

Modernization and Integration of New Technologies in a Thermodynamics Lab

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.Abstract:

Significant advances in digital data acquisition and data reduction in industry, enhancement and improvement in energy system simulation software such as Engineering Equation Solver (EES), recent interest in fuel cells and concern for protection of the global environment are among the reasons for the recent major overhaul of the Thermodynamics Laboratory at Wentworth Institute of Technology (WIT). Old equipment and experiments have been replaced with new apparatus that are equipped with automated data acquisition systems.

State-of-the-art computerized data acquisition systems enhance the quality of education by removing the need for tedious, repetitive data recording, thus keeping the students' attention focused on fundamental concepts. Furthermore, an industry standard graphical software package LabView, from National Instruments is used to provide an increased students' exposure to industry data acquisition practices. This software provides tools for instrument control, data acquisition, and data analysis. The data collection is handled by software, so that the students can focus on the underlying principles during laboratory time. The data analysis procedures are then discussed and the students are able to process the collected data using Microsoft Office Software (excel and word) in order to prepare detailed laboratory reports in both group and individual formats.

Small-scale proton exchange membrane (PEM) fuel cells have also been incorporated into the thermodynamics laboratory curriculum in order to better prepare our students in this new field of power generation and hydrogen-based technology. Additional exposure to environmental responsibility is provided by introducing photovoltaic solar cells used in the electrolysis of water for hydrogen production as a fuel for the fuel cell experiments.

The following paper is being submitted to document, detail and describe some of the laboratory enhancements.

Introduction:

Modern mechanical systems in manufacturing, power plants, and consumer products are making an increased use of digital controls, and sensors to monitor the controlled variables. This has increased the need for mechanical engineering students to have a thorough knowledge of electronic sensors and data acquisition. Furthermore, state-of-the-art computerized data acquisition systems should enhance the quality of education by removing the need for tedious, repetitive calculations, thus keeping the student's attention focused on fundamental concepts¹. Using an industry standard graphical software package such as LabVIEW from National Instruments², may increase the students' exposure to industry data acquisition practices and demonstrate advantages of object oriented, graphical software tools. The software provides tools for instrument control, data acquisition, data logging, and data analysis. The data collection is handled by software, so that the students can focus on the underlying principles during laboratory time. The students are then able to further refine the collected data using Microsoft Office Software (excel and word) to prepare detailed laboratory reports in both group and individual formats.

In the alternative power generation technology area, the recent growing interest worldwide for developing the hydrogen economy have generated considerable research and development of fuel cell systems and in their potential areas of applications³.

However, there are still many technical and economical challenges hindering the commercialization of fuel cells and further development is needed before those niche applications are found. Students who learn about fuel cell systems will be better prepared to contribute to this effort. The fuel cell technology coverage in the thermodynamics textbooks is very limited⁴, therefore a small-scale PEM fuel cell has been incorporated in the laboratory to expand the introductory material from the textbook.

Most of the power-generating systems that are covered in detail in the current thermodynamics textbooks used by mechanical engineering students^{5,6} are geared toward power generation, using the heat engine that converts heat energy to mechanical energy. The greater the source temperature is, for a given sink temperature, the greater the ideal efficiency of this conversion becomes (Carnot efficiency). Fuel cell is an electrochemical device that converts the chemical energy of a reaction into electricity and heat, without the intermediate step of combustion. Therefore, fuel cell theoretical efficiency can exceed the Carnot limit even when operating at relatively low temperature, i.e. PEM fuel cell. It is rewarding to see the increased students' interest as this concept is demonstrated through power cycle comparisons in the class and laboratory exercises.

Background:

In the thermodynamics laboratory at Wentworth Institute of Technology (WIT), Electromechanical Engineering and Mechanical Engineering Technology students are introduced to basic thermo-fluid properties, energy balance for heat exchangers and other components of the thermodynamics systems, and the first law efficiency for basic power-generating cycles. The traditional hands-on and laboratory oriented experiences have been the corner stone of a WIT education. In fact a minimum of 40 percent of a program's technical contact hours must be

associated with a combination of laboratory and project work over the entire baccalaureate experience.

