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Innovative Strategy to study of external forced convection in a plate by means of a Theoretical-Practical Guide

Edgar Zuluaga Zuluaga[1], Sergio Quintana Gonzalez[2], Guillermo Valencia Ochoa[3*]

[1,2] Mechanical Engineering/ Faculty of Engineering/Universidad del Atlántico, Colombia.
[3]Mechanical Engineering Program/Universidad del Atlántico, Colombia.

Abstract : For the realization of themechanical and termal design of many engineering system sitis important tounder stand the heat transfer phenomena, especially the phenomenon of external forced convection. This workaims to provide to students with a theoretical – practical toola tool to undestand some cases study related to this topic, where they reconstructs an equipment tomodel the fluidflow and heat transfer under alow Reynolds numbers in orderto determine the behavior of the forced convection. Similarly, a simulation was performed using the Solid Works engineering software, recreating the conditions that were used for the experimental study. In order to measure the efficiency of the innovative tool developed, a test was conducted in a heat transfer intersemestral course at the Universidad del Atlantico, allowing a statistical analysis basedona t-test to measured the performace that each studen to btained in the tests carried out, according to an evaluation matrix.
Keywords: external forced convection, Theoretical-Practical Guide, plate.

Introduction

The practical implementation of theoretical concepts is necessary throughout the academic processes of engineering students [1,2]since it allows developing a set of complementary learning competences to the development of the master classes, significantly impacting the process of students' conceptual appropriation[3,4]. Over time, student learning has been shown to be improved with the help of practical academic processes - activities that are developed through problem solving and collaborative work. According to the American Engineering Society it has been seen that the level of learning improves by 71% when theoretical knowledge is put into practice[5-7].

With the objective to improve the practical tools available in the study of the forced convection heat transfer phenomenon, some experimental level commercial solutions have been developed that allow to calculate and analyze the thermal conductivity of the fluid and the convective heat transfer coefficient, which make the educational processes generate self-learning in a practical way. Among the commercial solutions available is found the Cross Flow Heat Exchanger H352 equipment, which allows students to determine in the steady state condition the free and forced convection heat transfer to various air velocities by means of a variable speed fan, allowing additionally to study the natural or free convectionphenomena[8].In addition, the equipment HT10XC Computer Controlled Heat Transfer Teaching Equipment, allows the study of the phenomenon in conditions of forced flow[9], which consists of a heated cylinder mounted in a vertical air duct, with a fan used to change the air flow around the cylinder.

At the computational level, some computational programs have been developed that serve as tools for the analysis of the phenomenon of forced convection [10-13]. At the experimental level, projects have been carried out to calculate and determine what has been learned in the theoretical classes, allowing the self-learning of those who carry out the activity [13,14].

The main contribution of the present work is focused on the improvement of theoretical-practical knowledge in the mechanism of forced convection heat transfer allowing students to deepen knowledge and improve reception and learning.

Methodology

A theoretical-practical guide was designed to work with the equipment, in the first section the information related to the theory and fundamental concepts are presented, in the second section it is explained the experience that was developed, and the necessary guidelines that the student must attend for the correct use of the equipment, and the third section is aimed at recording and collecting data to analyze the results. To design the learning guide was used the approach of Learning by doing, as shown on Figure 1.

This model implement the real-world learning theory, is a direct and practical application of the theoretical phenomenon studied, which is necessary but not the only thing. Applying this model is achieved the ability to associate learning and experience, where the teacher invite to the student in front of the know-how, where it is expected that at the end of the experience the student will learn 20% of what he sees, 20% of what he hears, 40% of what he sees and hears, and finally 80% of what he hears[16].

