AC 2010-2176: DEVELOPMENT OF A THERMAL SYSTEMS COURSE FOR A POWER ENGINEERING TECHNOLOGY PROGRAM

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Development of a Thermal Systems Course for a Power Engineering Technology Program

Abstract

A new power engineering technology program has been created in the department of Engineering Technology and Industrial Distribution at the Texas A&M University with the objective of educating and preparing students for jobs in the Power Industry. As part of the new curriculum, several new courses have been developed to satisfy ABET requirements and the power industry needs. Development of a thermal systems course specifically for the power industry presents several challenges and opportunities. The course should be able to prepare students for an extensive range of thermal system problems commonly encountered in the field by introducing lecture materials from different engineering disciplines in an organized manner.

In this paper, the structure and content of a new thermal system course are described within the context of engineering technology. The course covers topics such as fluid properties; mass and energy conservation principles; fluid systems including friction losses in pipes, pumps, pump-piping system interaction; thermodynamics power cycles; conduction and convection heat transfer; analysis and design of heat exchangers; and cooling towers. The course also consists of a laboratory component where specific emphasis is given to thermal system hardware design and selection, and analysis and performance optimization of thermal systems through computational activities. The course laboratory activities also include hands-on exercises where students learn to characterize the performance of a commercial pump system, a convective heat transfer device, a lab-scale Rankine cycle, and lab-scale ground source heat pump. In the course, students also learn about the importance of component integration and how it affects the overall performance of a conventional thermal system.

Introduction

Recent studies and statistics[1] have shown that there will be significant increases in the demand for workers, utility and energy managers in the next two decades. The demand for engineers and technologists in the area of power generation is expected to grow particularly in the nuclear power industry, which has responded favorably to incentives provided by the Energy Policy Act of 2005[2]. Furthermore, the current workforce in the power industry is aging, and a significant number of power engineers and specialists will be retiring within the next 10 years. As a result, a new Power Engineering Technology program has been developed by the Department of Engineering Technology and Industrial Distribution at Texas A&M University to prepare students for new and exciting jobs in the power industry in the State of Texas and in the nation. The new program will provide students with the necessary expertise and skills to excel in the power industry.

One of the main challenges in organizing and structuring a Power Engineering Technology program is to design and implement a curriculum that reflects the current and future needs of the industry. To meet that objective, faculty members of Texas A&M University met with representatives of several utility companies to determine what skills, knowledge, and level of expertise are required in the industry today[1]. Once a list of required courses was obtained, individual faculty members within the department were asked to provide guidance and recommendations on which of the existing courses should be included in the program. After an initial list of existing courses was compiled, it became evident that a new course in the area of thermal sciences was required. A course that could cover topics such as heat exchanger design and analysis, as well as variations of the conventional Rankine cycle, was needed to complete the curriculum. The new course should also cover other fundamental concepts routinely used in the power industry to ensure each graduate has sufficient know-how to solve day-to-day engineering problems in a very dynamic work environment. In the next section a detailed explanation of how the course was structured and delivered is presented.

Course Development and Delivery

A thermal system course was proposed and included in the required Power Engineering Technology curriculum to cover topics not covered by traditional courses such as Fluid Mechanics and Thermodynamics. The course includes a wide variety of relevant topics for the Power Industry including fluid flow systems, variations of the Rankine (steam) cycle, as well as topics in applied heat transfer, including heat exchanger design and analysis. Both courses (fluid mechanics and thermodynamics) are prerequisite for the new thermal systems course. A detailed list of all the topics covered in the course can be found in Table 1.

As shown in Table 1, the relevant topics were grouped into five main categories including fluid systems, Rankine cycles, conduction heat transfer, convective heat transfer, and heat exchanger. Cooling tower analysis was also included as a separate lecture topic. Within the fluid systems category, Class I problems[3] (when flow rate is known and pressure head or elevation head difference is calculated), system head-loss curve generation using the equivalent length method, and pump performance curves were included as sub-topics. These sub-topics are briefly covered in a traditional fluid mechanics course. However, most instructors seldom present the materials from a thermal systems point of view.

The course also covers most of the Rankine cycles used today, including the reheat, regenerative (open and closed feedwater heater), and combined (Rankine + Brayton) cycles[4]. Special emphasis is given to the benefits of each cycle variation in terms of efficiency and power generation capacity while taking into account additional hardware requirements.

