained that the slope is:

$$slope = -\frac{hAs}{mCp}$$

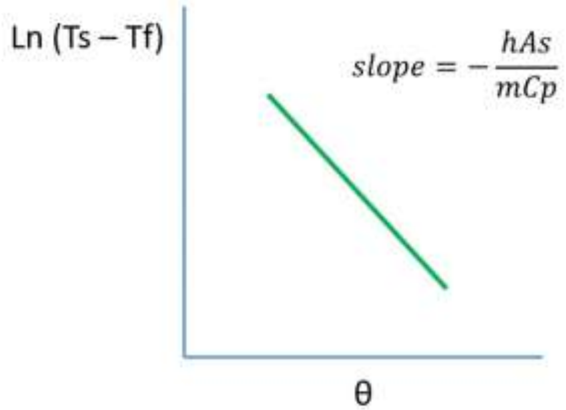


Fig. 2 - Graph of Ln (Ts – Tf) vs θ.

The researchers obtained experimentally that the cooling and heating of fluids that travel outside of tubes and in the direction normal to them can be correlated by (1), (2) and (3):

$$\frac{hDe}{k} = b(Re)^n \ldots\ldots (10)$$

In general, the heat transfer coefficient depends on the Reynolds number. The values of *n* and *b* are shown in the following table:

Re	n	b
1 - 4	0.33	0.891
4 - 40	0.385	0.821
40 - 4000	0.486	0.615
4000 - 40000	0.618	0.174
40 000 - 250 000	0.805	0.0239

2. EXPERIMENTAL WORK

In order to obtain experimentally the heat transfer coefficients, the students performed a practice to obtain the average coefficient of heat transfer. In the experiment, a copper rod that was initially at a maximum temperature was exposed to air flow that passes transversely around it. [5], [6]

The apparatus used during practice was designed by the British company Plint and is shown in Figure 3.

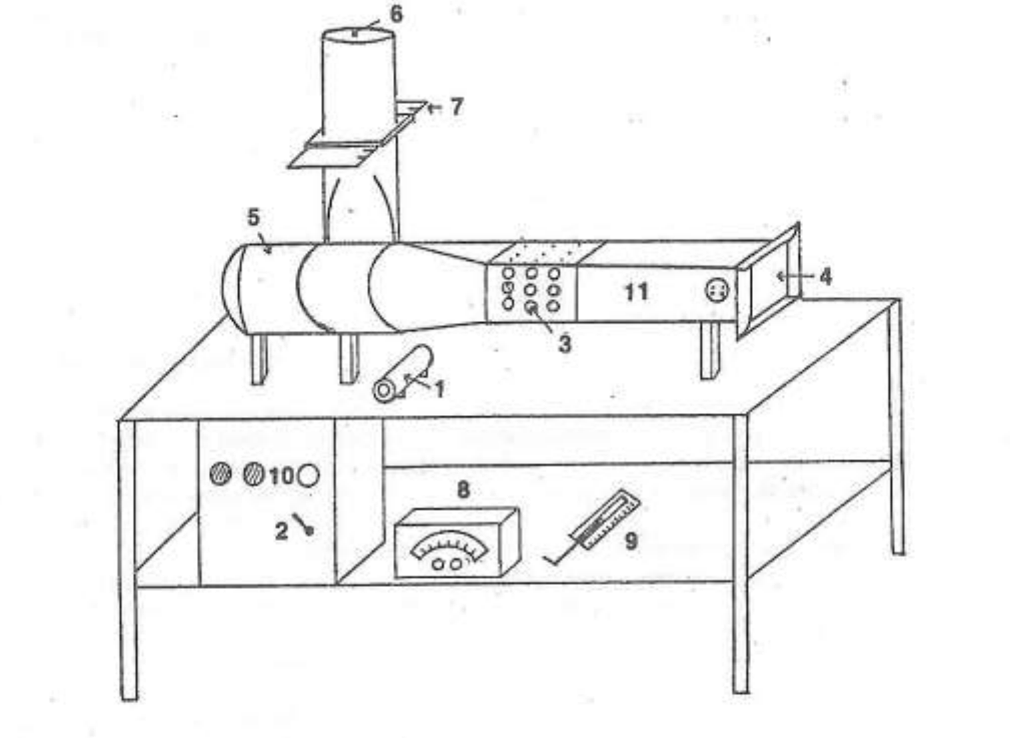


Fig. 3 - Convective heat transfer apparatus.

Number	Description
1	Heating resistance of the copper rod
2	Circuit power of resistance
3	Holes to place the bar in a transverse position to the flow of air
4	Input air
5	Fan to suck air
6	Vent air outlet
7	Window regulator of the air flow
8	Differential micromanometer of water
9	Pitot tube
10	Power-off
11	Air duct

In order to perform the experimental work, the students must:

a. Place the metal bar within the electrical resistance (1),

b. Turn on the resistance (2)

c. Turn off the resistance when the bar has reached a maximum temperature.

d. Insert the bar in one of the center holes in the duct (3) and seal the remaining by means of plugs.

