2006-989: A NEW DESIGN OF THERMAL-FLUID SYSTEMS ELECTIVE: DESCRIPTION, OBSERVATIONS, AND EXPERIENCES

Donald Mueller, Indiana University-Purdue University Fort Wayne

DON MUELLER is an Assistant Professor of Engineering at Indiana University--Purdue University Fort Wayne, in Fort Wayne, IN. He received his BS, MS, and PhD in Mechanical Engineering from the University of Missouri--Rolla. His teaching interests are in the areas of thermal-fluid sciences and numerical methods.

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Abstract

The purpose of this paper is to describe a new technical elective course in the thermal-fluid sciences, entitled *Design and Optimization of Thermal-Fluid Systems*. This course involves the application of the principles of thermodynamics, fluid mechanics, and heat transfer to the design of thermal systems with an emphasis on modeling, simulation, economic analysis, and optimization. Unique course activities and student learning outcomes are presented. Several textbooks and software tools that might be used in the course are also discussed.

Introduction

A new technical elective in the thermal-fluid sciences, entitled *Design and Optimization of Thermal-Fluid Systems*, has been developed at Indiana University-Purdue University Fort Wayne (IPFW) in order to address several issues. First, mechanical engineering students at IPFW have expressed a desire for technical electives of a more practical nature. Most of the technical electives offered at IPFW are more traditional courses such as Intermediate Heat Transfer, Vibrations, and the Finite Element Method—this new technical elective allows to students to apply material learned in other courses to more realistic engineering situations, often involving engineering systems. Second, in 2004, the mechanical engineering students' performance in the areas of engineering economics and energy conversion on the Fundamentals of Engineering (FE) Exam was slightly below the national average. As part of the engineering department's assessment process, the FE Exam is one of the measures that is used to assess whether or not the program outcomes are being achieved. This new course arose, in part, as an attempt to correct deficiencies identified by student scores on the FE Exam in the areas of engineering economics and energy conversion. Finally, some of the desired ABET program outcomes are difficult to develop in students with traditional, required courses. A technical elective, such as *Design and Optimization of Thermal-Fluid Systems*, presents opportunities for interesting, high-quality activities that can be used to develop these important abilities in students.

A thermal-fluid design elective is not necessarily new, and several excellent texts, see e.g. Refs. [1]-[5], have been written on this topic. However, one characteristic of these texts is that the material coverage is not uniform, and when developing an elective course like *Design and Optimization of Thermal-Fluid Systems*, choices must be made as to what material to cover and what approach to take, i.e. more analytical vs. more practical. This paper first provides a general description of this new technical elective course. Then several of the more common textbooks and software tools are compared. Next, the content and approach of the new course are reported, along with the experiences of the instructor and students. Of note is how some of the unique course activities relate to specific ABET program outcomes that are difficult integrate into traditional, required courses.

Course Description

The catalog description of the course is:

> Application of the principles of thermodynamics, fluid mechanics, and heat transfer to the design of thermal systems with an emphasis on modeling, simulation, economic analysis, and optimization. Systems to be studied include heat exchangers, thermal storage devices, fluid machinery, pipes and ducts, and electronics cooling devices.

At IPFW, as with most engineering programs, each course has a set of associated outcomes. For this course, six outcomes have been proposed and are listed below.

A student who successfully fulfills the course requirements will be:

1. able to integrate thermal component models and simulate a thermal system. (a,c,e,h,j)
2. able to perform an economic analysis of a thermal system. (a,e,j)
3. able to use the computer to solve thermal system models. (k)
4. able to communicate thermal system designs both orally and in writing. (g)
5. able to apply optimization procedures and design optimized thermal systems. (a,c,e)
6. exposed to the recent developments and practices in energy and thermal systems (h,j)

These course outcomes are linked to our department outcomes and to the program outcomes established by the Accreditation Board for Engineering and Technology (ABET). ABET requires that engineering programs must demonstrate that their graduates have

a. an ability to apply knowledge of mathematics, science, and engineering
b. an ability to design and conduct experiments, as well as to analyze and interpret data
c. an ability to design a system, component, or process to meet desired needs
d. an ability to function on multi-disciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively
h. the broad education necessary to understand the impact of engineering solutions in a global and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Many opportunities exist throughout the curriculum to develop some of the ABET outcomes, such as (a) and (e)—these outcomes are developed in almost every engineering course. However, few opportunities exist in traditional courses to develop some of the desired ABET outcomes, such as (h) and (j). This course was able to partially develop those outcomes with some of the activities explained below. Furthermore, outcomes (c), (g), and (k) are also emphasized in this course.