The heat transfer portion of the course focuses on conduction and convective heat transfer[5]. Steady conduction and fin systems analysis are introduced. Unsteady heat conduction is also covered briefly in the course. Convective heat transfer is also discussed by introducing students to the use of non-dimensional correlations (Nusselt number correlations) for a variety of fluid and heat transfer boundary conditions[6]. Then the students learn how to calculate the overall heat transfer coefficient for different heat exchanger configurations. The Log Mean Temperature Difference (LMTD) and ε-NTU (Effectiveness-Number of Transfer Units) methods are introduced so students can learn how to analyze and design (size) different types of heat exchanger configurations.

Lastly, heat (and mass) transfer associated with cooling towers in the last topic presented in the course.

Table 1. Topics covered in the new Thermal Systems course

Fluid Systems	Class I pipe systems problems that involve several components including pipes, valves, tanks, and pump
	Generation of system curve using equivalent-length method
	Pump selection and understanding of pump performance curve
	Identification of operating point
	Change of operating point by adjusting system curve or pump speed
Rankine Cycles	Ideal
	Actual
	Reheat
	Open feedwater heater
	Closed feedwater heater
	Combined (Rankine + Brayton) cycle
Conduction Heat Transfer	Conduction Heat Transfer
	One dimensional steady heat conduction
	Lumped capacitance method for transient heat conduction
	Fin systems and fin efficiency
Convective Heat Transfer	Convective heat transfer
	External flow
	Internal flow with laminar or turbulent flow with constant wall temperature or constant heat flux boundary condition
Heat Exchanger	Overall heat transfer coefficient calculations
	Design and analysis of heat exchangers
	LMTD method
	ε-NTU method
	Cooling tower analysis

Laboratory exercises are also an essential part of the course and are used to convey fundamental concepts in a physical and direct manner. The purpose of the laboratory activities is to ensure each student acquires the appropriate hands-on as well as computational skills necessary for a wide variety of thermal system problems. The students also study the effect of independent system variables on the performance of a thermal system (i.e. effect of boiler pressure on Rankine cycle efficiency) by computer simulation or by using lab-scale hardware.

A total of eleven laboratory activities were undertaken as part of the course as indicated in Table 2. The laboratory activities were grouped into two main categories: computational and hands-on activities. For each computational activity, each student had to work independently, while for the hands-on activities, the students formed groups of three students each.

Table 2. Thermal System course laboratory activities

Fluid Systems	Computational	Head losses EES
		System and Pump Performance Curves
	Hands-on	System and Pump Performance Curves and Operating Point
Rankine Cycle	Computational	Reheat Rankine Cycle
	Hands-on	Lab-scale Rankine Power Plant
Conduction and Convection Heat Transfer	Computational	Effect of Convective Heat Transfer Coefficient and Outside Temperature on Heat Transfer Conduction
		Effect of Material Properties on the Heat Transfer Performance of Multiple Fins
	Hands-on	Convective Heat Transfer on External Surfaces
	Computational	Effect of Effect of Prandtl (Fluid Properties) and Reynolds Numbers, and Surface Roughness on Heat Transfer Coefficient in Turbulent Flow
Heat Exchanger	Hands-on	Thermal Performance of Lab-Scale Ground Source Heat Pump
	Class Project: Computational	Design of heat exchangers using ε-NTU and LMTD methods

All computational activities were conducted using EES (Engineering Equation Solver) because it contains the necessary subroutines and fluid properties database for most thermal systems problems. EES uses an objective computer language which allows each user to type equations in a simple form. With EES, students can generate parametric tables for independent and dependent variables and create a variety of graphics and plots for easy interpretation of computational results.

Four hands-on laboratory activities were also undertaken as part of the course. The first hands-on activity consisted of obtaining the system and pump curves using one of the four lab-scale pump station in the laboratory[7]. Each pump station is equipped with a Gould-type centrifugal pump with variable frequency drive, flow control valve, flowmeter, pressure transmitter, large tank, and computer-based data acquisition system. Students were able to control pump speed as well as flowrate (using the flow control valve) to generate the system and pump performance curves, respectively.

The second hands-on activity consisted of finding the thermal efficiency and power output of a lab-scale Rankine cycle. An electrically-operated boiler was used to drive a steam turbine attached to a DC voltage generator. The entire set up was instrumented so data such as boiler temperature and pressure could be recorded.

