A CAPSTONE DESIGN COURSE IN FLUID THERMAL SYSTEMS

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ABSTRACT —An innovative design course in the fluid thermal systems area has been developed. The course includes topics such as design of piping systems, economics of pipe size selection for least annual cost, pump sizing and selection, system curves and operating points, heat exchanger sizing and selection. These topics integrate coursework in different subfields including material science, fluid mechanics, heat transfer, thermodynamics, economics and engineering graphics. Students give brief presentations on actual equipment: valves, pumps, viscometers, etc., rather than viewing a photograph provided by the instructor. Students work in groups to complete semester-long projects. Projects are awarded to the appropriate group on a lowest bidder basis. Groups select a project leader to manage the project, using pert-type charts and log books, and sees it through to its completion. At the conclusion of the semester, written and oral reports on the projects are required.

Keywords: Systems, Capstone, Design, Senior Projects

BACKGROUND

"Design of Fluid Thermal Systems" is a senior-level, capstone design course at the University of Memphis. The course is set up for seniors in engineering who intend to practice fluid/thermal design. Fluid mechanics is a prerequisite. Heat transfer is a corequisite.

Examples of fluid/thermal systems all contain some common elements. A fluid is moved by a prime mover through a piping system in which heat transfer may be taking place. Therefore piping systems, pumps, fans, heat exchangers and associated equipment are relevant to a study of fluid/thermal systems. As such, the course material is divided into two major sections. The first is on piping systems blended together with economics of pipe size selection and the sizing of pumps for piping systems. The second is on heat exchangers or, more generally, devices available for the exchange of heat between two process streams. The list of topics that can be added is almost endless (e.g., water hammer, fluid meters, etc.). Table 1 gives a list of topics and titles that are covered.

Table 1. *Table of course contents for Design of Fluid Thermal Systems.*

Number	Title or Topic
1	Introduction to the Course
2	Fluid Properties and Basic Equations
3	Piping Systems I
4	Piping Systems II
5	Pumps and Piping Systems
6	Some Heat Transfer Fundamentals
7	Double Pipe Heat Exchangers
8	Shell and Tube Heat Exchangers
9	Plate & Frame, and Cross Flow Heat Exchangers

Introduction to the Course

The course begins with introductory material in which examples of fluid/thermal systems are provided. A pump and piping system, a household air conditioner, a baseboard heater, a water slide and a vacuum cleaner are such examples.

Also presented are dimensions and unit systems that are used in conventional engineering practice (i.e., Engineering and the SI systems). The student is expected to know pertinent information on unit systems, but they are presented also to be sure that each student has access to conversion factor tables and to familiarize the student with the notation and units used in the field. The design process from concept to finish is also described.

Fluid Properties and Basic Equations
The next topic is a review of properties of fluids and the equations of fluid mechanics. It is included to ensure that students have access to tables of fluid properties. This chapter serves as a lead-in to the next topic.

Piping Systems I
It is expected that by the time students take this course, they have learned about piping systems in a first course in fluid mechanics. Here, however, the subject of piping systems is covered in greater detail and depth. Specifications for pipes and tubes are discussed. Circular, square, rectangular and annular cross sections are presented. Laminar and turbulent flow in each of these cross sections is modeled. Roughness factors for many types of pipe/tube materials are provided. Three friction factor graphs are given for the three types of flow in closed conduit problems. Minor loss values for many types of fittings are provided in two formats.

Piping Systems II. The next topic is a continuation of the same material. Economics of pipe size selection is covered. The least annual cost method of pipe size selection is formulated and presented. This method seeks to minimize the first plus operating costs of the prime mover and the pipeline. Also presented are three graphs of friction factor versus the friction factor–Reynold number product useful in finding the economic diameter. Minor losses again are discussed but in this context, the concept of an equivalent length is described. There are special methods for drawing piping systems (e.g., double line drawings, single line isometrics, etc.) and these are also presented. System behavior and system curves are discussed as are methods for supporting piping systems. Pipe hangers and associated hardware are described.

Pumps and Piping Systems
The next topic is pumps. Types of machines are discussed, and testing methods for centrifugal pumps are presented. Performance maps and composite charts from manufacturers' catalogs are given and are used to illustrate the steps in sizing a pump for a piping system. Cavitation and net positive suction head are also defined. This portion of the course concludes with a suggested procedure for designing a piping system.

Some Heat Transfer Fundamentals
The next topic provides an introduction to heat transfer basics in order to present appropriate heat transfer properties of fluids and to ensure that each student has access to heat transfer property tables. Conduction through planar and cylindrical geometries is touched on briefly. Convection for various simple problems is also presented.

Analysis of Heat Exchangers
There are three chapters that deal with heat exchangers. The types discussed and analyzed are: Double pipe, shell and tube, plate and frame, and cross flow heat exchangers. The emphasis is on analyzing such exchangers in order to predict their performance characteristics. Subsequently, design and selection of heat exchangers for a specific purpose is covered.