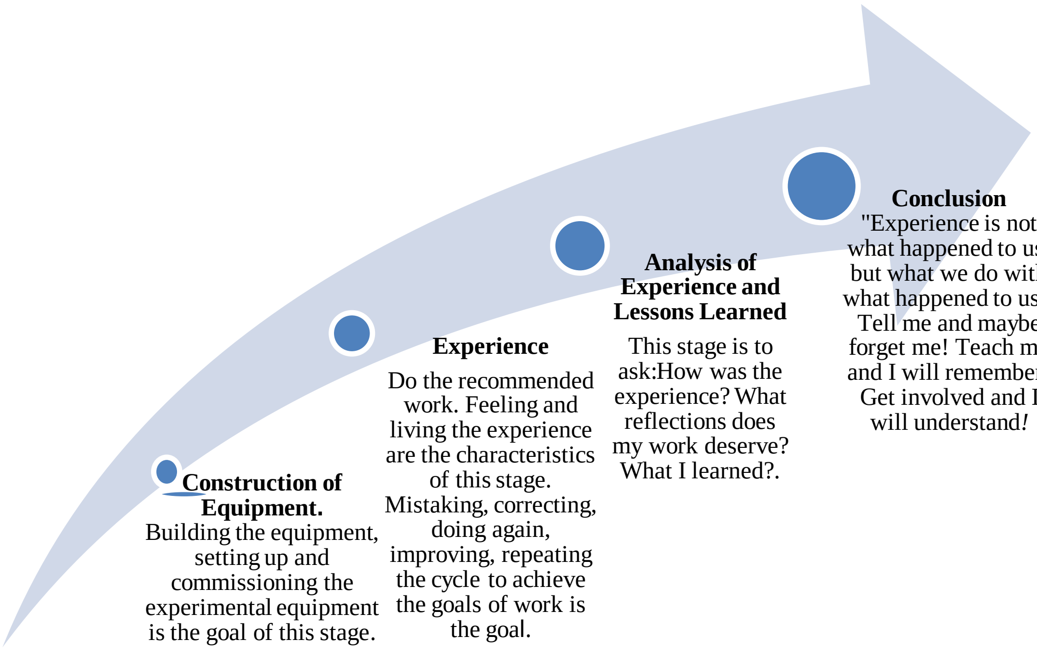


Figure 1.Methodological diagram of the Learning by doing approach.[15]

Development of the theoretical-practical guide

The theoretical-practical guide was designed as a tool to increase the level in the appropriation of theoretical knowledge using the equipment, the first part relates the whole theoretical part of the concepts, in the second part explains the procedure and rules that the student Should be followed for proper use, and the third part leads to the recording of the data and analysis of the results.

The guide was designed as a tool to analyze the self-efficacy for the learning of research that have university students and how these ideas interact with their conceptions regarding research [17]. The guide presents 4 items that are the introduction, theoretical framework, objectives and practical experience, where Figure 2 shows the theoretical part of the learning guide.

CHAPTER 7. EXTERNAL FORCED CONVECTION HEAT TRANSFER

7.1. INTRODUCTION

In engineering, heat transfer phenomena are studied, with convection being one of the most complicated to study due to the implication of many variables. Convection is defined as a mechanism of heat transfer that is performed through a fluid, in the presence of a massive movement or circulation of it. This phenomenon is classified as free and forced convection, which is determined by the way in which the movement is generated to the fluid.

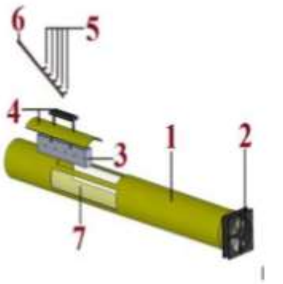


Figure 1. Experimental system consisting of housing (1), fan (2), study piece (3), gate (4), sensors (5), wiring (6), visor (7).

By experimental investigations it has been determined that the convection process depends on the properties *dynamic viscosity* μ, *thermal conductivity* k, *density* ρ and *specific heat* c_p of the fluid, as well as the *velocity of the fluid* V. Likewise, this depends on the structure geometric and roughness of the solid surface, in addition to the flow type either laminar or turbulent. It is for these conditions that the study of this phenomenon becomes complex due to the intervention of so many variables. Which leads to determine convection as the most complex mechanism of heat transfer.

For this case an experimental assembly was implemented for the study of the heat transfer by external forced convection, where the student of engineering will be able to realize a theoretical-practical experience, and through the obtaining of data to verify experimentally this phenomenon, for its later analysis With the results obtained analytically in theory.

7.2. FUNDAMEMNTAL EQUATIONS

The forced convection of steady state can be described by the correlations that include the abovementioned dimensionless numbers, obtaining equation (1).

$$Nu = a.Re^{b}.Pr^{c}.(L/D)^{e} \quad (1)$$

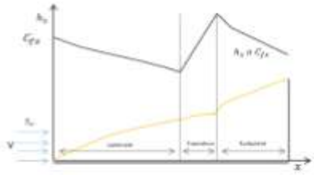


Figure 2. Change of the local friction coefficients and heat transfer for the flow on a plate.

Through the experimental practice values have been obtained for each of these numerical variables and their exponents. For example, in the case of the study of forced convection in turbulent flow, one has to:

$$Nu = 0.23 * Re^{0.8} * Pr^{0.4} \text{ for } (Re > 10.000) \quad (2)$$

Figure 2.Theoretical-Practical guide: Introduction and theoretical framework.

