AC 2007-1731: PROMOTING STUDENT ENGAGEMENT IN THERMODYNAMICS WITH ENGINEERING SCENARIOS

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Promoting Student Engagement in Thermodynamics with Engineering Scenarios

I. Introduction

Many of the thermo-fluids courses, and in particular Thermodynamics, are often taught with traditional teaching methods and textbooks. Thermodynamics, in particular, is prone to elicit a negative impression from students "who perceive the subject as dry and abstract."[1] While there has been progress in recent years, there are still limited visual aids depicting actual equipment or industry settings. Even though the topics covered often have a real-world basis they are generally simplified and only offer a superficial impression of industry applications. This is especially true in the first thermodynamics course which is theory heavy. The result is that many students have excessive difficulty with the subject and do not develop a "feel" for the topic or the associated real-world equipment[2,3]. Felder et al. have summarized this best by stating that without student interest or a belief in the need to learn the material, a course "stimulates neither interest nor motivation to learn. The fact that many students in these courses appear apathetic and do poorly…should not come as a surprise".[4]

The relevant educational research and literature is clear in the belief that greater student impact, understanding, and retention can only be achieved with greater student engagement[5]. This engagement must come by presenting material and problems in the context of concrete applications or requirements and by connecting problems to the student's pre-existing knowledge. A related deficiency exists within engineering design education. A common approach to promote design exposure is to attempt integration of real-world problems and design throughout the curriculum[6]. Normally this route involves the addition of one or more open-ended problems to a specific course. However, these problems are often assigned toward the end of the semester and are "by necessity limited in scope and complexity."[7] In addition, engineering programs continue to be criticized for not offering more experience with real-world applications[8]. In many cases only minimal information is presented on the "reality" or technological background of the problem and the design methods presented may be flawed and incomplete, especially in relation to real-world practices.

Many beginning thermodynamics courses are hampered by an inability to develop well-defined, feasible design problems around introductory topics[9]. A review of several of the major texts used for thermodynamics reveals that discussion of the working environment and methods used by practicing engineers are extremely limited. Design is largely integrated through the addition in each chapter of several Design and Open-Ended Problems.[10,11,12] Often these problems lack well-defined instructional objectives or grading rubrics. Therefore, instructors often have difficulty assessing student performance on these problems[13]. While dedicated instructors will attempt to modify normal problems or tailor real-world issues into design problems, difficulties arise as well-defined problems are broadened yet still remain circumscribed[14]. In addition, there are natural limitations to the instructor's time and experience that can hinder problem creation.

Most importantly, information on how a practicing engineer would attack the problem is rarely presented for either the textbook or instructor derived cases thereby limiting their impact. Research into good teaching practices, and active learning methods in particular, demonstrates that students' performance improves when strategies and skills are modeled for students[15]. In other words, students learn best when they see how others approach and solve a problem. With respect to critical thinking skills and design methods it is obvious that the best techniques to model are those actually used in the real world by practicing engineers.

Through a NSF Course, Curriculum, and Laboratory Improvement (CCLI) grant, supplementary course material for thermodynamics is being designed for dissemination/production in an electronic format and for use with standard thermodynamic textbooks on the market. The material will include descriptions of real-world settings, each with several skills based (i.e. standard homework) and design-based problems specified. The combination of real-world setting and problems (along with associated background information and solutions) is referred to as an "Engineering Scenario". Each Engineering Scenario is based on a real-world engineering facility in a form similar to, but expanded from, a case study. The scenario will include extensive background information on the facility history and purpose, and information on the engineering personnel responsible for the facility. For each scenario a series of problems are being developed. These problems will take one of three possible forms: skill-based problems, short design problems, and large design problems. While each scenario will center around one engineering facility, the topics covered by these problems will span several chapters or topics in a traditional textbook. This will allow problems to be used from a single scenario throughout the semester. It is expected that a greater sense of cohesion and continuity in the material will therefore be generated.