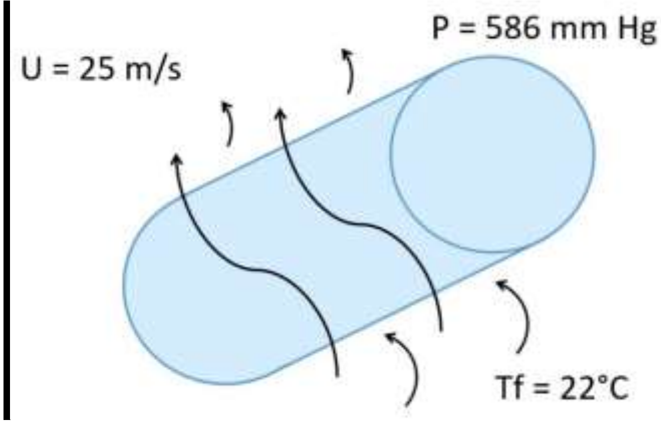
e. Pass a current of air (4), by means of the (5) fan.

f. Take temperatures.

g. Take times, temperatures and flows in each experiment.

2.1 Experimental development.

In an experiment in particular the students obtained the following results.

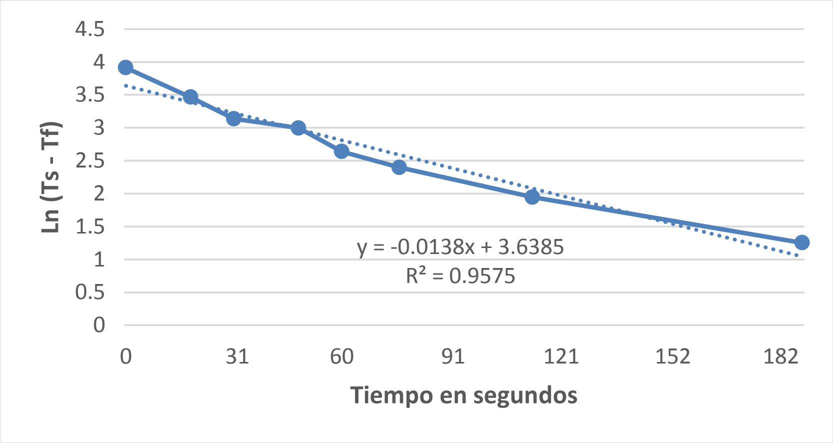


Temperature of 22°C, air velocity of 25 m/s, pressure of 586 mm of Hg (Mexico City pressure). Initial temperature of cylinder: 72° C; length: 9.51 cm; diameter: 1.238 cm; mass: 106 g; heat capacity of cylinder 0.09 kcal/kg°C (copper).

During the experiment the cylinder cools and the students obtained the following results:

Time in seconds	Ts -Tf	Ln (Ts -Tf)
0	50	3.912
18	32	3.465
30	23	3.135
48	20	2.995
60	14	2.639
76	11	2.397
113	7	1.946
188	3.5	1.252

Graph of the data obtained:



The graphic shows that the slope is - 0.0138

Then:

$$-0.0138 = -\frac{hAs}{mCp}$$

But, $As = 3.698 \times 10^{-3}$ m^2; $m = 0.106$ kg; $Cp = 0\ 09$ kcal/kg°C

Therefore, $h = 0.0355\,\frac{kcal}{s\,°C\,m^2} = 149\,\frac{W}{K\,m^2}$

2.2. Obtaining the coefficient by means of a correlation.

For the case under study it can be found that the coefficient could be obtained using the equation:

$$Nu = \frac{hDe}{k} = b\, Re^n$$

Where, b and n depend on the Reynolds number.
The properties of the air in the experiment were:
Ρ = 0.93 kg/m^3 ; μ = 0.019 cps ; k = 28 x 10^{-3} W/mK
Thus the Reynolds number is:

$$Re = \frac{0.01238 \times 0.92 \times 25}{1.9 \times 10^{-5}} = 14986$$

For this number of Reynolds, b = 0.174 and n = 0.618
Therefore the Nusselt would be:

$$Nu = 0.174(14986)^{0.618} = 66.24$$

And:

$$h = 66.24 \times 28 \times 10^{-3}\frac{W}{mK} \times \frac{1}{0.01238\, m} = 150\frac{W}{Km^2}$$

Which agrees pretty well with data obtained in the laboratory.

3. CONCLUSION

The students of chemical engineering through a simple experiment can analyzed the way in which heat transfer coefficients are obtained. They also practice their math skills, kinetics, linguistic, interdisciplinary, social competences and modifies their attitude towards experimentation as a means to get information of the universe that surrounds us.

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