ISSN (Online) : 2455 - 3662
SJIF Impact Factor :3.967

EPRA International Journal of

Multidisciplinary Research

Monthly Peer Reviewed & Indexed
International Online Journal

Volume: 3 Issue: 4 April 2017

Published By :
EPRA Journals

SJIF Impact Factor: 3.967 Volume: 3 | Issue: 4 | April|2017

EPRA International Journal of Multidisciplinary Research (IJMR) ISSN (Online): 2455-3662

EXPERIMENTAL STUDY OF THE COOLING OF A METAL BAR IN A LABORATORY OF TRANSPORT PHENOMENA

Antonio Valiente Barderas[1]
[1]Chemical Engineering Department,
Faculty of Chemistry - UNAM.
Mexico City. Mexico

Stephania Gómez Rodea[2]
[2]Chemical Engineering Department,
Faculty of Chemistry - UNAM.
Mexico City. Mexico

ABSTRACT

The experiment carried out to cool down a bar of metal or fin allows the students of Chemical Engineering, at the Faculty of Chemistry of the UNAM to study the physical behavior of those attachments, and also gives them the opportunity to compare their data with those that can be predicted through the equations that explain this phenomenon, which helps them to improve their professional skills.

KEYWORDS: *Chemical Engineering, Chemistry, cooling of motors and compressors,*

1. INTRODUCTION

Science is a set of knowledge that encompasses not only a set of empirical laws through which we can explains facts and properties of phenomena belonging to the domain of observation and experimentation, but also of certain theoretical principles or theories that explain why the observable phenomena behave as set out in the empirical laws. The principles are not arbitrary and imaginary creations, they have a connection with the domain of the observable world.

In the laboratory of Transport Phenomena at the Faculty of Chemistry of the Universidad Nacional Autónoma de México (UNAM), the students through experimentation connect with the observable world, and then through the treatment of the data, they try to deduce the laws that explain these facts. Such is the case of the study of the cooling of a bar of metal or a fin. This phenomenon has its application in Chemical Engineering since the fins are widely used in heat exchangers of cross flow, the air-coolers, the cooling of motors and compressors, etc.

1.1 COOLING OR HEATING OF A BAR OR FIN

Take the case of a bar which one end is subject to a constant temperature and is surrounded by a fluid such as air, Fig.1.

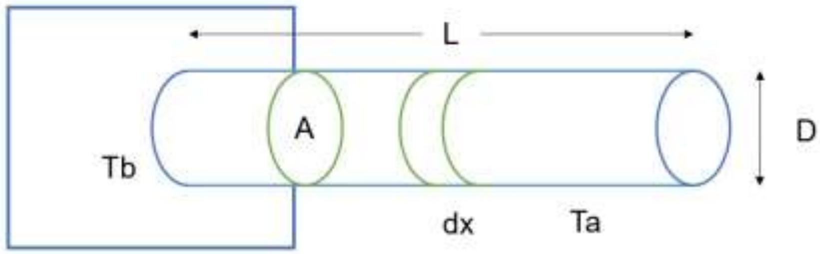


Fig.1. Heat transfer along a metal bar that is exposed to the air.

A balance of energy applied to the section Δx of the bar [1],[2]would result, if you despise the heat lost by the end :

$$Q_x = Q_{x+\Delta x} + Q_A \quad (1)$$

Q_x = incoming heat by conduction at x

$Q_{x+\Delta x}$ = outgoing heat by conduction in x + Δx

Q_A= outgoing heat by convection and radiation.

$$-kA\left[\frac{dT}{dx}\right] = \left\{-kA\left(\frac{dT}{dx}\right) + \frac{d}{dx}\left[-kA\left(\frac{dT}{dx}\right)\right]dx\right\} + hPdx(T-Ta) \quad (2)$$

Then,

$$\frac{d}{dx}\left(kA\frac{dT}{dx}\right)dx = hPdx(T-Ta) \quad (3)$$

Where, A is the sectional area and P the perimeter of the bar. P, A and k are constants.

Defining θ = T-Ta

$$\frac{d^2\theta}{dx^2} - \frac{hP}{kA}\theta = 0 \quad (4)$$

The solution of the above equation is of the form $\theta = e^{mx}$, where:

$$m = \pm\sqrt{\frac{hP}{kA}} = B \quad (5)$$

$$\theta = C_1 e^{Bx} + C_2 e^{-Bx} \quad (6)$$

Since the equation is linear.