II. Background for Initial Scenario

To test the Scenario concept, material is being generated around the engineering facilities of Minnesota State University Mankato (MSU), located in southern Minnesota. The campus consists of approximately sixteen academic buildings, three dormitories, and supports over 12,000 students. To address the University's heating and cooling needs the Facilities Department maintains a centralized facility plant and equipment distributed across campus. Equipment at the facility plant has expanded over the last two decades to include many processes which can be used to relate thermodynamic theory to the real world.

There are four boilers installed at the facility plant which supply all of the campus's heating needs. Steam flow rates vary from 7,000 lb/hr up to 50,000 lb/hr. This steam is used to heat rooms and provide hot water for dishwashers, bathroom facets and showers. Steam is produced by the boilers at 150 psi (gage) and 366°F and sent out to the campus buildings. Once the steam reaches each building it travels through pressure relief valves which maintain a building steam supply pressure of 10 psi (gage). This steam is then used for a variety of purposes. Some of the steam is sent through heat exchangers which heat a separate supply of water for distribution to the perimeter of the building for heating units similar to traditional radiators. Other steam is sent through a hot water heater to supply laboratories and rest rooms with hot water. The rest of the steam is sent through the air handlers throughout the building. The size of the building determines how many air handlers are installed. After use the steam is sent to a condensate collection tank. Once the condensate tank has enough water collected a pump is turned on to send the water back to the facilities plant. As the condensate returns to the facilities plant it is sent to another holding tank. This tank holds 5,000 gallons of water and is the supply to the boilers. As the water leaves the tank it is pumped back up to a pressure of 150 psi (gage) and is sent through the boilers to repeat the process again.

There are also three "chillers" installed with a total capacity of 3200 tons that provide air conditioning for the majority of campus buildings through chilled water distribution. The distributed steam and chilled water is run through air handling units in each building to heat or cool the air being supplied to the building space. Supplying the buildings with air conditioning works similarly to the steam cycle but in a slightly different manner. The chilled water exiting the evaporator of each chiller is directed into a main pipe and supplied to two 200 horsepower pumps. These pumps supply the campus buildings with chiller water. As the chilled water reaches the buildings it is sent through the air handlers to cool the air supply. After the chilled water has been used it is returned to the Facilities plant. Used chilled water is sent back to the plant in one main pipe and once reaching the chiller room is split between three different chillers. Each chiller has its own pump for the chilled water returning from campus, so depending upon which chillers are turned on; those valves will be open to receive incoming chilled water. The ideal temperature for this cycle is 45°F going out to the buildings and 55°F coming back. The chillers then remove energy from the water by transferring it to the refrigerant in the evaporator. The energy is then rejected from the refrigerant to a condensate water loop in the condenser. The condensate water leaves the condenser and is sent to three dual cell cooling towers outside of the facility plant. The water is poured into a basin which then overflows onto the wet deck. Air is brought into the tower through the wet deck and exits the top of the unit via a 30 horse power fan. Energy is rejected by evaporation and the remaining water is collected in a basin at the bottom of the tower. Water is then added to make up for the lost evaporated water. This water is then pumped back to the plant via three pumps of varying size.

In addition to the heating and cooling, the Facility plant is also responsible for emergency power generation. There are two emergency diesel generators able to supply power within 10 seconds of a power failure for exit signs and emergency lighting. The two KATOLIGHT diesel generators produce a total of 1200 kW. Another three diesel generators provide stand-by power for the University's full load. The three stand-by generators are designed by Caterpillar and are capable of producing 6 MW of electricity. This allows campus to be taken off of the local utility's grid to reduce overall load during peak demand and decreases the price the university pays in electricity to a constant $0.045/kWh by qualifying as a curtailment customer. Energy needs on campus vary according to time of day and season. For this reason the stand-by generators are usually designated to run on hot and humid days during the summer when the utility has the highest demand.