The introduction of the guide is focused on using the student's previous knowledge to begin to relate to the field of heat transfer by external forced convection, followed by the theoretical framework, the main concepts and the objectives of the experiences to be realized with the help of the equipment described in Figure 3.

7.3. EXPERIMENTAL EQUIPMENT SETUP

For the development of the theoretical experimental guide it is necessary for the students to develop their own equipment, perform their set-up, configuration and validation, as shown in Figure 4. Likewise, the programming of the acquisition system of data from the temperature sensor readings, which for this particular case was performed in ARDUINO.

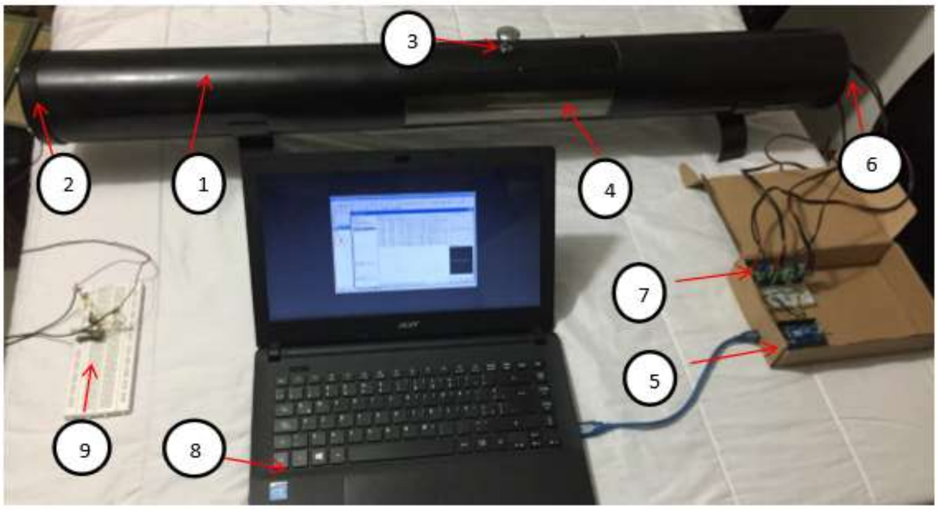


Figure 4. Experimental equipment setup to study the force convection heat transfer.

Among the components that make up the experimental equipment, is the housing made of PVC pvc 4¨ in diameter (1), the fan 10cm wide direct current at 12v and 1.35A (2), the gate (3) that allows the easy entry of the piece to the cooling medium, the viewer that allows to verify the correct position of the sensors (4), the microcontroller UNO that has 14 digital pins and 6 analog inputs, which operates with a voltage between 7-12 Volts and has a flash memory of 32k (5), thermocouples k type contact with measuring range between 0 ° C ~ 800 ° C (6), which allow the reading of the temperature in the time until reaching the stationary stage, a MAX6675 Card is the one that realizes and digitizes the signal of a thermocouple, allowing data transmission with a 12-bit resolution compatible with the SPI communication protocol and operating voltage between 3.0 ~ 5.5 V and measurement resolution of 0.25 degrees (7), computer for data processing (8) and protoboard for varying speed of the turbine (9), which allows different convective coefficients to be obtained by varying the flow regime.

Figure 3. Theoretical-Practical Guide: Description of the experimental setup.

