2006-697: ACTIVE-LEARNING BASED LABORATORY FOR INTRODUCTORY THERMODYNAMICS COURSE

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Active-Learning Based Laboratory for Introductory Thermodynamics

Abstract

This paper describes a laboratory component for a sophomore level introductory engineering thermodynamics course. The class is core component of the Engineering Science curriculum at Borough of Manhattan Community College. The introduction of the lab is part of a greater curricular modification to invigorate engineering education at BMCC by integrating real world situations and active-learning based instructions into classroom. Thermodynamics is an abstract subject. Many students lack first hand experience with the subject matter. They resort to memorization rather than gaining analytical understanding of concepts. The Lab component is designed to create an opportunity for students to accumulate experiential learning and gain problem-solving skills.

The lab consists of six modules: Real Time Measurements, Hand Cranked Generator and Calorimeter, Piston/Cylinder Device Gas Heat Engine, Propane Fueled Steam Rankin Cycle, Refrigeration/Air Conditioner Cycle, and Natural Gas Fueled Internal Combustion Engine. The lab component allows students to gain an overall knowledge of instrumentation of thermal systems, and the relationship between theoretical and physical systems. It also promotes teamwork and communication between students, particularly, in data collection, analysis and report preparation. Groups of 3 to 4 students work together on each project and prepare report.

Introduction

It is well known that students learn and retain more as they become more engaged with instructional materials. Reisman and Carr[1] concluded that students learn 20% of the material taught by hearing, 40% by seeing and hearing, and 75% by seeing, hearing, and doing. Furthermore, people learn concepts and skills better when sharing in teams than working in isolation. Thus, most of newer educational approaches emphasize active learning by students, in which instructors move from being lecturers to coaches. The laboratory is an ideal setting to introduce such hands-on activities where students can learn by experiencing. The physical devices and simulations used in the laboratory provide active experiences for the students, allowing them to make parametric adjustments, observe the effects in related thermodynamics variables, and reflect upon key concepts of the course [2].

Class Objectives

The Engineering science program at Borough of Manhattan Community College offers ESC 211, a sophomore year introductory thermodynamics course. The class learning objectives are parallel to those of ABET2000 A-K criteria. The course emphasizes fundamentals and their applications. It mainly requires students to able to:

- State the First Law and to define heat, work, thermal efficiency and the difference between various forms of energy.
- Identify and describe energy exchange processes (in terms of various forms of energy, heat and work)
- Explain how various heat engines work (e.g. a refrigerator, an IC engine, a jet engine)
- Apply the steady-flow energy equation or the First Law of Thermodynamics to a system of thermodynamic components (heaters, coolers, pumps, turbines, pistons, etc.) to estimate required balances of heat, work and energy flow.
- Explain the concepts of path dependence/independence and reversibility/irreversibility of various thermodynamic processes, to represent these in terms of changes in thermodynamic state, and to cite examples of how these would impact the performance of aerospace power and propulsion systems.
- Apply ideal cycle analysis to simple heat engine cycles to estimate thermal efficiency and work as a function of pressures and temperatures at various points in the cycle.

Additionally, it is also desired students gain an overall knowledge of instrumentation and measurement techniques of thermal systems, and become aware of differences between theoretical models and physical systems.

Laboratory Components

To meet the above requirements an active-learning based laboratory component was developed to complement the class. It was incorporated in ESC211 for the first time in fall, 2005. The thrust of it is a set of six workshops, which include:

- Real Time Measurement
- Hand-Cranked Generator
- Gas Heat engine
- Steam Engine Cycle
- Refrigeration Cycle
- Internal Combustion engine

Workshops Modules

In the first workshop students are introduced to real-time data measurements. The instruments used are temperature sensors, pressure gauges and low friction piston/cylinder device. The workshop objective is to allow students to familiarize themselves with the computerized data acquisition system. They also learn about gauge and absolute pressure using a low friction piston/cylinder device.