The third hands-on activity consisted of measuring the convective heat transfer coefficient of a heated cylinder exposed to external flow. Thermocouples and a copper block were used to determine surface temperatures and heat flow through an insulated aluminum cylinder. Once the appropriate steady state data was obtained, the insulation surrounding the cylinder was removed and a fan was used to provide forced convection. Appropriate temperature and heat flow data were used to determine the convective heat transfer coefficient when the cylinder was exposed to external flow.

The fourth and last hands-on experimental activity consisted of measuring the overall heat transfer coefficient of a lab-scale ground source heat pump[8]. The device consists of a U-shaped coil immersed in a large soil tank that can be used to remove or add heat to the fluid flowing inside the U-shaped coil. Thermocouples, a flowmeter, a pump, two large water tanks (discharge and suction tanks), and an electric heater placed upstream from the U-shaped coil were used to generate the required data to determine the overall heat transfer coefficient of the entire ground source heat pump system[8].

In the last laboratory activity, each student was asked to design computationally three heat exchangers (shell-and-tube, unmixed cross flow, mixed cross flow) using both the LMTD and ε-NTU methods. As part of the tasks, each student also had to determine the required pumping power required for each heat exchanger configuration, the overall cost and cost effectiveness (cost/unit of heat transfer). The students had to determine graphically the optimal length and number of tubes in each heat exchanger configuration taking into account the overall cost.

For the course, the textbook by D. Kaminski and M. K. Jensen[5] titled "Introduction to Thermal and Fluids Engineering" was used. The textbook by Kaminski and Jensen was selected because it is one of the few engineering textbooks that covers fluid mechanics, thermodynamics, and heat transfer topics.

Discussion and Concluding Remarks

The combination of lecture topics and laboratory exercises proved to be useful while teaching the course. The course was taught for the first time in the Fall of 2009. The students that took the course either belong to the mechanical engineering technology or power engineering program. It was a required course for the students in the power engineering technology program, but just a technical elective for the ones in the mechanical engineering technology program.

There are several lessons that were learned after teaching the course once. Firstly, the instructor needs to make sure all registered students have the proper prerequisites to be able to take the course. Secondly, the professor should spend some time with the students reviewing the fundamental concepts of fluid mechanics (i.e. continuity and energy equations) and thermodynamics (i.e. first and second laws of thermodynamics) before covering new material. It is also advisable to invite a couple of guest speakers from the power industry sector so students can learn how the topics covered in class have applicability in industry.

In general, the course was well perceived by students, administrators, and industry collaborators. The students provided valuable feedback and made useful recommendations which will be incorporated in the future. The following specific comments were provided by the students:

- “Great way to prepare for FE”
- “This class provides a more in-depth perspective than thermo”
- “I would prefer to see more proofs of formulas. If I don’t quite understand a formula, I don’t like applying it blindly”
- “Real world applications and examples”

In general, many of the students felt that the course prepared them well for the Fundamental of Engineering (FE) and Professional Engineering (PE) examinations. In the future, more emphasis will be given to understanding formula derivations and the role of boundary conditions in the development of analytical solutions for all applicable governing equations. The course will continue to be enhanced with the support of industry professionals and colleagues.

Bibliography

1. J. Porter, J. Alvarado, “Power engineering technology: a new program targeted at the nuclear power industry,” Proceedings of the 2008 ASEE Annual Conference & Exposition, June 2008.
2. L. Parker, M. Holt, “Nuclear Power: Outlook for New U.S. Reactors,” CRS Report for Congress, March 2007.
3. R. Mott, Applied Fluid Mechanics, 6th edition, Prentice Hall, Upper Saddle River, New Jersey, 2006.
4. Y. Cengel, M. Boles, Thermodynamics: An Engineering Approach, 6th edition, McGraw-Hill, New York, NY, 2008.
5. D. Kaminski, M. K. Jensen, Introduction to Thermal and Fluids Engineering, Wiley, Hoboken, NJ, 2005.
6. F. P. Incropera, D. P. DeWitt, T. L. Bergman, A. S. Lavine, Fundamentals of Heat and Mass Transfer, 6th edition, Wiley, Hoboken, NJ, 2007.
7. J. Alvarado, M. Golla, “A Successful Collaboration Model for Educators and Industry Partners for Laboratory Development and Enhancement,” Proceedings of the 2009 ASEE Annual Conference & Exposition, June 2009.
8. J. Alvarado, “Design and Construction of a Lab-Scale Ground Source Heat Pump,” Proceedings of the 2007 ASEE Annual Conference & Exposition, June 2007.