Textbook

There are many very good textbooks that deal with thermal-fluid design. Each textbook has its own approach to the coverage of the more traditional technical material such as piping systems and heat exchangers. The books vary with respect to the coverage of some of less traditional topics such as exergy analysis and optimization. A very brief comparison of the textbooks is given in Table 1 with respect to some of the desired topics in this course.

Table 1. Comparison of thermal-fluid design textbooks.

Author	Exergy	Economics	Optimization	Comments
Bejan, Tsatsaronis, and Moran [1]	Yes	Yes	Yes	Thermoeconomic approach, Cogeneration case study
Suryanarayana and Aran [2]	No	Yes	No	Several detailed examples, Engineering Economics notation agrees with FE
Burmeister [3]	No	Yes	Yes	Coverage of legal and patent issues
Janna [4]	No	Yes	No	Unique treatment of economic pipe diameter
Hodge and Taylor [5]	No	No	No	MathCAD integrated, Coverage of modeling and uncertainty

Instructors must examine each text and decide which best suits their needs. Perhaps the best approach might be to select a text that the instructor feels most comfortable with, even if it does not cover all of the topics desired. Material not covered in the selected text can then be provided with supplemental notes.

Software

Design activities often require numerous repetitive calculations that are well-suited for computer calculation. Many different types of computer software can be used to solve these types of problem, e.g. general mathematical packages such as MATLAB, MathCAD, MAPLE, Mathematica, spreadsheets such as EXCEL, and specialized packages such as EES, TK Solver, CyclePad and FEHT.

Students in this course were encouraged to use software to solve many of homework problems, as well as the projects. The approach used in this course was to present examples and solutions in MATLAB and EXCEL because these packages are taught to students in our program in a "computer-tools" class. However, students were allowed to use any software package that they desire. During one seventy-five minute lecture, two example problems were worked in detail using the thermodynamic cycle analysis software CyclePad.[6] A screenshot of the CyclePad interface is shown in Fig. 1.