During the 1960s the students were taught to operate an industrial power plant, using a three-story Erie City boiler located in the power plant of the main campus. The steam produced was supplied to a GE turbine located in a thermodynamics laboratory adjacent to the power plant with an accompanying condenser for the exhaust steam. Vacuum pumps operated the condenser at a pressure of 20 inches of Hg. The boiler produced saturated steam at approximately 200 psi, the steam rate was in the area of 1700 lb/hr. Analog gages were placed at strategic locations in order to perform various tests particularly the A.S.M.E. test code for Power Plant Systems.

Due to safety issues, high-pressure steam systems were eliminated from all of the labs in the 1970s. The real power plant system was substituted by a tabletop version. This system consisted of a boiler with superheat ability and a simple turbine-generator (Figure 1). It was an open system, meaning that the steam from the turbine was exhausted to the atmosphere and not condensed. The energy generated was supplied to resistors in order to consume the energy developed and measure the output conditions. The fuel used was standard propane and this was supplied to a burner, which heated the boiler. Pressures and temperatures were measured at various locations in the system to provide the students with the information to perform an energy balance. Calculations, results and characteristic graphs were performed by hand.

As a part of the preparation for an upcoming TAC-ABET visit and in response to their suggested comments from the previous visit, most of the systems newly purchased are now equipped with modern instrumentation and capable of high-level data acquisition. The following will describe some of the modernization and enhancements in the Thermodynamics laboratory at WIT.

Data Acquisition Goals For Thermodynamics Laboratory:

One of the goals of the recent upgrade of the thermodynamic laboratory at WIT is to incorporate new technologies and replace old equipment and experiments with new apparatus that are equipped with automated data acquisition systems using National Instruments hardware and software. The purpose of the new experiments is not only to introduce different type of power cycles but also to familiarize students with modern computer-based instrumentation and data acquisition equipment and techniques. However, the course is not intended to learn the details of LabVIEW programming. Instead, students may use standard data logging applications and custom-written Virtual Instruments (VIs) for each lab module to aid efficient progress through experiments, and to provide real-time graphic displays of data and cycle performance.

The LabVIEW software package was chosen because it is one of the primary choices in designing control and analysis solutions in the area of engineering technology and education. It is becoming so popular in engineering education that the International Journal of Engineering Education has recently devoted a whole issue on the applications of National Instruments LabVIEW in engineering education⁷.

Several experiments use National Instruments data acquisition hardware and its LabVIEW software, including custom VIs and data logger. These VIs or data logger acquire data during the

experiment and produce real-time graphs of the output, enabling students to observe the relationships between experimental variables as the experiment progresses and stream data to a disk for further analysis. Basically, LabVIEW and DAQ are used as tools to enhance the efficiency of the experiments in the thermodynamic laboratory and allow the faculty the flexibility to discuss subtleties of the experiments without worry of losing valuable data.

The Contrast of New and Old Equipment:

The Rankine cycle is a fundamental of classical thermodynamics. During our traditional laboratory exercise, steam was produced in a boiler and admitted to a turbine that was connected to an electric dynamometer. All data were manually acquired using pressure gauges, thermometers, voltmeters and amp meters. The fuel used was standard propane. The lab efforts of the students were consumed acquiring manual data leaving very limited time for the study of the system and its governing equations. A photograph of the Mega Tech system is provided below in Fig. 1.

A new Rankine cycle demonstrator was purchased from Turbine Technologies⁸ called the Rankine Cycler (see Fig. 2) to replace the Mega Tech system. The Rankine Cycler is a complete and functional micro steam turbine power plant equipped with computerized data acquisition hardware and software from National Instruments. Nine sensors are installed at key locations around the cycle. Each sensor output lead is routed to a centrally located terminal board and then to a computer for digital data acquisition. Using the data obtained from these sensors, many analysis options become available. For example, the entire system first law efficiency can be performed. By adjusting the throttle valve to change the steam flow rate admitted to the turbine, the turbine load can be varied to provide multiple steady state conditions for system and component efficiency analysis.