In the second workshop, transfer of mechanical energy to heat is explored; see Fig 1. The set-up is a classic experiment where electrical energy (provided by a hand-cranked generator) is converted to thermal energy in a container of water; see Fig 2. The equipment includes a 10-Ohm heating resistor inside a double-walled calorimeter cup. Water temperature, voltage and current output of the generator are recorded in real time as the generator is cranked. The electric power is obtained from the instantaneous voltage and current. The power output is then compared to the resulting increase in thermal energy of the water and the inner calorimeter cup. The module illustrates how mechanical energy is converted to electrical work and in turn to thermal energy of a system and its resulting temperature increase.

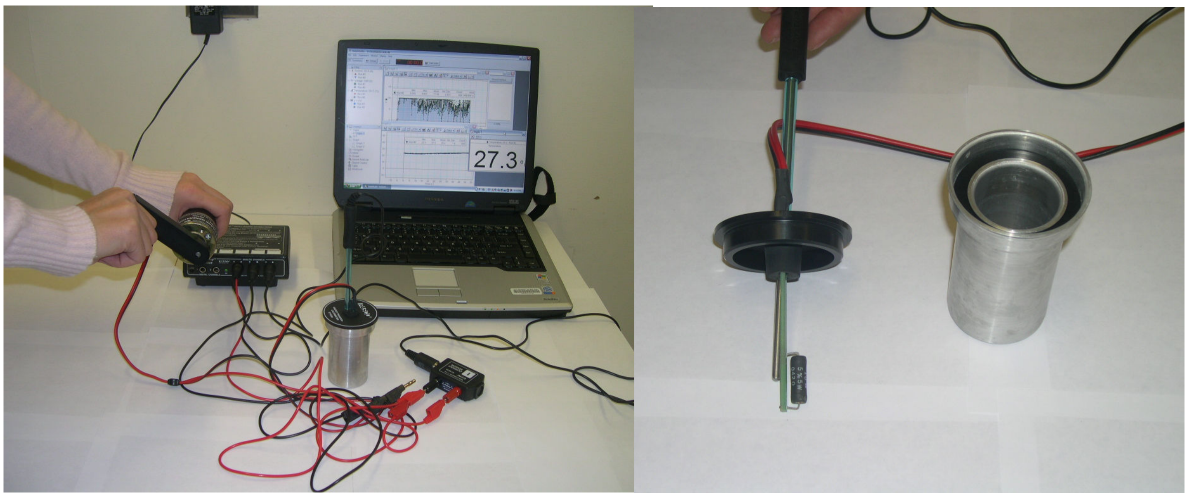


Fig 1. Hand-cranked generator module, Resistor and calorimeter

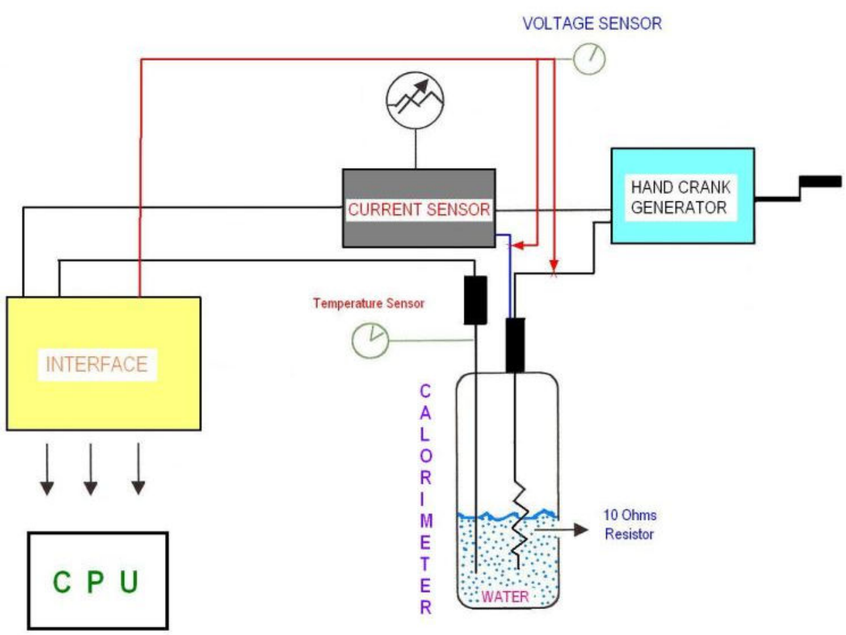