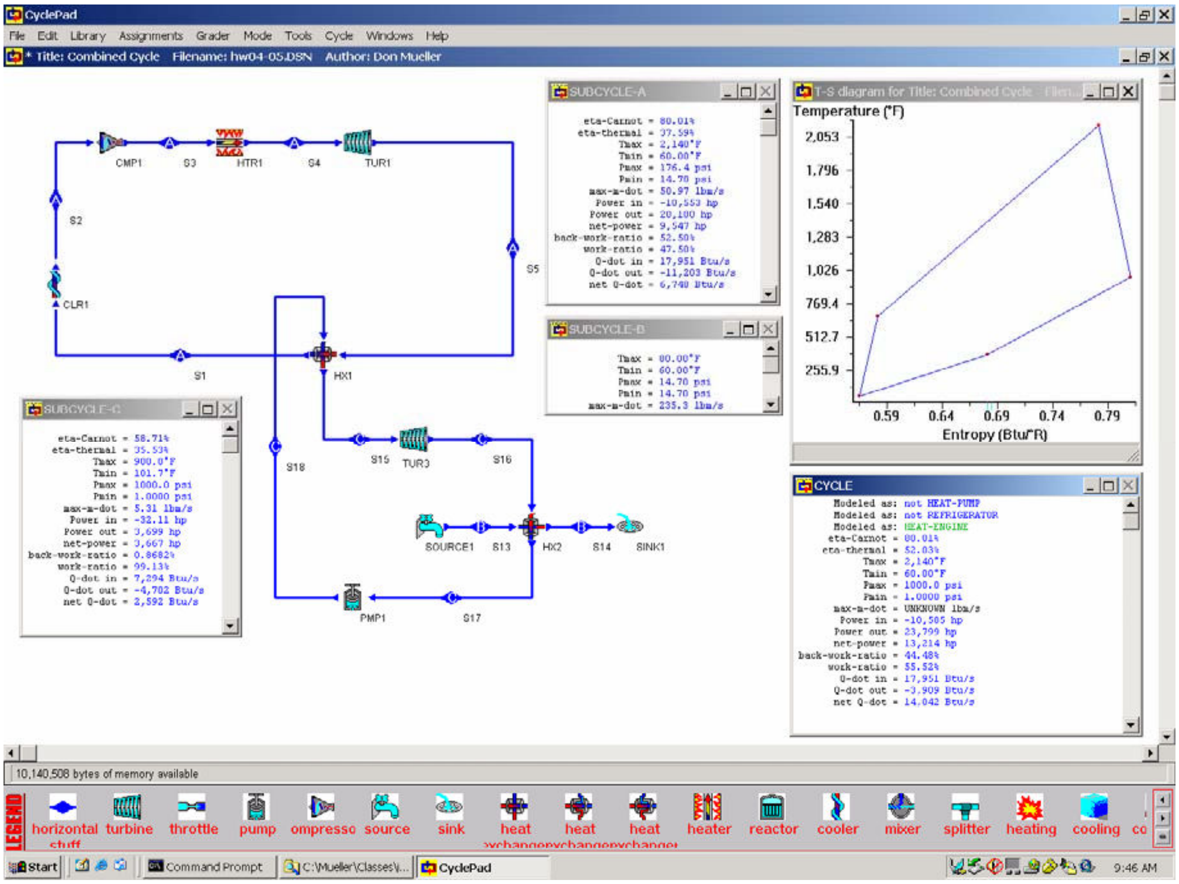

Figure 1. Screen shot showing a CyclePad model of a combined cycle.

Course Content

This course begins with an overview of the design process. The primary focus in this course is on the analysis part of the design process, as students also take a two-semester capstone design course. Next, simple numerical techniques, such as root finding and curve-fitting, are introduced with thermal-fluid examples. Most students have had limited experience with these methods and most have some initial difficulty applying them to engineering problems. The use of MATLAB and spreadsheets is discussed and encouraged throughout the course.

Next, a brief review of thermodynamics, fluid mechanics, and heat transfer is provided by looking at some real-world examples of power generation options, and the software package CyclePad is introduced and used to model a combined-cycle power plant. Students used CyclePad to analyze some of the homework problems.

Students are exposed to the concepts of availability and irreversibility in a required thermodynamics course, but in this course exergy analysis is presented in such a way evaluate thermodynamics system, as well as the system components. Exergy analysis leads naturally into economic analysis. Several weeks are spent on engineering economics. Students are encouraged to obtain a copy of the chapter of the FE Notes on engineering economics and consistent notation is used in the class. Students also used these notes on exams.

Thermal-fluid systems are studied with an emphasis on aspects that are not covered in traditional courses at IPFW, e.g. cogeneration, parallel-pipe systems, heat exchangers, and electronics cooling. The final topic covered in the course is optimization. A brief mathematical treatment is offered with thermal-fluid examples. Software tools are then used to solve optimization problems.

Course Assignments

The student's grade in this course was based on seven homework assignments, four projects, and three hour-long exams.

Homework

The homework assignments were comprised mostly of typical "analysis-type" problems. Many of the problems were modified problems from thermodynamics, fluid mechanics, and heat transfer textbooks. In addition to the traditional homework assignments, a few unique activities were assigned.

The ability to communicate is important for engineers, and activities throughout this course gave students the opportunity to develop their communication skills. In the first week of class students were provided handouts detailing a technical memo style to be used throughout the semester. To insure students quickly became familiar with the required memo style, students were asked to write a brief memo that explains the operation of the Rankine cycle. The memo was required to contain an original figure produced by the student. This activity gave students a "template" to use for writing project memos later in the semester.

About one month into the semester, the class visited a local manufacturer of heat pumps, WaterFurnance International. The students got to see first-hand how heat pumps were manufactured. During this visit, an alumnus gave us insight into many real-world issues such as membership in technical societies, international patent protection, and labor concerns. This trip was extremely insightful, and we plan to visit in the future. Later in the semester, students were given a design project dealing with heat pumps.

Midway through the semester, students were required to read an article from an on-line publication *Distributed Energy*[7] and write a brief memo summarizing the article. Three different articles were assigned, and the articles were discussed during the class in which the summaries were returned. This exercise not only gives the students an opportunity to practice their communication skills, but also to learn about recent technological advances. In the informal class discussion, students are asked to assess the information in the articles for technical accuracy and objectivity. During this discussion, students were asked: Could they trust material from on-line publications such as *Distributed Energy*? Could they trust all on-line publications? What makes them feel that they can trust an on-line publication? This discussion presents an opportunity to introduce the concept of information literacy and how engineers and scientists assess information. Students are directed to the IPFW library webpage and the *Integrated Information Foraging Environment* for a more detailed discussion of information literacy.

