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Integration of the Design-Build-Test concept into undergraduate engineering education

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ABSTRACT: One important educational outcome required of any engineering programme, as per ABET 2000 Criterion 3, is the ability of engineering graduates to design and conduct experiments, as well as the ability to analyse and interpret data and to design a system, component or process to meet desired needs. One of the tools used to achieve such an educational outcome is the Design-Build-Test approach. This article presents the use of this approach in developing an experiment for a junior-level heat transfer laboratory. In this exercise, student teams design, build and test an experimental setup in which a solar collector is used to heat water in a reservoir. This kind of experience serves to enhance the understanding of the transfer of thermal energy by undergraduate mechanical engineering students, while also facilitating their exposure to several important concepts involved in heat transfer.

INTRODUCTION

ABET 2000 Criterion 3 requires that for an engineering programme to be accredited, it must demonstrate that appropriate educational programme outcomes are met. In 2000, ABET changed from a *bean counting* approach to an outcome oriented approach - EC2000. Engineering programmes must now demonstrate that their graduates have 11 specific outcomes identified as (a) to (k). According to these criteria, all undergraduate engineering programmes need to provide for design of experiment experience. This fact is stated in Outcome b): *an ability to design and conduct experiments, as well as to analyze and interpret data* [1]. To meet the requirements of the ABET accreditation criteria, namely educational Outcome (b), the mechanical engineering academic staff at Indiana University-Purdue University Fort Wayne have integrated design of experiment throughout the laboratory based courses in the undergraduate mechanical engineering curriculum (Measurement and Instrumentation laboratory, Mechanics and Materials laboratory, Fluid Mechanics laboratory, and Heat transfer laboratory). The faculty believes that this approach would enhance and add another dimension to the teaching/learning experience in a laboratory course.

The Design-Build-Test (DBT) concept has been used in undergraduate engineering laboratories [2][3]. In 2004, Abu-Mulaweh published a study describing the integration of their first DBT experiment in an undergraduate heat transfer laboratory [4]. In that experiment, student teams design, build and test a fin attachment in order to increase the heat loss from a surface. The DBT concept has also been utilised in capstone senior design projects, in which students design, develop, build and test [5]. Traditional undergraduate heat transfer laboratories in mechanical engineering expose students to heat transfer concepts presented in lecture classes, but do not provide them with design experiences similar to what they might face as thermal engineers in industrial positions.

Thermo-fluid subjects such as heat transfer, fluid mechanics and thermodynamics are very important subjects and have long been an essential part of mechanical engineering curricula all over the world. Heat transfer, fluid mechanics and thermodynamics principles are encountered in a wide variety of engineering applications where heating and cooling is required. Heat transfer plays an important role in the design of many devices, such as spacecraft, radiators, heating and air conditioning systems, refrigerators, power plants and many other engineering applications.

In this article, the authors present a design project that they have integrated in a junior-level heat transfer laboratory at Indiana University-Purdue University Fort Wayne. In the proposed design project, students are asked to design, build, and test an experimental setup in which a solar collector is used to heat tap water in a reservoir. This kind of activity serves to enhance the understanding of the transfer of thermal energy by undergraduate mechanical engineering students, while also facilitating to expose them to several important concepts involved in heat transfer, fluid mechanics and thermodynamics.

EQUIPMENT AND INSTRUMENTS

The equipment and instruments utilised were as follows:

- SunMaxx flat plate solar collector mounted on a wooden frame at 45 degree angle. The solar collector assembly is mounted on a cart to facilitate experimental setup movement.
- A 12 V DC, 1/12 horsepower Shurflo diaphragm water pump rated at 3 GPM.
- A flow meter that can be used to control the water flow rate in the range of 0.3 – 3.5 GPM.
- A reservoir made of plastic tub with a hose fitting attached.
- Thermocouples and readout.

PROBLEM STATEMENT

Student teams were instructed to design, develop and construct a portable experimental apparatus for an undergraduate heat transfer laboratory that met the following requirements and specifications:

- Utilise an existing flat plate solar collector (shown in Figure 1) to heat a certain amount of tap water (say, for example, 15 kg) contained in a reservoir.
- The experimental setup should have the capability of handling various flow rates.
- The experimental setup should have the necessary instrumentations to allow for the temperature and flow rate measurements needed for heat transfer calculations, such as the amount of heat gained by the water over a period of time.
- Run and test the experimental setup and submit a written report.