7.4. OBJETIVES

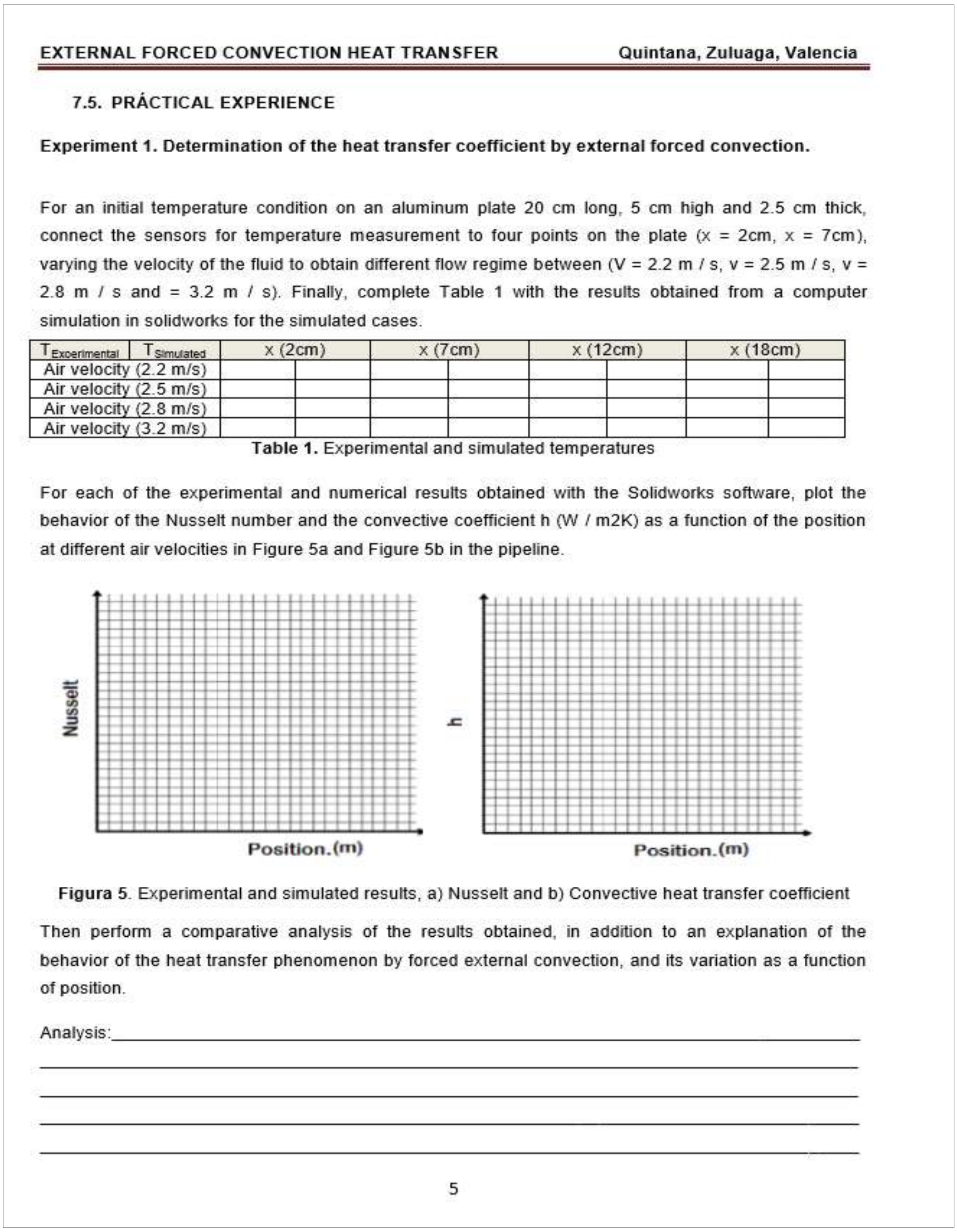
- Provide the student with a meaningful learning experience from the practice of external forced convection.
- Evaluate the heat transfer associated with the flow on a flat plate, for different flows.
- Determine experimentally and properly use the dimensionless numbers corresponding to the heat transfer process by forced convection.
- Determine experimentally the heat transfer coefficient by external forced convection for a given assembly.

Figure 4.Practical guide: Objectives of the experiences.

Figure 4 shows the part of the practical theoretical guide corresponds to the objectives of the experiments to be carried out with the help of the experimental assembly built by the students.

Finally, the practical component of the guide is initially composed of the methodology to carry out the experience, data collection and drawing, and finally a space where the student or professional must perform the analysis and discussion of the results, which are aimed at knowing the relationship between the different variables of external forced convection, as shown in Figure 5 for the particular case of practical experience N ° 1.

From Experiment N°1, the student is expected to understand the parameters involved in the process of external forced convection, observing how each of the effects interact between them and practically identifying the degree of correlation between them.



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7.5. PRÁCTICAL EXPERIENCE

Experiment 1. Determination of the heat transfer coefficient by external forced convection.

For an initial temperature condition on an aluminum plate 20 cm long, 5 cm high and 2.5 cm thick, connect the sensors for temperature measurement to four points on the plate (x = 2cm, x = 7cm), varying the velocity of the fluid to obtain different flow regime between (V = 2.2 m / s, v = 2.5 m / s, v = 2.8 m / s and = 3.2 m / s). Finally, complete Table 1 with the results obtained from a computer simulation in solidworks for the simulated cases.