Projects

The first project dealt with the properties of air, which was treated as an ideal gas with temperature-dependent specific heats.[8] Students were give two options—use NASA curve-fits or a table look-up scheme—to produce the thermophysical properties h, s, and c_p and the transport properties μ, k, and α. This first project was designed to familiarize students with the computer.

The second project required the students to model the compression of an ideal gas with temperature-dependent specific heats. Students were given a simple MATLAB computer code to solve a similar problem—this program was explained in class. Students were then instructed to utilize this computer program to study the multistage compression process with intercooling. The effects of intercooler effectiveness and compressor efficiency were studied. Students were to determine the optimum pressure ratios.

The third project involved economic comparison of a ground-source heat pump and an air-source heat pump. Students were given cost-estimation information and instructed to analyze both options. The ground-source heat pump was estimated to cost $4000 more than the air-source heat pump, due to the added capital cost of the ground loop; however, the ground-source heat pump was found have higher coefficient of performance. Thus, an economic analysis would indicate the pay-back period for the higher initial cost investment. This project was similar to the project detailed in Ref. [9], which considered an AC system instead of heat pump.

The final project was a parallel-pipe flow problem similar to that described in Ref. [10]. For this project, students were to completely characterize a piping system and compute the initial cost and an equivalent uniform annual cost for their system.

Exams

Three hour-long exams were given. The first exam covered a review of the thermodynamic, fluid mechanics, and heat transfer and engineering economics. The second exam tested the students on piping systems and heat exchangers. The third exam covered the overall design process, including economic analysis and optimization. Students were allowed to refer to the FE Exam notes during exams.

Course Assessment

Assessment is an important issue in the engineering department at IPFW, and multiple measures are used to study the program outcomes—one such measure is the Fundamentals of Engineering Exam. All graduating seniors are strongly encouraged to take the exam; however, the number of students taking the exam has not been consistent. The process of how data from Fundamentals of Engineering Exam is used in assessment is shown in Figure 2.