Show and Tell
Where appropriate, students are required to participate in something entitled "Show and Tell." Students are required to provide very brief presentations on selected topics. For example, one Show and Tell requires the student to give a presentation on various types of valves that are commonly used. The valves that are available are brought to class and taken apart (or cut in half prior to class) to illustrate how each works. Another involves a description of the types of pumps that are available commercially. A third requires a description of the types of viscometers that are available. Each student has the opportunity of participating. A Show and Tell on these and similar topics (no duplication of subject matter) is far more effective than a photograph in a text. In addition, each student will get practice in making an oral presentation.

Semester Projects
A group project is required in this course. Each project has associated with it a project description which begins with a few introductory comments and concludes with several tasks that are to be completed. Each project has an estimate of the number of engineers required to finish it in the given school term. The students are responsible for selecting

project partners and as a group, deciding on which projects they would like to work. Each group elects its own project manager or leader.

Students enrolled in this course are divided into groups of 3, 4 or 5 members who work together as a team on a design project. Selected projects are presented to the design teams who must bid competitively on three of the projects. The design team with the lowest bid is awarded that particular project to work on for the entire semester. Design teams function like companies and as such, each group chooses a company name and designs a company logo. Titles of projects worked on in Fall 2004 are provided in Table 2. Some groups developed web sites for their companies. More detailed project descriptions are provided in the Appendix of this paper.

Table 2. *Project titles and company logos.*

Title	# of Engrs	Student Designed Logos
A "Bad Guy's" Pond	3	WPC Engineering
Determination of Valve Coefficient	4	YNERGY ENGINEERING
Flash Freezing of Chicken	5	Dumas Engineering Firm
Pneumatic Freight Pipeline	3	T
Fireplace Heat Recovery	4	Apis Engineering Technologies

Each group elects a Project Director who meets with the course instructor on a weekly basis. The Project Director works with the group members to identify a list of tasks to complete in order to finish the project by the end of the semester. The list of tasks includes, for example, sizing and selecting a pipe to convey a specific fluid; sizing and selecting a pump; selecting a heat exchanger; predicting system performance; and writing a report about the design of the system.

Table 3 is an example of a task planning sheet for a project titled "Fireplace Heat Recovery Project." The plan shows a completion date selected for each task. By the end of the fifth week of the semester, for example, a CAD model is to be developed. Also included in the task planner (although not shown in Table 3) is the name/initials of the individual responsible for completing the task.

Each group member maintains a notebook or diary of all tasks completed for the project. The diary contains any and all details of the work done by that particular member on the project. This would include something as short as a phone call, or as detailed as calculations to predict when a pump will cavitate.

The Project Director meets with the course instructor on a weekly basis, and brings his/her group member's notebooks. The instructor checks to be sure that the group or company is working on schedule. If so, the "company" earns a satisfactory performance evaluation for the week. If not, the company's performance is deemed unsatisfactory and repeated unsatisfactory evaluations will affect the group's final grade. A student who continually fails to perform satisfactorily is "fired" from the company by the instructor.

Table 3. *List of tasks to be completed for the Fireplace Heat Recovery Project.*

	Week Number									
Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Research existing fireplaces	■	■								
Select fireplace		■								
Suggest Heat Exchanger designs		■	■							
Decide on HX design & optimize			■	■						
Optimize blower				■						
Do cost analysis				■	■					
Develop CAD models & parts		■	■	■	■					
Write Report						■	■	■		
Write oral presentation						■	■	■		
Finalize Report									■	
Finalize oral presentation									■	
Present & submit reports									■	■

Project reports are to be given in two forms: written and oral. The written report details the solution to all phases of the project as outlined in the original description or as modified in discussion sessions with the instructor. The oral report should summarize the findings and give recommendations.

CONCLUSIONS

It must be emphasized that the Design of Fluid Thermal Systems course does not provide a complete description in any one area. The objective here is to provide some design concepts currently used by practicing engineers in the area of fluid/thermal systems. It should be remembered that actual design details of various systems can be found in textbooks, reference books and periodicals.

As indicated in the above description, Design of Fluid Thermal Systems at Memphis State University is indeed a capstone course where students integrate previous coursework from different subfields including Materials Science, Fluid Mechanics, Heat Transfer, Thermodynamics, Economics, and Engineering Graphics. Furthermore, the semester long group design projects can be considered a “practicum” which integrates previous student work in a practical setting. A great deal of effort is made to introduce the student to methods used by practicing engineers. Such methods include:

Student groups bidding on projects
Students working together under a leader with a common objective
Students working on individual components of a composite project
Students keeping a journal of all project related activities
Students producing final written and oral group reports

REFERENCES

1. Janna, W. S., *Design of Fluid Thermal Systems*, Brooks/Cole Publishers, Monterey, CA, 1998.
   See also: http://www.people.memphis.edu/~herffcoll/mech4314.html