Fig 2. Schematic diagram of Hand-Cranked Module

The heat engine module investigates the gas laws using a low friction piston/cylinder device; see Fig 3. It constitutes a simple thermal engine that is taken through a four-stage expansion and compression cycle; see Fig 4. The engine does useful mechanical work by lifting small masses to higher elevation. Students verify useful mechanical work done in lifting a mass, *m,* through a vertical distance, *y*, is equal to the net thermodynamic work done during a cycle as determined by finding the enclosed area on *P*-*V* diagram. The module allows students to gain understanding of how useful mechanical work can be obtained from a cyclic engine, and investigate cycle performance as a function of system variables.

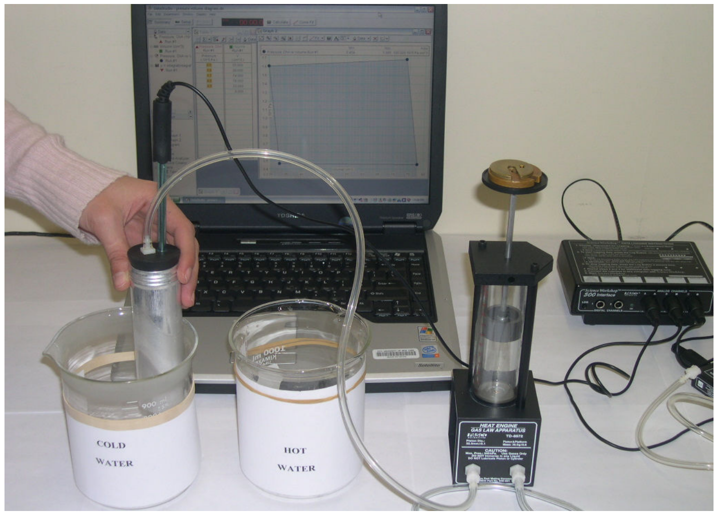
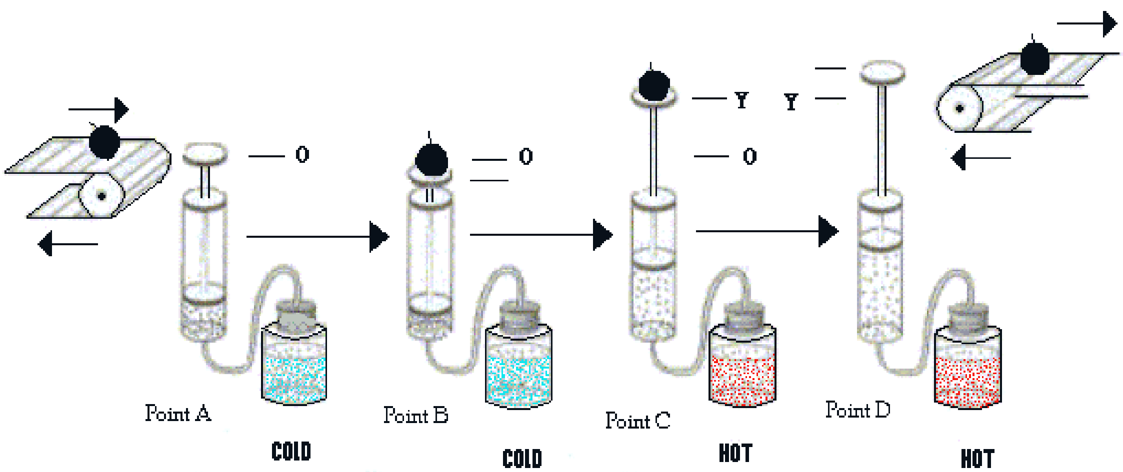


Fig 3. Gas heat engine module



Point A: The calorimeter is placed in cold water and no weight applied on the platform.