In terms of design discussion MSU offers several case study possibilities, demonstrating both good and poor design. In 1995, the decision was made to install a cogeneration unit at MSU. Currently in place were four boilers with a heat capacity of 225,000 lbs/hr, along with one 1,000 ton centrifugal chiller. The boilers produced steam at 150 psig which was then sent out to the buildings on campus. After reaching a building, the steam was reduced by pressure relief valves to approximately 10 psig. The number of pressure relief valves varied according to the size of the building. After traveling through heat exchangers and air handlers in the building condensate was gathered in a holding take at each building. The condensate was then pumped back to a pressure of 150 psig to be fed into the boilers again. MSU hired a consulting firm to gather data about the steam system and determine if a cogeneration system would be a sensible investment. The resulting design consisted of a Coppus model RLHB24 single stage turbine and Reliance Frame E5010S generator. In 1997 the installation of the 434kW cogeneration system was completed. Saturated steam entered the turbine at 150 psig and 366°F and exited at 50 psig and 297°F. The unit was able to accept a steam mass flow rate up to 40,000 lbs/hr, any additional steam that was produced above this amount was sent through a bypass valve. The bypass valve reduced the pressure of the steam to 50 psig to be combined with the steam exiting the turbine.

However, during the first winter of operation campus buildings were not receiving the required amount of heating. This was due to the decreased pressure of the steam being supplied to the buildings. Pressure relief valves at each building were designed to keep a constant pressure on the building side of the valve around 10 psig. With the increased steam demand during the winter months the amount of flow rate supplied by the pressure relief valves was significantly lower than what they were designed for. The pressure relief valves operate due to a pressure differential across the valve, in this case 150 psig to 10 psig. When the cogeneration unit was installed the differential changed to 50 psig to 10 psig. With this pressure change the current valves let a maximum amount of steam flow into the building one third less than the required amount. Attempts were made to adjust the exiting pressure of the turbine to a higher value, however; this had the effect of lowering the turbine's efficiency. In addition to the unachieved heating loads, the turbine was not designed to handle the variable loads of the campus system. The peak efficiency for the turbine is obtained at a flow rate of 40,000 lbs/hr. However, when in operation a flow rate of 8,000 lbs/hr was all that could be guaranteed. Running the turbine at these low flow rates caused a large drop in efficiency. Because of these problems the co-generation turbine was eventually taken out of service and has not been used for several years. It is currently scheduled for removal.

III. Description of Initial Scenario Site

Over the course of Summer 2006 two undergraduate research assistants determined everything they could about the facility equipment and the co-generation design on campus. Photographs were taken of the equipment, interviews were held with plant personnel, and plant data was reviewed for many operational aspects. From this a narrative was created explaining all of the major systems on campus and how they operate. Pictures and schematics of the systems were included as well as links to manufacturers' websites and specification sheets. The initial Scenario was then built from this information.

Due to the large amount of cross referenced information which can be included in material of this sort an electronic format is preferred. However, the manner in which this has been done is being guided by a formative assessment process which has included a student focus group concerning textbook formats. A group of students who had already taken both thermodynamics courses was asked to review several textbooks which use different formats. Interestingly, online and electronic materials did not review well with the students. There was a definite preference for a traditional hard bound textbook. Taking this into consideration care has been taken to structure the Scenario material so that all problems and text sections can be opened in an alternative pdf format for printing.

A Scenario is generated from a combination of the generated narratives, skill-based problems, and design problems. Skill-based problems differ from existing textbook problems in that they are written in the context of the existing facility instead of being written in generic terms. By basing these problems on a specific and well-researched facility the instructor's knowledge is fortified and the student's interest can be exploited to encourage greater engagement. Even if a student is not motivated to research beyond the problem statement the added visual information and the move from a generic problem to one with its' own identity is expected to increase student engagement and subsequently performance. As with skill-based problems design problems are written in the context of the scenario environment and will take into greater consideration the normal tasks required of an engineer there. All points of the description, data, and objectives are being taken from the real-world facility. Coupled with this will be an in-depth description of how the problem was approached and solved in reality through an industry modeled solution of the basic design problem, and the full industry solution encompassing all related issues (including those not covered in the course). The full solution will be presented as a first person accounting from the on-site engineer (similar to a case history). This is intended to strengthen the exposure to real-world practices, provide valuable information to the student, and provide greater appeal through increased student interest.

