DOCUMENT RESUME

ED 452 037		SE 064 553
AUTHOR	Neto, Alberto Hernandez; Tribess, Arlindo; Fiorelli, Flavio Augusto Sanzogo	
TITLE	The Laboratory as a Tool for Learning Thermodynamics, Heat Transfer, and Thermal Systems.	
PUB DATE	1998-08-00	
NOTE	7p.; Paper presented at the International Conference on Engineering Education (18th, Rio de Janeiro, Brazil, August 17-20, 1998).	
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)	
EDRS PRICE	MF01/PC01 Plus Postage.	
DESCRIPTORS	*Chemistry; Foreign Countries; *Heat; Higher Education; *Laboratory Experiments; Science Activities; Science Instruction; Secondary Education; Teaching Methods; *Thermodynamics	
IDENTIFIERS	*Brazil (Sao Paulo)	

ABSTRACT

The consolidation of the theoretical concepts as well as the use and learning of experimental techniques that are compatible with the technological evolution has been the main goals in Thermodynamics and Heat Transfer and Thermal Systems Laboratories at Escola Politecnica of University of Sao Paulo. The infra-structure and experimental benches in the laboratories are presented. Besides, the guidelines which drive the conception of the laboratories for making the engineers conscious of the deep relation between the development of engineering and experimental work is focused. (Contains 12 references.) (Author/YDS)

The Laboratory as a Tool for Learning Thermodynamics, Heat Transfer, and Thermal Systems

Alberto Hernandez Neto, Arlindo Tribess & Flávio Augusto Sanzogo Fiorelli
Escola Politécnica da University de São Paulo - Depto de Engenharia Mecânica
Av Prof. Mello Moraes, 2231
05508-900 - São Paulo (SP) - Brazil
Phone: (+55 11) 818-5510 - Fax: (+55 11) 813-1886
e-mails: ahneto@usp.br ; atribess@usp.br ; fiorelli@usp.br

Abstract *- The consolidation of the theoretical concepts as well use and learning of experimental techniques that are compatible with the technological evolution has been the main goals in Thermodynamics & Heat Transfer and Thermal Systems Laboratories at Escola Politécnica of University of São Paulo. The infra-structure and experimental benches in the laboratories are presented. Besides, the guidelines which drive the conception of the laboratories for making the engineers conscious of the deep relation between the development of Engineering and Experimental Work is focused.*

INTRODUCTION

Experiments have been proved to be essential for the scientifical and technological development of the mankind. The basis of Nature Laws is experimental evidence. Validation of theories and numerical simulation results as well as development and optimization of machine design are examples of the support given by Experimental Work to Engineering.

Another important contribution from experiments is to ease learning processes of theoretical concepts and to present to engineering students experimental techniques currently used in the industry. Besides that, team work, scientific curiosity, critic view and search for information in a continuous process of learning has been reinforced in order to prepare the future engineers for their new positions in global economy where they will face constant challenges with increasing complexity.

The curriculum structure of the Mechanical Engineering Department at Escola Politécnica of the University of São Paulo tries to respond to the technological evolution by including concepts of electronics and computers as well as automation techniques in order to prepare students for their professional challenges (Yamane et al. [12]).

Based on these guidelines, the Thermodynamics & Heat Transfer and Thermal Systems Laboratories were developed to teach fundamental and applied concepts through experimental analysis. These laboratories has been rebuilt and the detailed project can be found in Hernandez et al. [5,6,7]. Some modifications of the laboratories will be presented in this paper, such as changes in class structure and implementation of computers and softwares to help the students along this course.

TEACHING AT THE LABORATORY

According to Valenti [11], during the development of a Engineering undergraduate laboratory course, the following aspects should be included:

- learning of skills to develop experimental work;
- theoretical concepts should be introduced through experiments;
- enhancement on the analysis of experimental results and on the prediction of results through theory;
- use of up-to-date equipments and technologies;
- team work;
- use of computer networks;
- development of skills on written and verbal communication;
- search for information in order to support conclusions and experimental results.

So, when one considers the development of a laboratory course, the main goal is to give to engineers a solid theoretical background with full understanding of the basic experimental procedures in order to provide the student important tools to deal with the constant technological changes and demands from society. This also gives to engineers a high adaptability for using new technologies in order to find solutions for daily technical problems. A second goal is to reinforce to the engineering student the deep relation between engineering development and experimental work. Besides these goals, the formulation of appropriate hypothesis to model a certain phenomenon and its validation through experimental analysis is emphasized.

Nowadays, due to constant changes in the industries (interdisciplinary project involving team work, higher demands on quality as well efficiency on projects execution, etc.), the engineer has to be also prepared to work as part of a team, manage his own schedule to be sure to deliver his projects on time and write reports in a precise and clear way.