Point B: The calorimeter is in cold water and 100-200 gm mass is applied on the platform. Pressure increases and the platform height decreases (below zero mark.)

Point C: The calorimeter is plced in hot water and the mass is still on the platform. Pressure remains the same but platform height increases (0 to Y), temperature increases.

Point D: The calorimeter is in hot water and the applied mass is taken off the platform. Temperature remains the same pressure decreases, platform height increases (above Y.)

The cycle is completed by placing the calorimeter back in cold water; the platform height will go back to initial position, (zero mark.)

Fig 4. Schematic diagram of gas heat engine experiment

Fig 5. Propane fueled steam engine cycle

The objective of the steam engine module, shown in Fig 5 along with its schematic in Fig 6, is to offer students hands-on experience with the operation of a propane fueled functional steam turbine power plant. A comparison of real world operating characteristics to that of the ideal Rankin power cycle is made. The apparatus is scaled for educational use and utilizes components and systems similar to full-scale industrial facilities. Students are able to operate and analyze this system in detail, allowing them to determine the efficiency of the facility and suggest possible modifications for further improvement. Nine sensors are installed at key locations around the cycle. Using the data obtained from these sensors, many analysis options are available. For example, the entire system first law efficiency can be analyzed. Adjusting the throttle valve to change steam flow rate admitted to the turbine provides multiple steady state conditions. By incorporation of these strategically placed instruments, not only can the cycle be analyzed but also individual components. The boiling temperature / pressure of water can be verified in the boiler to study water saturation conditions, and the thermodynamic efficiency of the turbine can be monitored and compared to computer simulations.

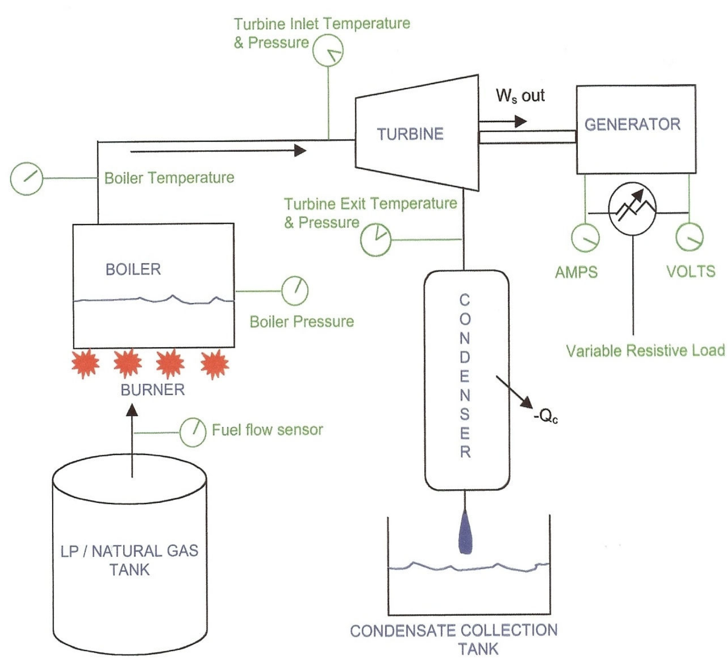


Fig 6. Schematic diagram of steam engine cycle

Due to large numbers of data collected, analysis is accomplished using MS Excel and XL thermal fluid. XL thermal fluid is a MS Excel function for calculation of thermodynamic properties of common engineering fluids. The thermodynamic properties calculated include temperature, pressure, specific volume, internal energy, enthalpy, entropy, and quality.