$T_{Experimental}$ $T_{Simulated}$	x (2cm)		x (7cm)		x (12cm)		x (18cm)	
Air velocity (2.2 m/s)								
Air velocity (2.5 m/s)								
Air velocity (2.8 m/s)								
Air velocity (3.2 m/s)								

Table 1. Experimental and simulated temperatures

For each of the experimental and numerical results obtained with the Solidworks software, plot the behavior of the Nusselt number and the convective coefficient h (W / m2K) as a function of the position at different air velocities in Figure 5a and Figure 5b in the pipeline.

Figura 5. Experimental and simulated results, a) Nusselt and b) Convective heat transfer coefficient

Then perform a comparative analysis of the results obtained, in addition to an explanation of the behavior of the heat transfer phenomenon by forced external convection, and its variation as a function of position.

Analysis:____

5

Figure 5.Practical guide: Methodology, data collection and analysis of results.

Results and discussions

In order to determine in a practical and experimental way the coefficient of heat transfer by forced convection, the construction of a study bank was carried out, with its respective data acquisition system. The study of the phenomenon with its respective guide and experimental system allowed providing students with an innovative learning tool to reach an empirical approach of the fundamental equation that describes the convection, and through the obtaining of data perform an experimental theoretical study of this phenomenon.

Similarly, a theoretical-practical guide was designed to guide the student in the correct use of the equipment and record the data obtained during their experimental practice. The guide contains four assignments or experiences, in the first experience the analysis and determination of the coefficient of heat transfer by external forced convection, as a function of the position, is evaluated in which the student must set some parameters and modify the input variables involved In the analysis, to allow the generation of both theoretical or numerical and experimental graphs of the behavior of the heat transfer coefficient by external forced convection and the Nusselt number as a function of the position

The following are the typical results that students obtain both experimentally and theoretically, which allow them to identify and observe each of the variables or effects that influence the calculation of the heat transfer coefficient by external forced convection, Shows a general description of the required computational simulation, in order to make a comparison of the obtained data. Figure 6 shows an image that the computer-assisted simulation to be performed in Solid works to obtain the simulated or theoretical values of the process under study. It should be taken into account as air flow boundary conditions at a given velocity, temperature and pressure condition at the inlet, and initial conditions of solid temperature; In addition to checking the mesh independence in order to determine a correct numerical value for comparison with the experimental data.