Figure 1: Flat plate solar collector mounted on a wooden frame at a 45-degree angle.

DESIGN AND BUILDING PROCESS

To heat up the water in the reservoir using solar energy that is absorbed by the solar collector, the water will have to be pumped from the reservoir into the inlet of the solar collector (at the bottom of the collector), up through the tubes of the collector, out of the collector outlet at the top and back into the reservoir.

The reservoir is simply a plastic tub with a hose fitting. The first task is the selection of a suitable pump. A Shurflo diaphragm pump (12 V DC, 1/12 horsepower, rated at 3 GPM) from MSC Industrial Supply Co., was selected as presented in Figure 2). An on-off switch and inline fuse are mounted next to the flow meter on the solar collector's frame.

Figure 2: Water pump.

A flow meter was attached between the pump and the solar collector (Figure 3) to adjust and measure the flow rate through the system. The flow meter has a built-in control knob with a range of 0.3-3.5 GPM. However, lowering the flow rate below 1.8 GPM put too much pressure on the pump, so a relief valve (Figure 4) was installed between the pump and the flow meter. This relief valve can be opened to let excess liquid bypass the flow meter and run back into the reservoir. With this installed, the flow rate can be lowered to 0.5 GPM.

Figure 3: Flow meter.

Type T thermocouples were installed at the inlet (Figure 5) and outlet of the solar collector. The tip of each thermocouple was placed directly in the flow stream by poking a small hole in the flexible hose and putting the wire through. The hole was sealed using a Magic Match Patch and covered with tape. The pressures in the hoses were low enough that there was no leakage.

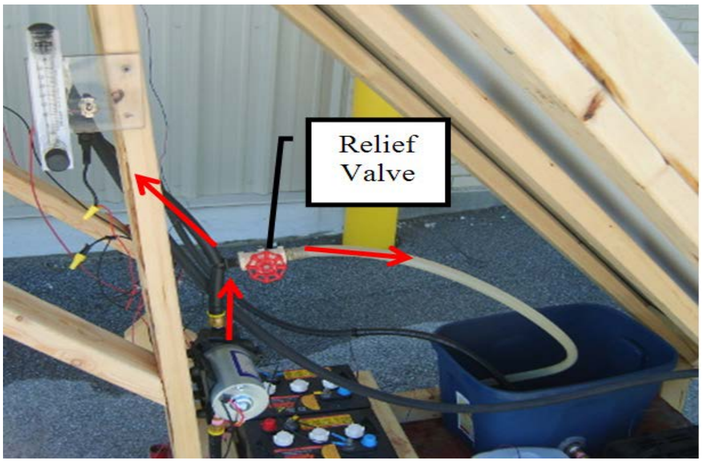

Figure 4: Relief valve.

Figure 5: Thermocouple in the hose (solar collector inlet).

TESTING PROCEDURE

- Fill the reservoir with the desired amount of liquid.
- Ensure that the outlet hose from the top of the collector and the relief valve hose will empty into the reservoir.
- Open the flow meter's control valve most of the way.
- Close the relief valve.
- Connect the thermocouple leads to a read out.
- Switch on the pump. It will take a few seconds for air to be pushed out of the system.
- If needed, open the relief valve and use it to get the flow rate close to the desired value.
- Use the control knob on the flow meter to fine-tune the flow rate.
- Read and record the temperatures of the water at the inlet and outlet of the solar collector along with the time interval.
- To empty the system, turn off the pump and move the collector's outlet hose from the reservoir to a safe area for drainage. Turn the pump on to pump the liquid out of the system. The reservoir can be removed using the dry-lock connector between it and the pump to dump any remaining liquid.

