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IMPLEMENTATION OF DESIGN IN APPLIED THERMODYNAMICS COURSE

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Abstract

This paper discusses the restructuring of the Applied Thermodynamics course in the Mechanical Engineering Program at the University of Wisconsin-Platteville. The goals of the effort are to integrate design education throughout the curriculum and to provide meaningful design experience in the thermofluids area to every graduate. The effort includes revision of lecture topics, selection of design projects and design methodology. Incorporation of design education into this previously engineering science course has produced many positive results. Students are better motivated for course materials when subjects are presented on a need-to-know basis. They also learn the subjects at a deeper level at a setting where application of course fundamentals is required to solve real world problems.

I. Introduction

To prepare our graduates to meet the challenges of the new millennium, the mechanical engineering faculty at the University of Wisconsin-Platteville have revised the curriculum. Integration of design throughout the curriculum and reduction of the curriculum core to allow flexibility in course selection were the two main goals. During the revision process, it was decided to strengthen the design education at the junior level and to provide the needed design experience in thermofluids to every graduate (an ABET requirement). To this end, the Applied Thermodynamics course was designated as the required design course in thermofluids to complement various senior design electives. The course was modified to have 50% engineering design and 50% engineering science.

Applied Thermodynamics (ME 3630) is the third course in a four-course thermal science sequence. It is preceded by Thermodynamics (ME 2630) and Fluid Dynamics (ME 3300), and followed by the Heat Transfer course (ME 3640). Since one of the major goals in integrating design throughout the curriculum is to show students the connection between courses, the teaching of fundamentals in this course must be built on the student's earlier experience and illustrate what needs to be learned in the future. The strategic position of this course in the thermal science sequence make it ideal for our purpose. On the other hand, we believe that adding a design component can play a significant role in improving student learning. Through solving real world problems, design projects can reinforce concepts currently being taught, demonstrate the relevancy of these concepts, stimulate and motivate students, and show what is needed to be learned in the future.

In response to the goals outlined in the mechanical engineering curriculum at the University of Wisconsin-Platteville, the course objectives are set as:

- To reinforce the understanding of basic thermodynamics principles through application and design.
- To learn and perform analysis on basic power cycles, refrigeration cycles, gas mixtures, and combustion systems.
- To gain experience in the design of thermal systems using appropriate optimization techniques and computer modeling tools.

This paper presents our experience in restructuring the course to meet the curriculum revision goals. The focal points of this paper are: how to effectively teach the course by blending design activities with lecture materials and how to conduct the design activities?

II. Course Structure

The new Applied Thermodynamics course is a required 3-credit hour course in our mechanical engineering curriculum. It has a lecture component and a design component, and meets four hours per week with two hours for lecture (previously three) and two hours for design/discussions (previously zero). Because of the reduced lecture time, it became necessary to remove certain subjects from the course. All thermofluids faculty in the program were involved in prioritizing the topics to be covered and discussed how the change would affect other courses. There was agreement to include the following topics: vapor power systems, gas power systems, refrigeration and heat pump systems, ideal gas mixtures and psychrometrics, and first law analysis of combustion processes.

The lecture component of the course is to cover the topics mentioned above to provide some background knowledge for the design projects. Without this knowledge, students would not be able to conduct relevant design works. This is a common problem in junior design courses because students do not have the necessary engineering science knowledge base for the design process.

The design component of the course was conducted by student design teams. Three small-scale design projects were spaced throughout the semester to match the pace of lectures. These projects were chosen carefully so that they were closely related to lecture topics and require the use of a wide scope of technical knowledge to solve them. This new design component provided an opportunity to significantly improve the course. In addition to nurturing students' ability to solve open-ended problems, the design projects motivate students and make them learn the subject at a deeper level since the projects are built on the material covered in lectures.

III. Design Implementation

The challenge of design implementation is two fold: to create a set of design projects to complement and support the lecture component, and to devise an effective approach to conduct the design projects.

A) Project selection

The three small scale design projects were: (a) optimization of an energy system for cogeneration, (b) renovation of an air-storage gas turbine unit, and (c) process design for a drying operation. These projects were selected for their integrative nature as well as their industrial realism. Working on these projects, students reinforce concepts currently learned in this course, refresh concepts learned in previous courses, and know what they need to learn in future courses.

(1) Project #1 -- Optimization of an Energy System for Cogeneration

Students were given a simple power plant consisting of an extraction turbine for cogeneration of heat and electric power. The states of steam at the inlet, and at the two extraction ports and the exit are specified. Also given are the mass flow rate of steam at the turbine inlet, and the revenue rates of electricity and steam at both high and low pressures.

The design tasks include the following aspects: to understand the advantage of cogeneration from first law and second law considerations; to find the extraction rates at each of the extraction ports to yield the maximum revenue (linear programming technique is used to solve this problem); to compare the current scheme with two other cycles, i.e., the regeneration power cycle and the combination of cogeneration and binary vapor power cycle; and to obtain the energy utilization factor from the design. Two computer programs, EES (Engineering Equation Solver) and CMMS (Computer Models for Management Science), were used to facilitate the thermodynamic analysis and the optimization process with linear programming technique. The project was to be completed in five weeks, including a week for writing reports.

Incorporating several important topics in vapor power systems covered in our textbook[1], this project complemented and reinforced the lecture materials currently being taught. Since second law and availability analysis (covered in the prerequisite course ME 2630) was used in this project, students have the opportunity to integrate these two courses and understand these abstract concepts at a deeper level through application. In addition, the project also broadened the student's scope of learning by combining teamwork, decision-making, linear programming technique for system optimization, and computer skills (through the use of the two computer programs).