The conditions are:

Hot side x = 0; $\theta = \theta_b$

Cold side x = L $\left(\frac{d\theta}{dx}\right) = 0$; T-Ta = 0

$$\therefore \quad \theta_b = C_1 + C_2 \quad ; \; 0 = C_1 e^{BL} - C_2 e^{-BL} \quad (7)$$

$$C_1 = \frac{\theta_b e^{-BL}}{e^{BL} + e^{-BL}} \quad ; \therefore \quad C_2 = \theta_b - C_1 \quad (8)$$

$$\therefore \quad \frac{\theta}{\theta_b} = \frac{e^{-B(L-x)} + e^{B(L-x)}}{e^{-BL} + e^{BL}} = \frac{\cosh B(L-x)}{\cosh BL} \quad (9)$$

$$\theta = T - Ta \quad ; \theta_b = Tb - Ta$$

The above equation can provide reasonable results only if the heat that is lost by the end is negligible.

The heat transferred from the base of the bar is calculated by:

$$Q_b = \int_0^L h\,P\,\theta\,dx \quad (10)$$

and the heat transferred in the entire bar is:

$$Q = \sqrt{h\,P\,k\,A}\quad \theta_b \tanh BL \quad (11)$$

The Ω efficiency factor is defined as the heat transferred from the bar between the transferred heat if the bar has an uniform temperature Tb.

$$\Omega = \frac{Qfin}{h\,P\,L\,\theta_b} = \frac{\sqrt{h\,PkA}\quad \theta_b \tanh BL}{h\,P\,L\,\theta_b} = \frac{\tanh BL}{BL} \quad (12)$$

remember that:

$$B = \sqrt{\frac{hf\;P}{k\;A}} \quad (5)$$

2. EXPERIMENTATION

The equipment used in the laboratory of Transport Phenomena of the Faculty of Chemistry at the UNAM is showed at the Fig. 2:

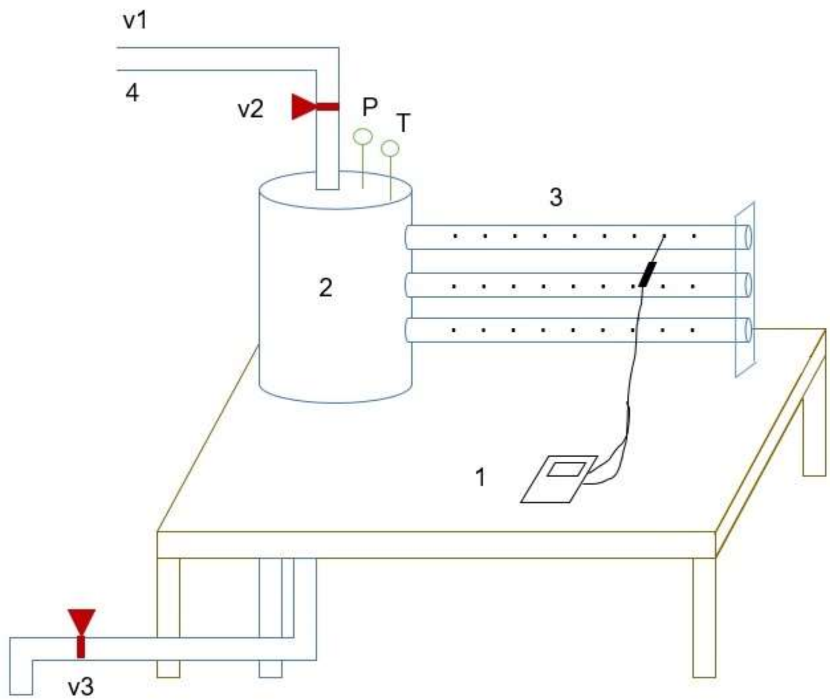


Fig. 2. Heat conduction equipment.

V1 - Steam inlet valve
V2 - Valve to the steam chamber
V3 - Outlet valve
1. Digital thermometer with thermocouple
2. Steam Chamber
3. Parallel bars of aluminum and iron
4. Steam pipe

2.1. EXPERIMENTAL PROCEDURE

To conduct the experiment students must [3]:

a) To purge the steam (8) lines by opening the valves V1 and V3.
b) Close the valve V2 and open the V1.
c) Slowly open valve V2 until the operating pressure is reached.
d) If the pressure is stabilized obtain the corresponding readings along the bar with the help of a digital thermocouple, inserting the thermocouple in the holes.