LABORATORY INFRA-STRUCTURE

The idea behind the development of the experimental benches was to construct simple equipments that are easy to handle and to identify their components. In the next topics the two laboratories are presented separately because each one has its own specific experiments and organization.

THERMAL SYSTEMS LABORATORY

In this first laboratory, the focus is the study of aspects related to overall performance of certain equipments and its main performance curves. There are five experiments and a small description of them follows.

- Compressor bench : an automated and fully instrumented compressor test is used to obtain the volumetric flow rate against inlet pressure curve, according to the PTC-9 standard from ASME [3]. By using a computer and data acquisition system (Moreira & Tribess [9]), several parameters (pressure, power consumption, etc.) can be measured in real time. It is also possible to obtain the compressor *p-v* diagram (Rocha Jr. [10]) and visualize, through this diagram, the air compression and expansion processes.
- Fan test : this bench was built based on AMCA 210-74 Standard [2]. By using strain gages and the same data acquisition system of the compressor bench, it is possible to measure the effective power given by the electrical motor to the fan. Therefore, by measuring the volumetric flow rate, it is possible to build several curves to analyze the performance of the fan (see Fig. 01).
  Refrigeration cycle : this is a typical refrigeration system used in household refrigeration. The evaporator and condenser tubes are made of glass in order to allow visualization of two-phase flow on heat exchangers. The cycle has four types of expansion device: manual and thermostatic expansion valve, capillary tube and low pressure floating valve. Several thermocouple are placed along the cycle, so it is possible to compare the actual cycle with theoretical one. Using a flow meter and a wattmeter, the mass flow and power consumption can be determined and therefore, all heat fluxes and COP are calculated.
- Internal Combustion Engines : Based on the NBR 5484 [1], a hydraulic dynamometer is used to evaluate the engine main performance curves: power, momentum and fuel consumption versus engine rotation.
- Steam cycle : this is an open steam cycle that uses a electrical boiler, a piston engine and a water condenser. By measuring several parameters, this cycle is compared to the Carnot and Rankine cycles. By evaluating the state of steam in each point of the cycle, steam and cold water flow rates, it is possible to evaluate engine power generation and actual cycle efficiency (see Fig. 02).

For the Thermal Engines Laboratory as well for the Thermodynamic and Heat Transfer Laboratory, brochures are used as textbook where the students can find theoretical aspects and how to measure the main parameters of each experiment. Tables are included to help the students to know which parameters should be measure and how to calculate the others.