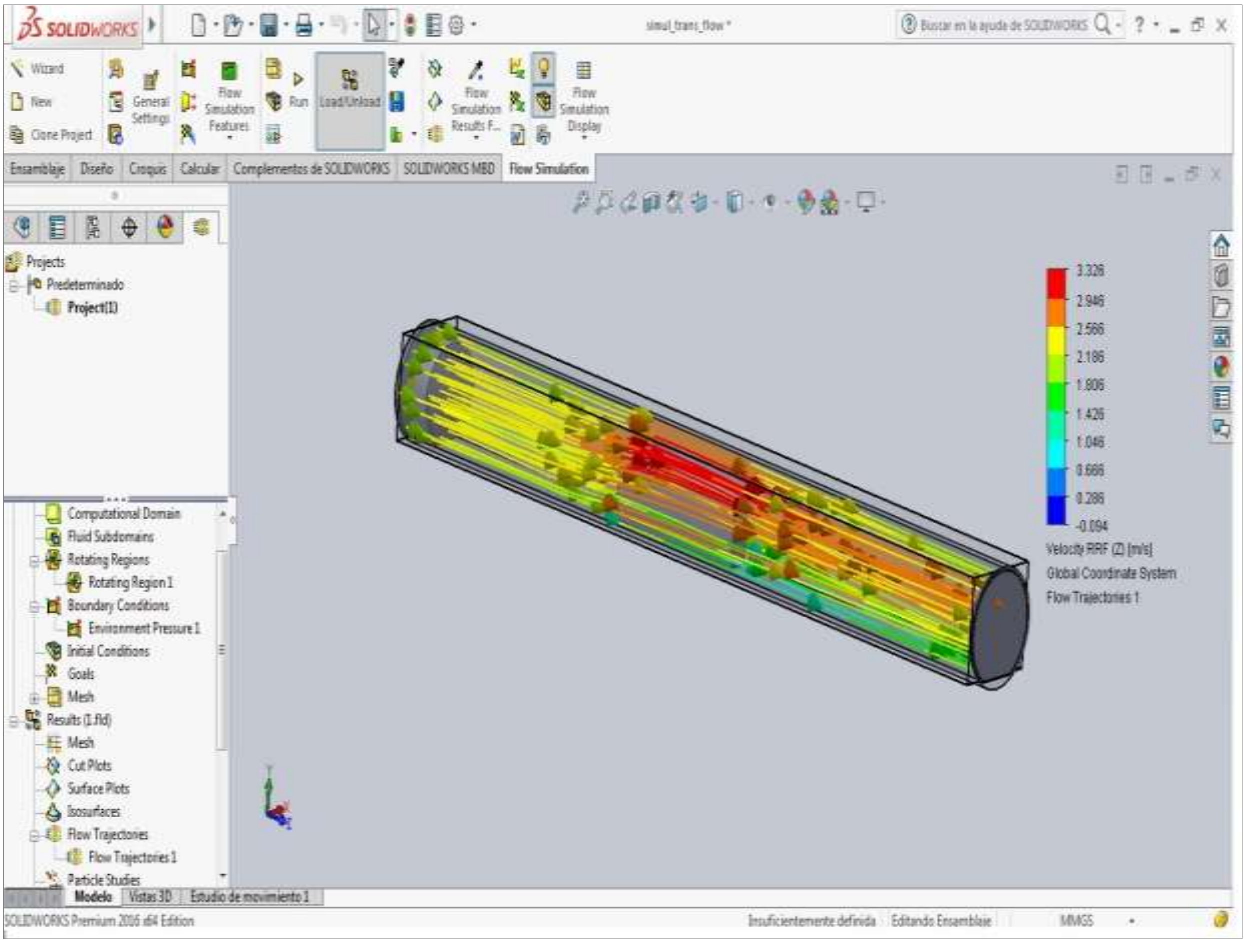

Figure 6.Experimental modeling of the case study.

Figure 7 shows the values obtained from the convective coefficient as a function of the position by simulation and experimentally, at different air flow velocities. In order to obtain the convective coefficient of heat transfer by forced convection in steady state, the temperature data were recorded for each position in time, which allowed the calculation of the properties of both the fluid and the material of the plate. From the results of the coefficient convective as a function of the position, it is observed that these decreases in length, initially there are sudden decreases due to the high temperature difference between the solid and the fluid, gradient tending to zero at the end of the plate, since the fluid has already been heated.

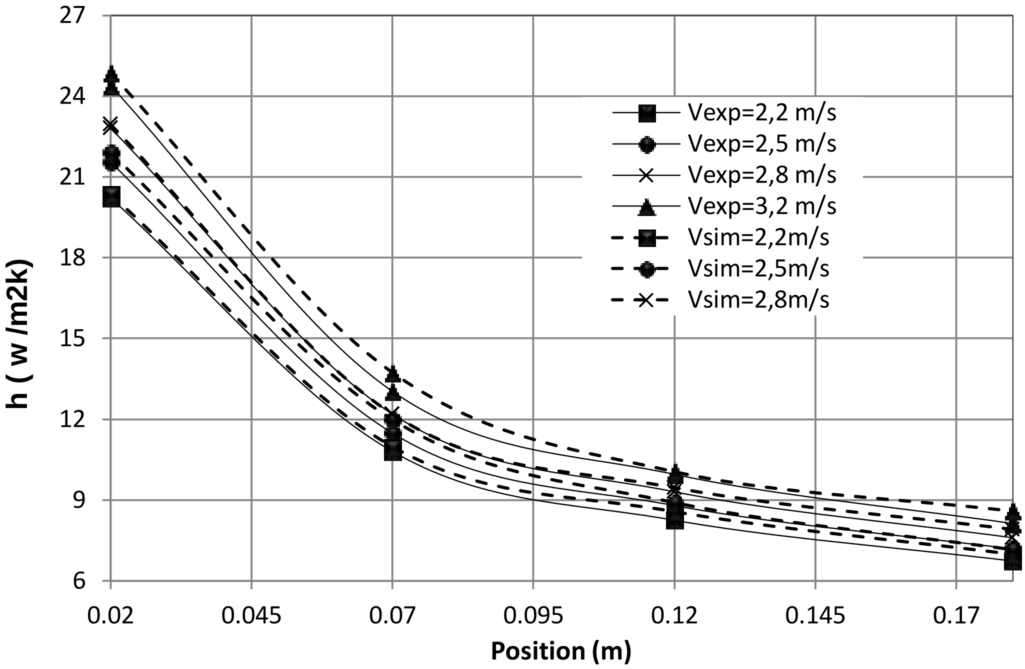

Figure 7.Graph of the behavior of the heat transfer coefficient by external forced convection as a function of the position.