2.2. EXPERIMENTAL DATA

In an experiment the students obtained the following experimental data when the steam pressure was 2 kg f/cm2 and the surrounding air temperature was 19°C.

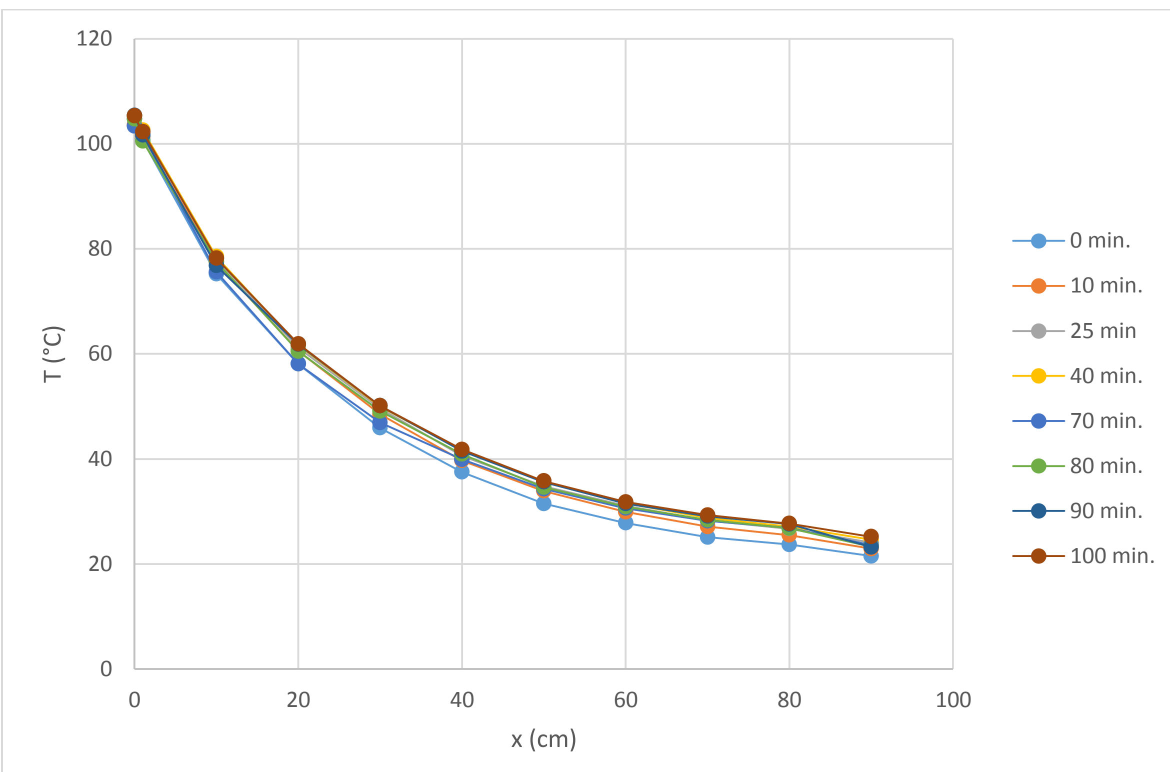
The employed bar was of aluminum with 90.5 cm in length and 1.9 cm in diameter.

Position (x) in cm	Temperature (°C) at 0 min.	Temperature (°C) at 10 min.	Temperature (°C) at 25 min.	Temperature (°C) at 40 min.	Temperature (°C) at 70 min.	Temperature (°C) at 80 min.	Temperature (°C) at 90 min.	Temperature (°C) at 100 min.
0	103.4	103.6	104.7	105.3	103.4	104.7	105.4	105.3
1	100.7	101.4	102.3	102.6	101.7	100.5	101.7	102.3
10	75.2	77.5	78.1	78.5	75.6	77.6	76.8	78.2
20	58.1	60.6	61.2	61.7	58.1	60.5	61.8	61.9
30	45.9	48.5	49.6	50	46.9	49.1	50.1	50.1
40	37.5	39.7	40.6	41.6	39.9	40.9	41.5	41.8
50	31.5	33.9	34.8	35.7	34.3	34.6	35.6	35.8
60	27.8	29.9	31.1	31.6	30.6	30.9	31.5	31.8
70	25.1	27.1	28.3	28.8	28.2	28.4	29.1	29.3
80	23.7	25.5	26.7	27.1	26.9	26.8	27.6	27.7
90	21.5	22.9	24.1	24.6	23.6	23.3	23.2	25.2