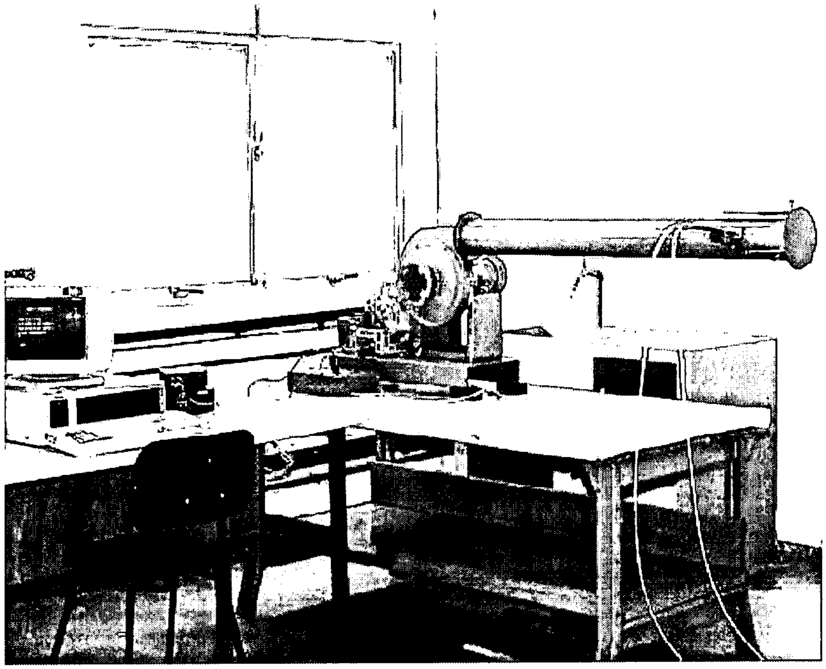

Figure 01. Fan test

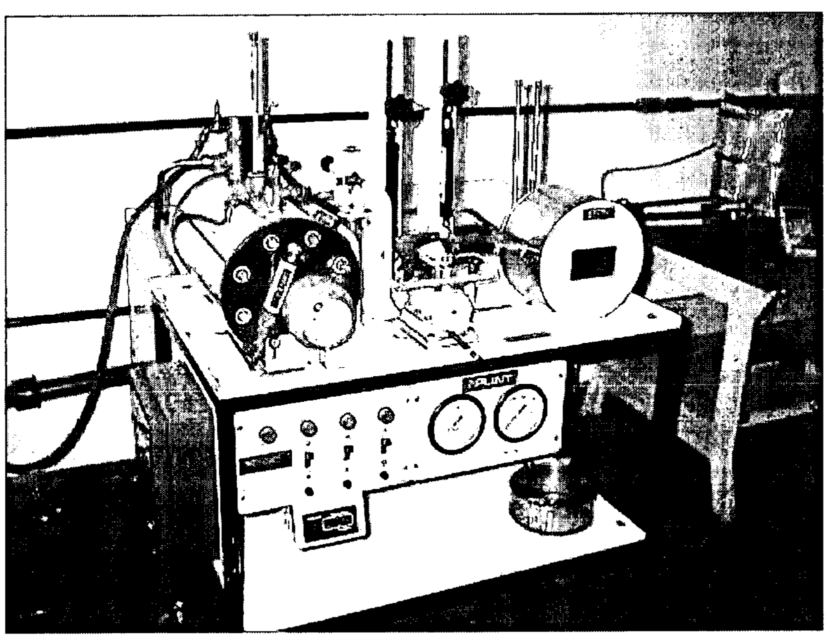

Figure 02. Steam cycle bench

THERMODYNAMIC AND HEAT TRANSFER LABORATORY

The main focus in this laboratory is the study of phenomenological aspects of thermodynamic cycles and mechanisms of heat, mass and momentum transfer. Like the Thermal Engines Laboratory, this one has five benches briefly explained as follows:

- Convection bench : the idea behind this experiment is to analyze and experimentally determine the convection heat transfer coefficient (h_c) and compare it with some correlations in open literature. Two methods are used for the evaluation of convection heat transfer coefficient: transient and steady-state method. Several geometries are tested (spheres, cylinders and plates) as well as different fluids (air and water), giving to the students the chance to compare the effect of different geometries and fluids in heat transfer processes (see Fig. 03).
- Heat exchanger : the performance of a concentric tube heat exchanger is studied. The direction (counter and co-current), the fluid (air or water) and the tube (smooth or finned) can be varied for a more complete analysis of the heat exchanger behavior.
- Saturation process : due to the extensive use of equipments such as cooling towers, evaporative condensers, etc. a small saturation process was built where the concepts of psicrometry and combined heat and mass transfer processes can be studied.
- Minto wheel : developed by Wallace Minto [8] to use small temperature differences reservoirs to produce work, this bench can also help to study and discuss the use of renewable energy sources and how unconventional thermodynamic cycle works.
- Radiation and natural convection : Inside a pressure vessel, there is an electrically heated horizontal cylinder surrounded by air, initially at atmospheric pressure. By decreasing the vessel pressure through a vacuum pump, the influence of natural convection decreases while the radiation influence increases. By monitoring the vessel pressure, cylinder and vessel temperatures and heater electric power consumption, it is possible to evaluate the emissivity of the cylinder and how much each mechanism (radiation and natural convection) participates on the overall heat transfer between the vessel, the cylinder and the air in the experiment (see Fig. 04).

CLASS ORGANIZATION

The classes are organized with an average of 25 students each divided in groups of 4 to 5 persons. In a four-hour class, under the supervision of the teacher, groups take and analyze the data for a specific experiment. Then, a report is written and presented by the end of the class. This report should include the theoretical basis (hypothesis, equations, etc.), the calculations made and the final conclusions. All those items are checked by the teacher while grading the report and also if it was written in a clear and using a proper structure for its presentation. The report is afterwards graded and a feedback is given to the students in the next class. In this feedback, the teacher discuss with each group the good and bad points of the report, showing ways of how it should be improved. These comments are made in the beginning of the class, so the students can use the discussions previously made to improve the next report. The comments range from theoretical misconceptions to poor report organization.

Initially, for both laboratories, a rotating scheme was adopted. By rotating, we mean that each group makes a different experiment each class. This procedure is very adequate to the Thermal Systems Laboratory, mainly because the students who attend this laboratory are in their last year, when they already have enough theoretical basis to follow the experiments. Regarding to Thermodynamics & Heat Transfer Laboratory, this procedure did not work properly because the theoretical basis for it was given in the same term. Therefore, it was necessary that the experiments should be done in a certain order and all the groups should do the same experiment on each class. This helps the students to reinforce the theory about the experiment and fully discussed it on the theory class before coming to the laboratory.