The results of the measurements vary in small values with respect to the results obtained in the simulation, which can be associated to human errors, not correctly connecting the sensors to the plate, or of any specific sensor that marks an incorrect temperature, Even it is possible that the plate in the experimental study has not been uniformly heated, which if considered at the moment of the simulation. The minimum and maximum error values were 0.61% for the 0.02m position, and 5.35% for 0.12m respectively, for a 2.8 m / s air velocity condition.

Figure 8 compiles the graph of each of the isothermal lines referring to the Nusseltvs Position, (experimental and simulation) associated to each flow rate. Initially the development of each of the curves shows the classical behavior of the Nusselt number with respect to each of the positions. The lines show a significant increase of the Nusselt depending on its position, noting also that the higher the velocity of the flow, the greater the Nusselt value.

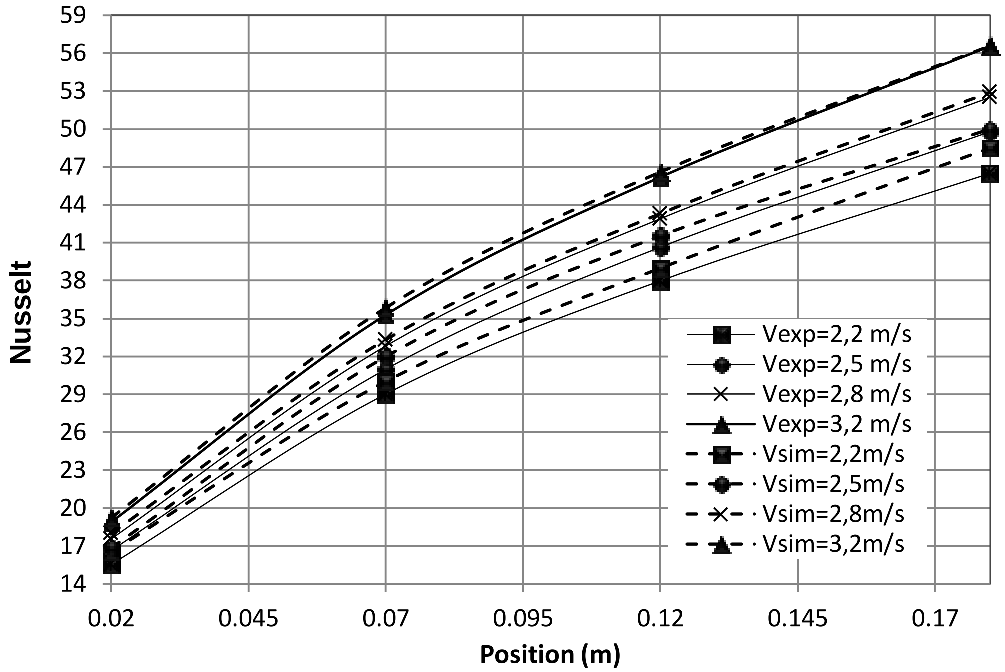

Figure 8.Graphical behavior of the Nusselt number according to the position.

For this case the calculation of errors showed values of 0.33% for the minimum error which was given for flow velocity conditions of 3.2 (m / s) and a position of 0.12 (m), while the maximum error was 6.04% for a flow at 2.2 (m / s) and a position of 0.02 (m). Finally, the average error value was 2.05%.

In order to measure the effectiveness of the innovative tool developed, a test was conducted in an intersemestral course of the course of heat transfer at the University of Atlántico, allowing to perform a statistical analysis based on the qualification obtained by each student in the tests carried out According to an evaluation matrix or rubric formed by criteria and an assessment scale. Among the criteria included in the rubric are the clarity, precision and relevance with which students respond to experience 1 of the guide, in an assessment scale it is composed of 4 ranges as shown in Figure 9, with 5 being the maximum score and 0 the minimum.

HEADING TO ASSESS ANSWERS TO OPEN QUESTIONS							
INSTRUMENT: THEORETICAL GUIDE - PRACTICE STUDENT:						EXPERIMENTAL GROUP	CONTROL GROUP
CRITERIA		Excellent	Good	Regular	Deficient	Experience1	Experience 1
		[4,5 - 5,0]	[3,8 - 4,4]	[3,0 - 3,7]	[2,9 - 0]		
1	CLARITY	The answer given by the student is understandable or intelligible. It expresses very clearly what it means. Express what is understood in his own words. You can give examples. It is expected to be met in 100%	It is expected that 80%	It is expected that 80%	It is expected that 80%		
2	PRECISION	The answer given by the student is specific, presenting details or details that give their understanding of the subject. It is expected to be met in 100%	It is expected that 80%	It is expected that 80%	It is expected that 80%		
3	RELEVANCE	The answer given by the student considers the factors or aspects that are closely related to the question asked. It is expected to be met in 100%	It is expected that 80%	It is expected that 80%	It is expected that 80%		

Figure 9.Rubric for the evaluation of the results of the theoretical-practical guide.