By the incorporation of these strategically placed instruments, not only can the cycle be analyzed but also individual components. The boiling temperature / pressure relationship of water can be verified in the saturation boiler, and the thermodynamic efficiency of the turbine can be monitored and compared to computer simulations.

Another system that is still located in the existing thermodynamics laboratory is the Rover Gas Turbine, Figure 3. This unit was purchased in the early 1960s from Rover Gas Turbines LTD, Warwickshire, England. The engine is a single stage gas turbine able to produce 60 hp at 46,000 rpm. It is fully instrumented with analog gages and has a water brake dynamometer to measure horsepower output of the turbine. The fuel used can be either jet fuel or kerosene. Students are required to manually record the various pressures, temperatures, flow rates, voltages, amps, and exhaust gas temperature measurements at various loads. The Rover absorbs power in a water brake dynamometer. Although in the past forty years the engine has been very reliable, a major obstacle to overcome is the inability to purchase spare parts.



Fig. 1. Mega Tech steam engine and steam boiler.



Fig. 2. Rankine Cycler micro steam turbine power plant from Turbine Technologies.



Fig. 3. Rover gas turbine.

A new miniature turbine engine called Minilab has been purchased from Turbine Technologies to replace the Rover. The Minilab is shown in Figure 4. The objectives of the new Minilab jet engine^{8,9} are: to familiarize the students with the operation and theoretical analysis of a turbojet engine, to perform a complete energy balance on the jet engine, and to apply the linear momentum equation to determine theoretical and measured engine thrust. Using the Minilab jet engine's automatic data acquisition system, the students operate the engine at 60,000-80,000 rpm and measure various pressures and temperatures as well as fuel flow rate, and engine thrust.

An industrial stainless steel shell and tube heat exchanger is shown in Figure 5. This unit is equipped with 2 rotameters and 4 thermocouples for flow and temperature measurements. The unit provides for an extremely simple energy balance exercise in both parallel and counter flow configurations. The students manually record all data.

Figure 6 shows a plexi-glass HT33 Shell & Tube Heat Exchanger mounted on the HT30X Heat Exchanger Service Unit from Armfield¹⁰ that provides the necessary facilities to support this heat exchanger model. A USB port interface unit provides



Fig. 4. Minilab jet engine from Turbine Technologies

communications between the PC and the sensors attached to the heat exchanger. The Armfield data logger collects and stores all sensor information. The service unit supplies hot and cold water to the heat exchanger and monitors these flow rates and temperatures via flow meters and thermocouples. The service unit connection to the PC also provides real time monitoring of data and performs detailed heat exchanger analysis including energy balance.

Computer Simulation Capability:

In addition to the new power systems hardware, new computers were added to the lab for the purpose of developing the students' awareness and capability of the process/cycle simulation. Labs are alternated between simulation and experimentation in order to reduce the ratio of the students per equipment. The measured test data for both the Rankine Cyclers steam turbine generating system and the Minilab jet engine are compared with analytical results obtained by using the Engineering Equation Solver (EES).



Fig. 5. Stainless still shell and tube heat exchanger.



Fig. 6. Armfield heat exchanger unit.

PEM Fuel Cells:

A miniature solar-hydrogen proton exchange membrane (PEM) fuel cell has also been incorporated into the thermodynamics laboratory curriculum in order to introduce our students to this leading alternative power generating technology and broaden the scope of students' learning. Voltage from a small photovoltaic solar cell module or from a power-supply can be used in the electrolysis of water for hydrogen production as a fuel for the fuel cell experiments.