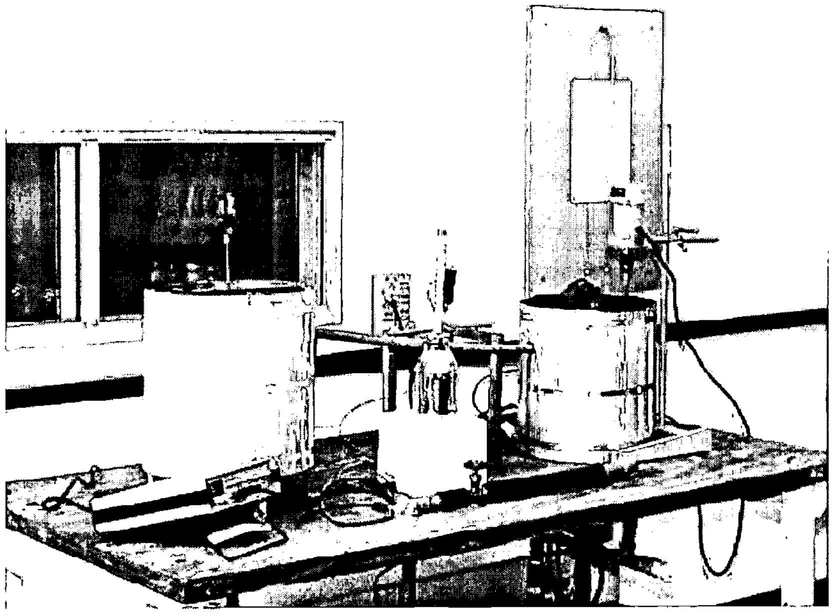

Figure 03. Convection bench

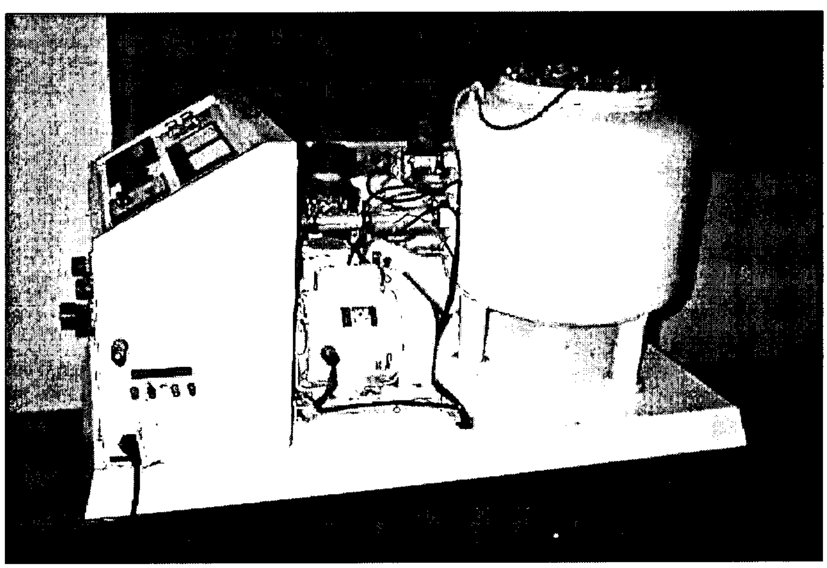

Figure 04. Radiation and Natural Convection bench

A computer network was installed in both laboratories with five computers and a server. This provides to the students to interact with this new environment during the data analysis and report elaboration steps. Besides an word editor and a spread sheet programs, another software called EES - Engineering Equation Solver [4] is used. This last software includes Newton-Raphson routines and also thermodynamics and transport properties functions for several fluids.

CONCLUSIONS

The experiments developed so far give a fair view of the basic theories on Thermal Systems, Heat Transfer and Thermodynamics. By using automated benches with easy use and identification of the components of the data acquisition system gives a more dynamic environment and makes the laboratories more interesting to the students. It also improves the quality of the acquired data, offering the students better conditions to develop their studies.

The different ways of organizing the laboratories showed that the rotating scheme is more suitable for the Thermal Systems Laboratory because the students who attend this course are in the last year when the theoretical basis is more solid. For the Thermodynamics & Heat Transfer Laboratory, each experiment is done by all the groups in the same day, giving the student a period to acquire the theoretical concepts in theory classes . These concepts are reinforced by the teacher in the laboratory.

The use of a computer network helps to introduce a more dynamic environment to the laboratories and also provides the students a chance to use it as tool for their work, a reality more and more present in the industries nowadays.

Finally, there are a variety of nontechnical skills that are critical for accomplishing a successful carrier in engineering. Among them, one can include communication, management and interpersonal skills. There is a trend nowadays showing that those skills have stronger influence on keeping an engineer than the technical ones. We believe that laboratory courses are an excellent chance to improve those skills therefore such courses should more and more be supported by the Universities. The students learn by doing but, for more effective results, it should be done with proper guidance and providing the student with feedback of their faults and improvements.

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