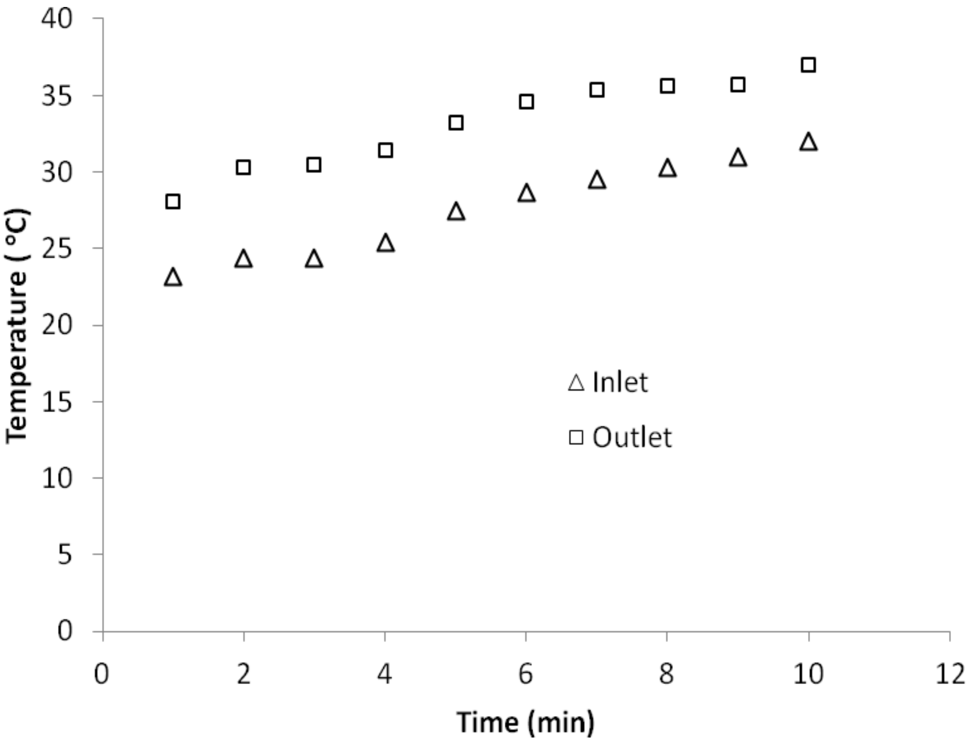

Figure 6: Variation of water temperature at the inlet and outlet of the solar collector with time.

TESTING AND SAMPLE RESULTS

The experimental setup was tested for different flow rates. For each flow rate, the water temperature at the the inlet and outlet of the solar collector was recorded every minute. Figure 6 shows the variation of water temperature with time at the inlet and outlet of the solar collector for a water flow rate of 0.5 GPM.

The amount of water in the reservoir was 15 kg. It can be seen from the figure that the water temperature at both the inlet and outlet of the solar collector increase as time passes, indicating that the water in the reservoir is being heated because of heat transfer through the solar collector. The heat gained by the water in the reservoir, Q, during the period shown in the figure can be calculated from [6]:

$$Q = m\, C_p\, \Delta T = 602\ kJ \tag{1}$$

where m is the mass of the water in the reservoir, C_p is the water specific heat, and $\Delta T = T_{final} - T_{initial}$ (at the inlet of the solar collector).

CONCLUSIONS

A practical example of designing an experiment in the area of thermal sciences (heat transfer) was developed for the undergraduate heat transfer laboratory in the Mechanical Engineering programme at Indiana University-Purdue University Fort Wayne. This article presented the detailed implementation of the Design-Build-Test concept in developing an experiment for a junior-level heat transfer laboratory. In this exercise, student teams design, build and test an experimental setup in which a solar collector is used to heat water in a reservoir. This experiment is a relatively easy-to-implement experiment. This kind of design project can be used as a measure of students' understanding of heat transfer and thermodynamics basic principles. Feedback from the students is very positive.

REFERENCES

1. ABET Engineering Accreditation Criteria, Criterion 3: Program Outcomes and Assessment (2010), http://www.abet.org.
2. Elger, D.F., Beyerlein, S.W. and Budwig, R.S., Using design, build, and test projects to teach engineering. *Proc. 30th ASEE/IEEE Frontiers in Educ. Conf.*, Kansas City, USA (2000).
3. Elger, D.F., Budwig, R.S. and Beyerlein, S.W., Using Design, Build, and Test Projects in a Wind Tunnel to Improve Engineering Education. Award Abstract from NSF Web Pages. NSF Grant DUE-9952308, Project Dates: 1 April 2000 to 28 February 2002 (2002).
4. Abu-Mulaweh, H.I., Integration of the Design-Build-Test concept in undergraduate heat transfer laboratory. *World Transactions on Engng. and Technol. Educ.*, 3, **1**, 151-154 (2004).
5. Shervin, K. and Mavromihales, M., Design fabrication and testing a heat exchanger as a student project. *Proc. ASEE 2001 Annual Conf.*, Albuquerque, USA (2001).
6. Incropera, F.P. and DeWitt, D.P., *Fundamentals of Heat and Mass Transfer*. John Wiley & Sons (2006).