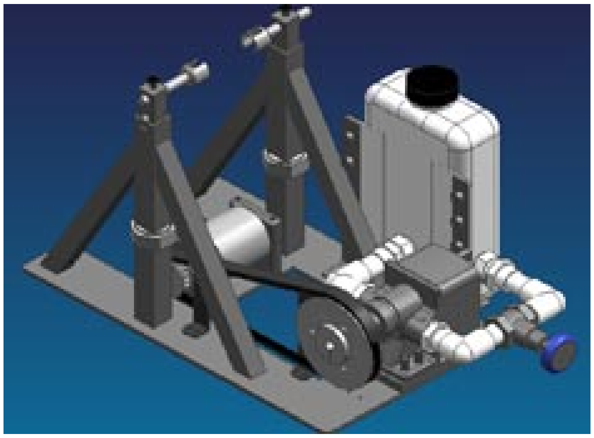
BIOGRAPHICAL INFORMATION

William S. Janna—William S. Janna joined the faculty of The University of Memphis in 1987. His research interests include boundary layer methods of solution for various engineering problems, and modeling the melting of ice objects of various shapes. He is the author of three textbooks, a member of ASEE and of ASME. He teaches continuing education courses in the area of piping systems and in heat exchanger design and selection, for ASME. Dr. Janna received a B.S. degree, an M.S.M.E. and a Ph.D. from the University of Toledo.

John I. Hochstein—John I. Hochstein joined the faculty of The University of Memphis in 1991 and currently holds the position of Chair of the Department of Mechanical Engineering. In addition to engineering education, his research interests include simulation of micro gravity processes and computational modeling of fluid flows with free surfaces. He is a co-author of a textbook, *Fundamentals of Fluid Mechanics*, with P. Gerhart and R. Gross and is an Associate Fellow of AIAA. Dr. Hochstein received a B.E. degree from the Stevens Institute of Technology (1973), an M.S.M.E. degree from The Pennsylvania State University (1979), and a Ph.D. from The University of Akron (1984).

APPENDIX: SELECTED PROJECT DESCRIPTIONS

Bicycle Dynamometer

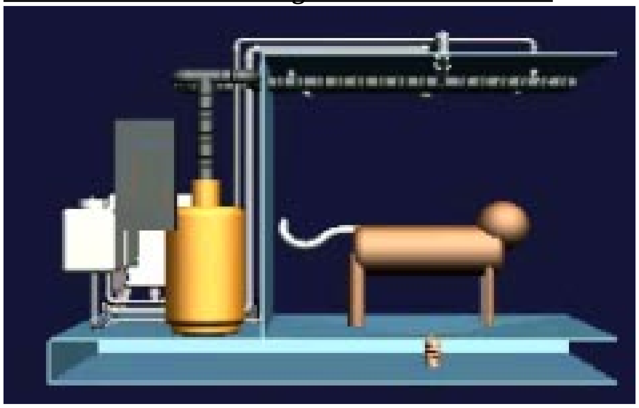


A dynamometer is a device for measuring the output power of a system. Dynamometers have been used extensively for measuring power from an internal combustion engine, from a turbine, and from an automobile. Dynamometers can be of the electric type, in which the output power is used to produce electric power, or of the fluid type, where the output power is used to pump a liquid (usually water) or move air. On a smaller scale (than IC engines), it is desirable to measure the output of a person pedaling a bicycle. Results of such tests are of interest in physical education studies of human power output and endurance, and to manufacturers of bicycles. Consequently, there is a need to have a dynamometer onto which a complete bicycle can be attached and pedaled, and from which output power can be calculated.

Fireplace Heat Recovery

Sheet metal fireplaces can be added to a room after the structure is built; that is, the fireplace need not be built when the home is. In order to enhance the usefulness of a sheet metal fireplace, it has been proposed to devise a means for recovering more of the heat that would ordinarily be discharged up the stack with the exhaust gases. It is believed that the most effective way to transfer more of the heat from combustion is by convection so that the air in the room is heated.

The Cat's Meow: Design of a Cat Washer



Consider a Cat Washer that would be targeted for use by large commercial pet stores, such as "PetCo." The Cat Washer would do more than merely wash a cat. A more inclusive list of objectives would be to design a device that will:

- Wash a cat with water and liquid shampoo,
- Apply up to two post-wash water soluble additives such as conditioner/deodorizer/flea killer,
- Remove loose hair from the cat's coat, and
- Dry the cat.

The Cat Washer should be adaptable to any size of cat, and should minimize trauma to the animal. The device should optimally clean all parts of the cat.

The Cat Washer should be reliable and rugged, as well as inexpensive. It should operate quietly, and be easy to clean and maintain. Ideally, the device should operate automatically to minimize any actions required of an operator.

If electricity is needed, the device should operate at 120 V AC. The Washer must be safe for both the cat and the operator, and should be designed for indoor use.