Table 1. Experimental data. Steady-state is reached after 100 minutes

2.3. PROCESSING DATA

Perimeter of the bar: P = 0.05969 m
Length bar: 0.905 m
Temperature of the frame base: 105.3 ° C.
Thermal conductivity of the bar (aluminum): 229 W/m ° C
Transfer area of heat by conduction: 2.833 x 10^{-4} m^2
With the experimental data, students built the following graph (1).

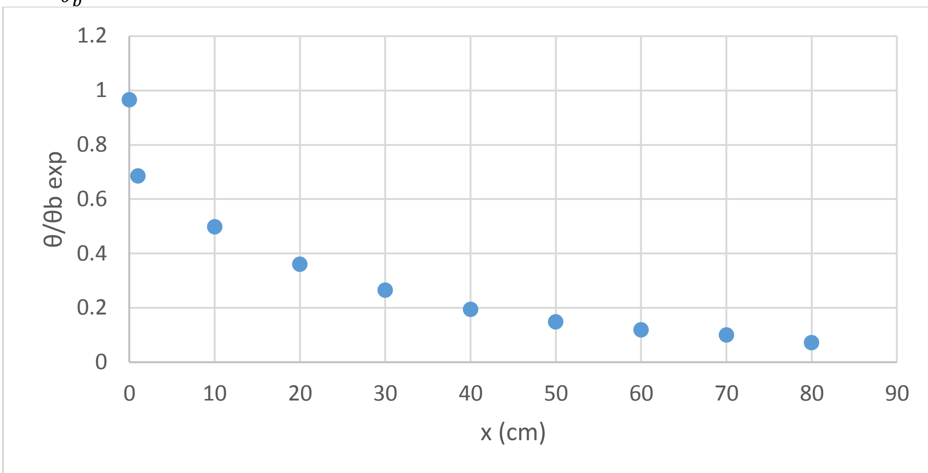


Graph 1. Experimental temperature against and position at different times.

The students also built from the data in the steady-state, the graphics (2) and the table (2).

Position	0	1	10	20	30	40	50	60	70	80	90
$\frac{\theta}{\theta_b}$ exp	1	0.965	0.685	0.497	0.360	0.264	0.194	0.148	0.119	0.100	0.0718

Table 2. $\frac{\theta}{\theta_b}$experimental data at steady state. Where $\theta = T - 19$ and $\theta_b = 105.3 - 19 = 86.3$



Graph 2. $\frac{\theta}{\theta_b}$ experimental data at steady state.

3. THEORETICAL TREATMENT

The phenomenon under study can be predicted from the equation (9)

$$\therefore \quad \frac{\theta}{\theta_b} = \frac{e^{-B(L-x)} + e^{B(L-x)}}{e^{-BL} + e^{BL}} = \frac{\cosh B(L-x)}{\cosh BL} \quad (9)$$

Where $B = \sqrt{\frac{hf\ P}{k\ A}}$ (5)

For our case, L = 0.905 m, P =.05969 m, k = 228 W / ° C m, A = 2.833 x 10^{-4} m^2

The only unknown is h, which is the coefficient of heat transfer by convection and radiation between the bar and the air. This coefficient can be evaluated approximately by the equation proposed by Pavlov et. al. [4]

$h = 9.74 + 0.07(T - Ta)$, h en $\frac{W}{°C\ m^2}$ (13)

If we take the average temperature of the bar as:

$$T = \frac{105.3 - 25}{ln\frac{105.3}{25}} = 60°C$$

Therefore the average coefficient will be:

$$h = 9.74 + 0.07(60 - 19) = 12.61\frac{W}{°Cm^2}$$

Then:

$$B = \sqrt{\frac{0.05969 \times 12.61}{229 \times 2.833 \times 10^{-4}}} = 3.406$$

And BL = 3 406 X (0.905) = 3.0825

Therefore:

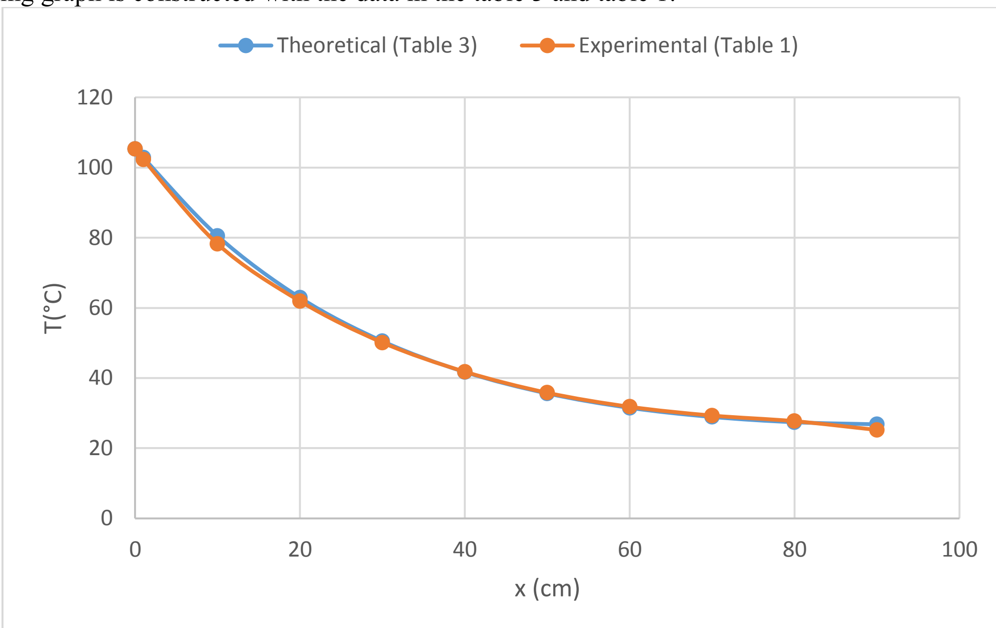
$$\frac{\theta}{\theta_b}\ theoretical = \frac{\cos h\ (3.406(0.905 - x)}{\cos h\ (3.406\ (0.905)} = \frac{\cos h\ (3.406)(0.905 - x)}{\cos h\ \ 3.0825}$$

But T = T=$(T_b - T_a)\frac{\cos h\ (3.406(0.905-x)}{\cos h\ (3.406\ (0.905)} + T_a = 86.3\frac{\cos h\ (12.09)(0.905-x)}{\cos h\ \ 3.0825} + 19$

The following table 3 can be constructed from these equations.

Position	0	1	10	20	30	40	50	60	70	80	90
$\frac{\theta}{\theta_b}$ Theoretical	1	0.9711	0.712	0.51	0.36	0.26	0.19	0.14	0.11	0.097	0.091
T°C Theoretical	105.3	102.8	80.5	62.9	50.5	41.7	35.6	31.5	28.9	27.4	26.8

The following graph is constructed with the data in the table 3 and table 1:



Graph 3. Theoretical and experimental temperature against position to steady-state.

The heat transferred is

$$Q = \sqrt{h\,P\,k\,A}\quad \theta_b \tanh BL \quad (11)$$

$$Q = \sqrt{12.61 \times 0.05969 \times 229 \times 2.833 \times 10^{-4}}(86.3) \tan h\ 3.0406\ (0.905) = 18.91 \text{ W}$$

The ideal heat transferred should be:

Q ideal =h P L θ_b $= 12.61 \times 0.05969 \times 0.905 \times 86.3 = 58.78\ W$

Therefore the efficiency of the bar would be

$$\Omega = \frac{18.91}{58.78} = 0.31$$

3. CONCLUSIONS

Through a simple experiment the students could observe the behavior of the heating of a bar or fin in the air. The theoretical data agree well with the experimental data. That experiment and others related to the observation of phenomena allow the students of Chemical Engineering to develop their epistemological, linguistic, computational skills and their abilities and attitudes.

BIBLIOGRAPHY

1. *Valiente A. "Introducción a la transferencia de calor". UNAM. México, 2009.*
2. *Valiente A. "Problemas de transferencia de calor". Limusa. México, 1988.*
3. *"Practicas del laboratorio de fenómenos de transporte". Laboratorio de Ing. Química. UNAM. México, 1998.*
4. *Pavlov K. F., Romankov P. G., Noskov A. A. "Problemas y ejemplos para el curso de operaciones básicas y aparatos en tecnología química". MIR. Moscú, 1981.*