The thermodynamic refrigeration cycle is investigated using an R-22 based commercial window air conditioner unit (shown in Fig 7). It is outfitted with two pressure sensors, five thermocouples and a flow meter. The sensors measure pressures on the high and low sides of the cycle (compressor inlet and outlet), the refrigerant temperatures between the four major components and volumetric flow rate of refrigerant at outlet of compressor (see Fig 8). An additional thermocouple is employed to measure ambient temperature and to serve as a cold junction for the other thermocouples. A National Instrument high-speed 12-bit analog to digital data acquisition card interfaces to a PC computer to acquire data from the sensors. A Matlab program was developed to process and filter the acquired digital date. It is designed to let the user vary the duration and sampling rate of data collection. Additionally, a power-meter is employed to measure the electric power delivered to compressor and fans motors.

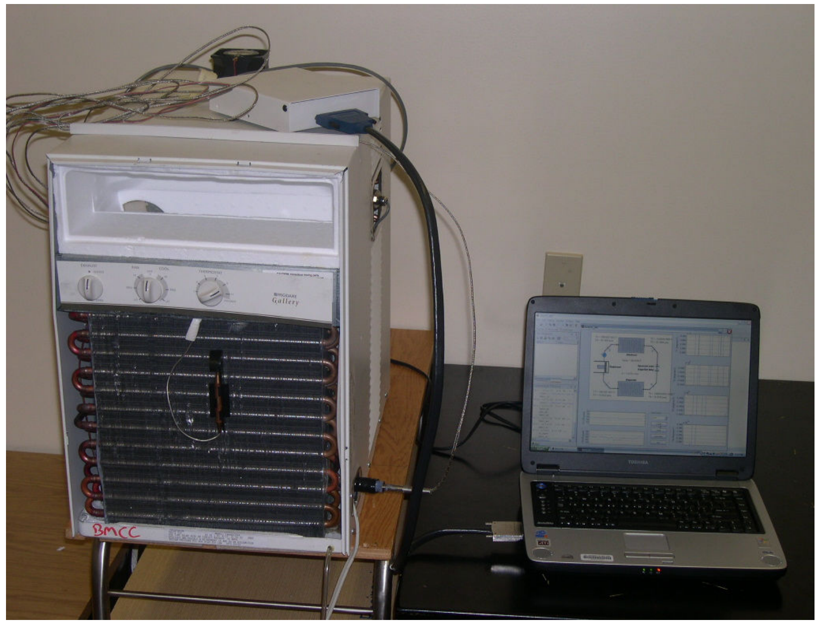


Fig 7. Air-conditioner/refrigeration cycle module

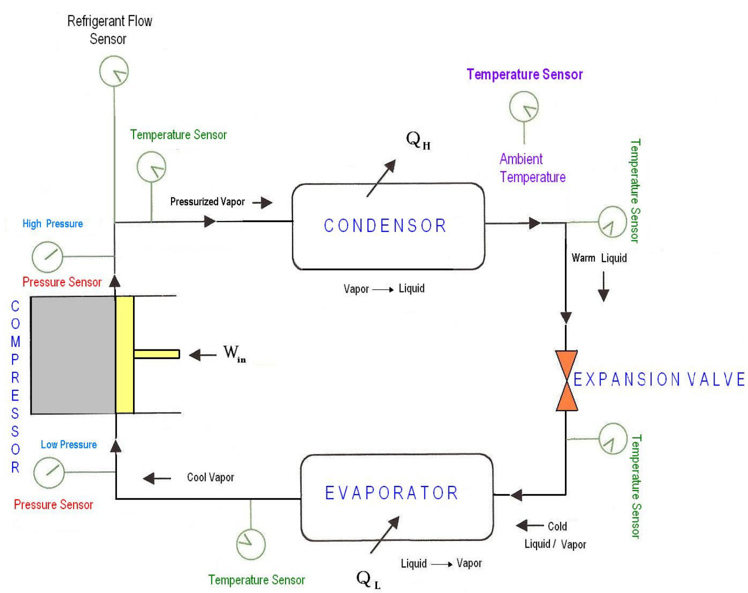


Fig 8. Schematic diagram of air conditioner cycle

A single cylinder four-stroke 12-HP Briggs &Stratton engine coupled to a 5500-kw Homelite generator constitute the internal combustion engine module. The engine's carburetor is retrofitted for natural gas. The generator is connected to a bank of light bulbs and electric heaters. Switching on and off different numbers of light bulbs and electric heaters load the generator, which in turn loads the engine. The electric power delivered is measured using a hand-held power-meter. A fuel flow meter records the fuel consumption. A magnetic sensor in vicinity of the flywheel enables engine speed to be determined by measuring the frequency with which spark plug fires. The purpose of this laboratory assignment is to provide participants an opportunity to study the different terms involved in the 1st law of thermodynamics and obtain system-wide efficiency.