With respect to the statistical analysis shown in Table 1, the t-test was performed with a significance level of 0.05 for two samples with unequal variances and one normal population, to the students' responses before the intervention for the control group And the experimental group, where the experimental group performed the experiment at a first opportunity without the guide and later with the guide, while in the control group in the two Opportunities the study was carried out without the guide. Initially, from the P values thedifference of means is not significant, indicating that the groups are Equal in terms of clarity, precision and relevance, guaranteeing population homogeneity prior to intervention.

Table 1.Statistical analysis of both groups in the previous test.

Dependent Variables	N	Control Group				Experimental Group				Value P	Tcrit	T
		H	SD	MIN	MAX	H	SD	MIN	MAX			
Clarity	12	2,46	0,28	2,25	2,91	2,67	0,16	2,40	2,93	0,8710	2.21	-0.12
Precisión	12	2,51	0,24	2,36	2,98	2,60	0,24	2,30	3,00	0,8482	2.21	0.19
Relevance	12	2,81	0,21	2,31	3,2	2,61	0,22	2,23	3,03	0,2321	2.21	1.26

Note: H=Half, S.D. =standard deviation, Tcrit. = T Critical value

In order to statistically evaluate the difference between the average score between the control group and the experimental group, which used the patrician theoretical guide to study the process, the t-test for the clarity, precision and relevance variables was performed once again. Table 2 shows the statistical results for the data obtained in both groups after the intervention of the experimental group, where it is observed that all P values are less than 0.05, indicating that statistically there is a difference between the mean scores of the groups, indicating That the theoretical-experimental guide has a significant effect on the learning process of the students.

Table 2.Statistical analysis of both groups after the intervention.

Dependent Variables	N	Control Group				Experimental Group				Value P	Tcrit	T
		H	SD	MIN	MAX	H	SD	MIN	MAX			
Clarity	12	2,92	0,22	2,41	3,32	4,13	0,22	3,86	4,54	0,0000	2.21	-15.16
Precisión	12	2,87	0,23	2,62	3,45	3,97	0,28	3,43	4,57	0,0000	2.21	-10.68
Relevance	12	2,89	0,24	2,51	3,33	3,99	0,19	3,42	4,48	0,0000	2.21	-9.94

Note: H=Half, S.D. = standard deviation, Sig. =Level of significance, E.T. =Typical error

Conclusión

The development of an experimental assembly with its respective data acquisition system allowed the experimental and analytical characterization of the actual process of heat transfer by external forced convection, besides forming together with the theoretical-practical guide an important learning tool for the students From the visualization of the main input and output variables that are taken into account in the different processes of this phenomenon.

It was evidenced that from the guide the experimental group achieved in the second test excellent results in the evaluation n of the first experience in terms of clarity, precision and relevance of their answers, implying that they have the clear theoretical concepts and fundamentals For the calculation of dimensionless numbers, and interpret the differences between the types of flow that exist in the study, in order to establish if the heat transfer in the system is by convection or conduction, in addition to determining the predominant mechanism of Energy transfer.

The non-dimensional equations were used to evaluate forced convection heat transfer coefficients for different flows in a theoretical manner, results that were compared with the experimental results to estimate the margin of error of the experiment, which was mainly due to human error at the time to connect the four temperature sensors for simultaneous measurement every 15 seconds.

The results obtained in the simulated thermal and geometric parameters, besides the instructions given in the guide and the analytical results, it was possible to validate the pertinence of the study method to learn doing raised in this work, obtaining as a result that the theoretical-practical guide development Can be used in teaching an undergraduate course in heat transfer.

Finally, the theoretical-practical guide to work with the experimental assembly allows to use the knowledge previously acquired by students, to relate to the fundamental concepts of heat transfer by external forced convection and to show its relevance in the industrial environment, since the Guide presents the whole theoretical part of the concepts, explains the objectives of the experiments to be carried out in a clear way and gives the guidelines that the student should follow when using the equipment to record the data and analyze the results.

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