(2) Project #2 – Renovation of a Compressed Air Energy Storage (CAES) System

It is well known that a CAES system addresses the problem of time-varying demand of electricity[2]. In this project students were given a schematic drawing of a proposed CAES system. This unit consists of a regenerative gas turbine with reheat, a two-stage air compressor, heat exchangers, a throttling valve, and an air storage cavern. The turbine axle is connected through a clutch to the axle of a motor/generator which is in turn connected to the two-stage compressor through another clutch. During the off-peak hour, the system is operating in the storage mode where the motor/generator would act as a motor with electricity from the power grid to drive the air compressor. The compressed air at 70 bar is stored in an underground cavern for use when the system is in power generating mode. During peak power demand period, the compressed air is released from the cavern, throttled to 40 bars, and preheated before entering the two-stage gas turbine. The temperatures and pressures at both the inlet and outlet of the two-stage gas turbine, its isentropic efficiency and its power rating were known.

In the preliminary design stage, students were to assess the proposed design and explore whether they can improve the system through modifications. Through a brainstorming process students identified several ideas to make the system more efficient. These ideas were: (i) using an expansion turbine to replace the throttling valve and reduce the destruction of availability; (ii) installing a heat recovery system for the two-stage air compressor; and (iii) installing an energy storage system for cooling the incoming hot air to the cavern and heating the stored air during the discharging process. Analysis was performed to evaluate the validity of these ideas.

Following the preliminary design, students worked on the determination of the required volume of the cavern. To this end they performed an energy analysis of the process in the two-stage turbine. An actual Brayton cycle including the irreversibility in the turbine and piping are considered. From the energy analysis one can find the required mass flow rate for the determination of the needed storage volume.

This project was conducted concurrently with the teaching of Gas Power System and Refrigeration System. The project was completed in four weeks.

(3) <u>Project #3</u> – Process Design for a Drying Operation

This project was originated from a local company that produced loud speaker cones. The production of the cones involved the forming of the cone from paper pulp and the drying of the wet cone with a propane-fueled heater which used air from the factory floor. Hot air streams from the heater were directed towards the cone for drying and were subsequently discharged to the open space inside the factory, creating a rather uncomfortable working environment, especially in the summer time.

The objectives of the project are: (i) to make the facility more energy efficient, (ii) to increase the drying rate, and (iii) to improve the working environment for the workers. The scope of the study encompasses psychrometrics, combustion, and heat and mass transfer. The project was assigned to match the progress of lectures on the topics of ideal gas mixtures and combustion.

To make the facility more energy efficient, students examined two design alternatives. The first is to use an electric heater to replace the current propane-fueled heater; the second is to add an air duct with a heat exchanger to reclaim waste heat from the exhaust air of the drying operation. After performing a simple economic analysis and considering the benefits to the working environment, students had recommended the second alternative.

The drying rate is affected by the temperature, the humidity, and the air speed of the hot air stream. These factors are in turn related to the excess air during the combustion process. Applying the theories covered in lectures, students calculated the temperature of the air stream for a variety of air/fuel ratios. They also learned that the mass of excess air in the combustion process would affect the drying rate in a rather complicated manner. On the one hand, reducing excess air for the combustion process would raise the temperature of the air stream which is beneficial to drying. But on the other hand, this would also reduce the convection speed and thus reduce the drying rate. A compromise between these two conflicting factors will have to be made to determine the optimum amount of excess air.

The actual drying process is very complicated because it is a simultaneous heat and mass transfer process. Moreover, majority of students in the class had not even taken the Heat Transfer course. To address this problem we used part of the discussion session to introduce the most necessary topics on a just-in-time basis. We also made certain assumptions to make the problem tractable to junior level students. The computer software EES was used extensively in the analysis. In addition to seeing the application aspect of lecture materials, the project also provided students some understanding of optimization and economics, and showed them why they need to take Heat Transfer in the future to complete the thermal science sequence in the mechanical engineering curriculum at the University of Wisconsin-Platteville.

B) Method for Conducting Discussion Sessions

In conducting the weekly discussion/design session, we adopted the problem-based-learning approach to create an active learning environment[3]. The success of this approach depends on proper guidance from the instructor, which is done through the weekly discussion session in the course and faculty-student interaction outside of the classroom. A typical discussion session starts with an oral report by one or two design groups followed by an open forum discussion. Prior to the discussion session, each design team hands in a weekly progress report and a plan for next week. This step results in better student preparation and ensures their active participation in the discussion. Through this process, the instructor evaluates students' approach and progress, points out errors and inappropriate methodologies, raises questions to encourage critical thinking, and provides personal guidance to all students. Teamwork, critical thinking, and real-world applications were successfully incorporated into the Applied Thermodynamics course with the measures discussed above.

IV. Closure

The effort to integrate design into the Applied Thermodynamics course has produced the following positive results: (i) reinforcing concepts currently being taught, (ii) creating linkages among courses in the thermal science area, (iii) exposing students to meaningful open-ended problems, and (iv) emphasizing on teamwork, communication, and computer skills. While we believed that the objective of the course had been met very effectively, some students complained that the workload was too heavy for a 3-credit hour course. Despite the complaints and grievance, most of the students agreed that the experience was worthwhile.

Bibliography

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