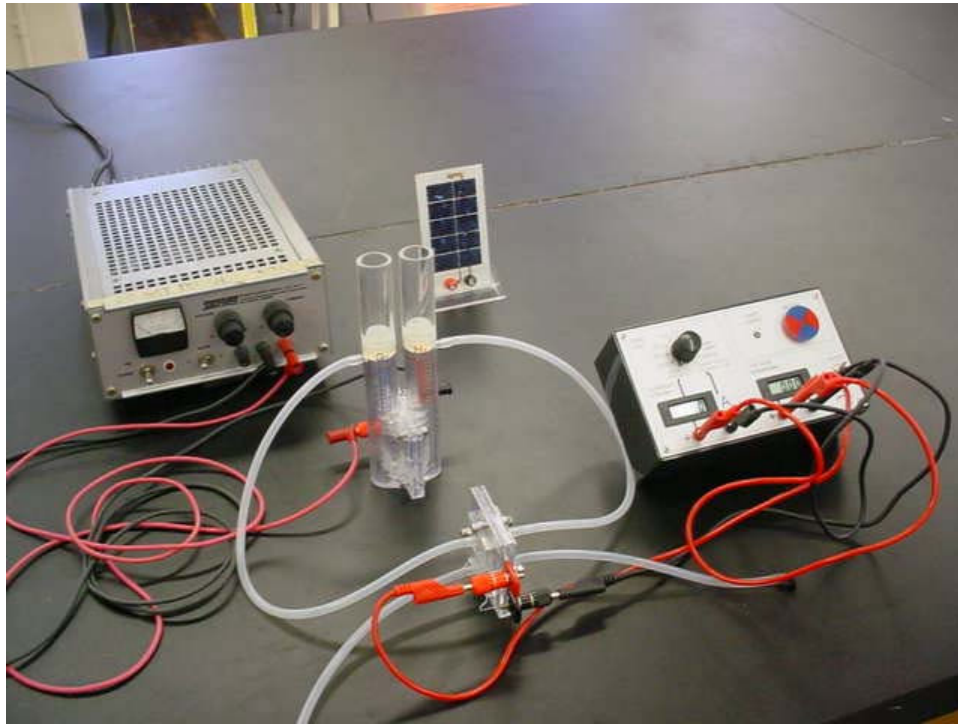


Fig. 7. Hydro-Genius Solar Hydrogen Kit; PEM fuel cell, Electrolyser, Load measurement box, Power-supply, and Photovoltaic solar cell module.

The Hydro-Genius Solar Hydrogen Kit was purchased from “The Fuel Cell Store” and is used in the thermodynamics lab. The solar module converts light into electrical energy. This electrical energy is used in a PEM electrolyser and splits water into hydrogen and oxygen. The low pressure gases are stored in the storage cylinders of the electrolyser. The hydrogen and oxygen are fed into the fuel cell and converted back to water in the process of generating electrical energy. Power-supply can be used in the absence of solar module or if there is not enough illumination. The unit is supplied with a variety of experiments to evaluate both system and component performance.

Experiments such as developing the characteristic curve of a fuel cell can be conducted by measuring current and voltage output of a fuel cell (Fig. 8) with the supplied measurement hardware.