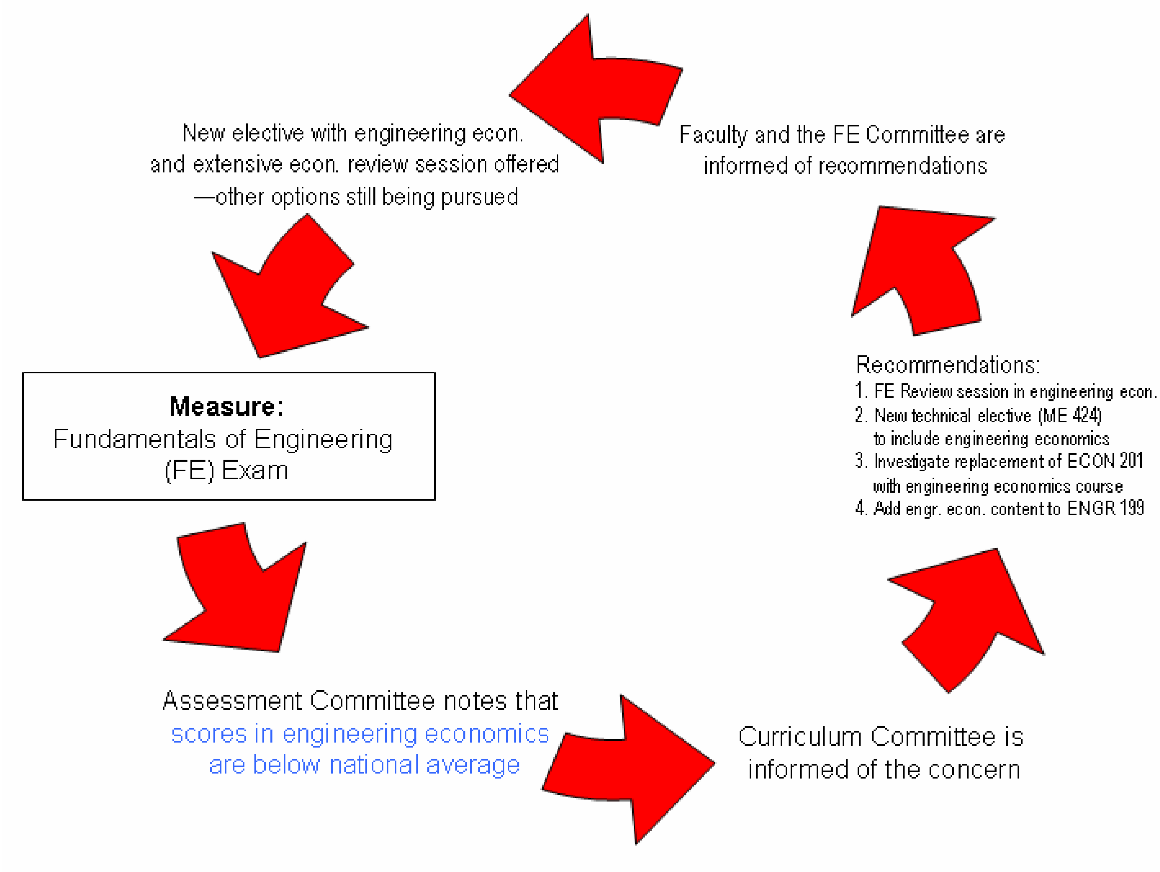

Figure 2. Program outcomes assessment process at IPFW.

Examination of data from the 2004 FE exam (see Figure 3) and scrutiny of the curriculum indicated a need to better prepare students in the areas of Engineering Economics and Energy Conversion. (In 2004, twelve, graduating mechanical engineering students took the FE Exam.) The Assessment Committee recommended the development of a new technical elective that covers that Engineering Economics and Energy Conversion—this recommendation was partial motivation for the course.

In 2005, only three mechanical engineering students took the FE Exam. All three students who took the FE Exam also took the elective course described in this paper. The results from the 2005 exam show improvement in students' Engineering Economics and Energy Conversion scores in comparison to the national averages. This improvement is encouraging, but due to the small sample size not conclusive. However, it should be stressed that this course contains the students' only significant exposure to Engineering Economics in the curriculum.

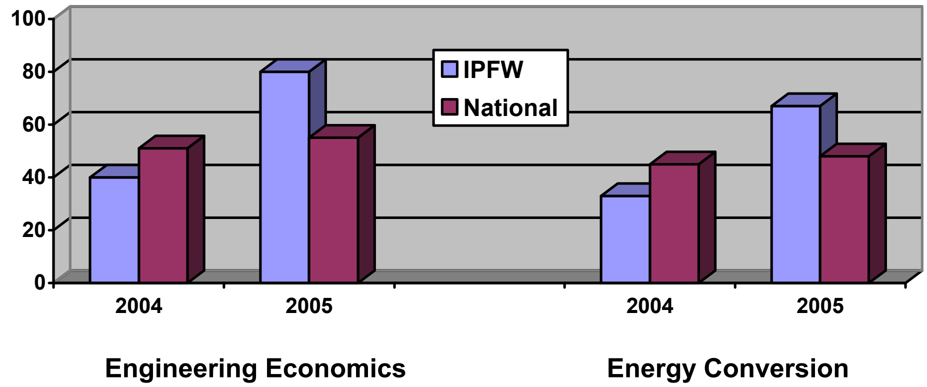

Figure 3. Results from the FE Fundamentals Exam.

The course outcomes were also qualitatively assessed by both students and the instructor—both students and the instructor felt that the outcomes were being achieved. Finally, student satisfaction with the course was measured with end-of-the-semester course evaluation surveys. These surveys contain seventeen questions with a maximum score of 4.00. Results of two of the relevant questions are provided below.

Class content was appropriate	3.11
Class overall	3.14

In addition to survey questions, students also provide written comments. In response to "What did you like most about this course?" typical student comments were:

> "…The course did a good job meshing together of individual class knowledge (fluids, thermo, heat transfer, econ) to give a better understanding of what we will be doing in industry."

> "The knowledge that helped connect heat transfer, thermodynamics, and fluids."

Most students also felt that the course required too much work, especially the traditional homework. These results and written student comments indicate that students were reasonably satisfied with the course.

Concluding Remarks

A new technical elective involving the design of thermal-fluid systems has been developed. Several of the unique activities in this course include:

- Students are required to read and summarize brief articles on state-of-the-art thermal systems. The concept of information literacy is presented and discussed.

- The course has four projects. The first project is a computer project. The next three are design projects in which students are required to design a thermal-fluid system to accomplish given objectives. Several projects have been adopted from those described in ASEE papers.

- During the semester, the class visits a local manufacturer of heat pumps, WaterFurnance International. During this visit, an alumnus gave us insight into many real-world issues such as international patent protection and labor issues. One of the design projects in the course involved the economic comparison of air-source heat pump versus a ground-source heat pump.

Student satisfaction with the course was high, and the course outcomes were achieved according to faculty and student assessment. After taking the course, student performance on the FE Exam in the areas of engineering economics and energy conversion was improved.

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