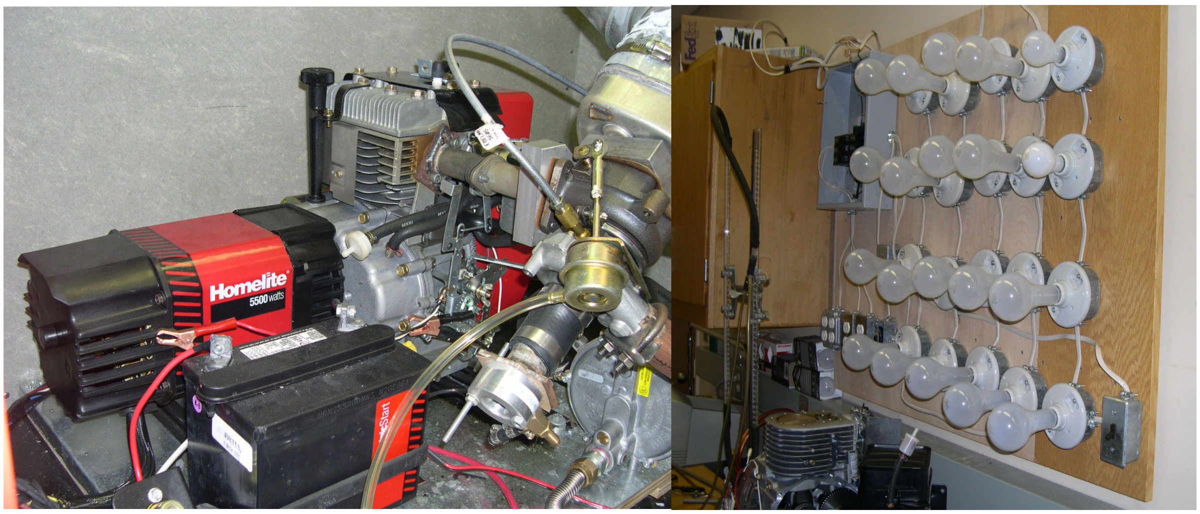


Fig 9. Internal combustion engine and light bulb bank

Remarks

Thermodynamics is a discipline that deals with energy utilization as constrained by Natural laws that are expressed in fundamental properties, and with its applications via mathematical models. Its study is basic to science and engineering and is a core subject in many engineering curricula. The above-discussed laboratory is an attempt to give students hands-on experience with fundamental properties and concepts.

The Thermodynamics laboratory has been offered for the first time in fall, 2005. The introduction of the lab took up class time and consequently, the designated syllabus could not be entirely covered. This situation was alleviated by a team-based approach to the lab. Teams (a group of 3-4 students) perform the necessary measurements together and prepare a group report. Team members helped one another in understanding the materials and learning the concepts. The team-based approach promoted peer instruction, which in turn helped to reduce the need to lecture and compensated for time used by the lab.

Acknowledgment

Funding for this project was provided by an NSF-CCLI grant DUE-0126877. The author gratefully acknowledges assistance of Dr. Dennis Robbins and Ms. Gaye Ozgur in setting up these modules.

References

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2. Bailey, M. and Chambers, J., "Using the Experiential Learning Model to Transform an Engineering Thermodynamics Course", 34th ASEE/IEEE Frontiers in Education Conference, October 20 – 23, 2004, Savannah, GA