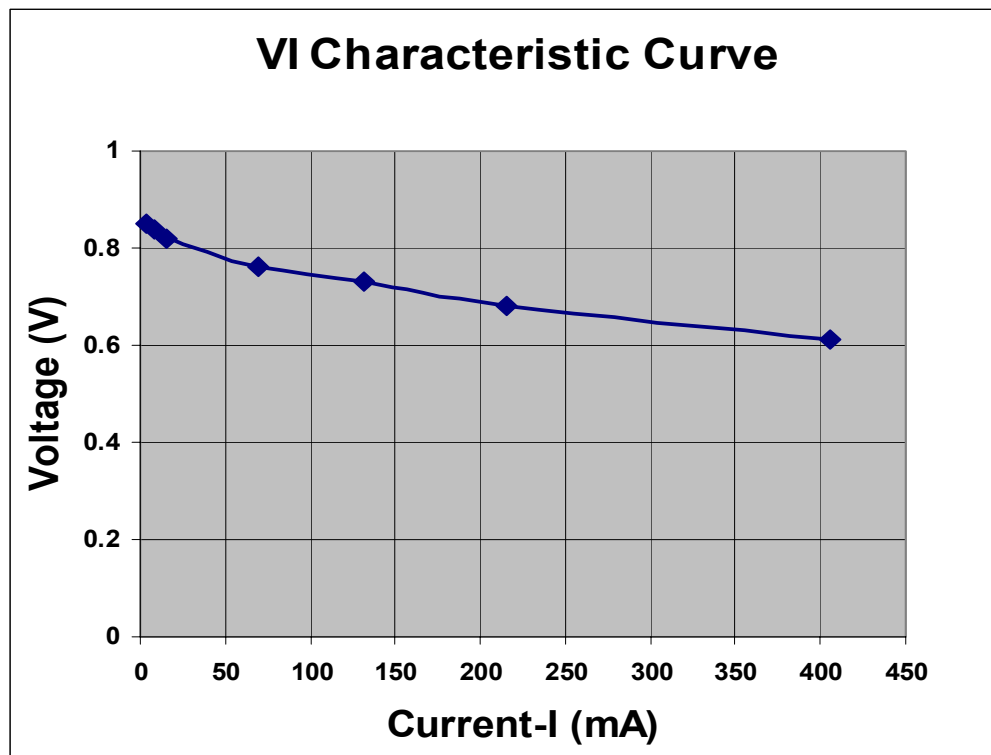


Fig. 8. Characteristic Curve of the PEM fuel cell.

Summary and Recommendation:

In general the renovation of our laboratories has been a rewarding experience from both an educational effectiveness and general intellectual standpoint. The new equipment has sparked program wide interest in developing new adaptations of various lab experiments to compare and contrast the various types of power generation methods. This enthusiasm is not limited to the faculty but also the students are asking to extend the efforts in independent studies.

All these benefits however do come at a cost; Table 1 shows the approximate costs for the equipment purchased during the initial phases of the renovation. The obvious cost of equipment must include the necessary facility modifications to effectively remove exhaust and excessive noise conditions from the lab. The expense of installing a forced air exhaust system for the Minilab was greater than that of the Minilab itself. It can cost upwards of \$35,000, depending upon the particular lab condition. A less tangible cost is the time required to address the development of new experiments that allows the use of the equipment to its full potential.

Given the ever increasing number of computer controlled mechanical systems in widespread use, the mechanical engineering and technology students must be aware of how data are acquired and used for system control. The faculty at WIT has dedicated a large portion of laboratory modernization efforts to address this important aspect of mechanical system integration by continuing to expand the education of the principles and practices of digital data acquisition and

control. A cooperative development of an Automation, Data Acquisition and Control Laboratory with National Instruments is being initiated to augment the efforts in the Thermodynamics lab. With this effort, WIT faculty hope to spread the technology throughout the lab curriculum and introduce a new state of the art Laboratory.

Table 1. Approximate costs of the Equipment.

Equipment	Approximate Costs
Minilab - Turbo Jet Engine	\$35,000
Rankine Cyclor	\$24,000
Exhaust System	\$35,000
10 Computers For Simulations	\$11,500
Fuel Cell Kits	\$1,500
Armfield Heat Exchanger Unit	\$20,500

References:

1. Zenouzi, M., Krygowski, F., and Bosela, T. "Modernization of Instrumentation in a physical measurement course," NSF-ILI Grant #DUE-9750992.
2. House, R., "Choosing the right software for data acquisition," IEEE Spectrum, May 1995.
3. Larminie, J., Dicks, A., Fuel cell systems explained, Second Edition, John Wiley and Sons, 2003.
4. Chen, E.L. and Chen, P.I., "Integration of fuel cell technology into engineering thermodynamic textbooks," IMECE2001/AES-23647.
5. Moran, M.J. and Shapiro, N.S., Fundamentals of engineering thermodynamics, 5th Ed., John Wiley and Sons, 2004.
6. Cengel, Y.A. and Boles, M.A., Thermodynamics: An engineering approach, 4th Ed., Mc Graw Hill, 2003.
7. Ertugrul, N., "Towards virtual laboratories: a survey of LabVIEW-based teaching/learning tools and future trends," Int. J. of Engineering Education, Vol. 16, No. 3, pp. 171-180, 2000.
8. Turbine Technologies, <http://www.turbine technologies.com/>
9. Pourmovahed, A., Jeruzal, C.M., Brinker, K.D., "Development of a jet engine experiment for the energy systems Laboratory," IMECE2003-43638.
10. Armfield Inc., <http://www.armfield.co.uk/>

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