Currently the material is still in the preliminary development stages. The main interface screen can be seen in Figure 1. A first draft of the narrative material is complete. Content is divided into major sections with specific information linked within the narrative (Figure 2). Numerous skill based problems were generated for a first semester thermodynamics course (Figure 3), however; only a few of these have been pursued to full Scenario formatting and used in a class. Examples of the pdf versions of these are shown in Figure 4 and Figure 5. One short design problem was also developed and was included under the heading "Plant Assignments" (Figure 6).

IV. Continuing Development of the Material

Currently the material is still under development. During the Fall 2006 semester the preliminary material was used and assessed in an introductory thermodynamics course. This was done mainly for purposes of working out "bugs" in the system and getting student feedback on the format. The assessment data is more fully described in a companion paper[16]. Several general results did emerge. Results indicated the students come into thermodynamics with high expectations of being exposed to real world problems. Using a traditional textbook and course format these expectations are not met. By using several of the Scenario skill based problems in place of textbook homework the before and after disparity was largely eliminated. However, no appreciable changes were noticed in student performance on examinations or concept inventories by this limited use.

Through the course of the Spring 2007 semester skill based and design problems will be finalized for the Applied Thermodynamics course (i.e. Thermodynamics II). These will include several problems related to the design and use of the co-generation system. They will be assessed during this semester. Based on these initial trials the material will move to its Beta format during the course of Summer 2007 for a full assessment during the 2007-2008 academic year.

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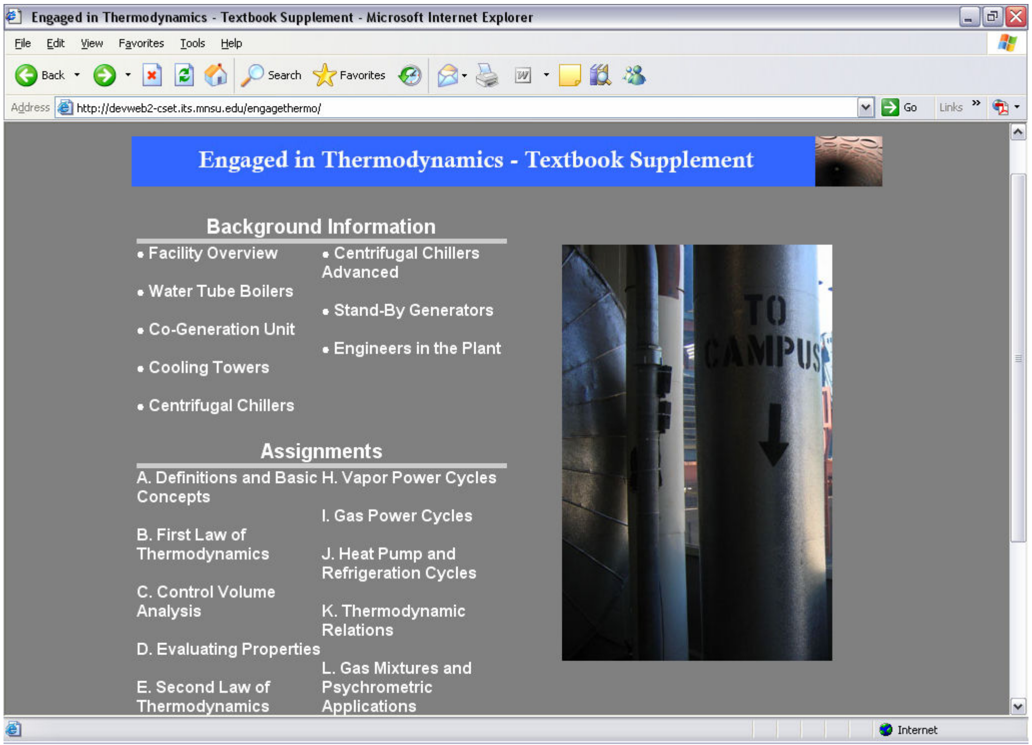


Figure 1: Main interface screen for the Engaged in Thermodynamics material (a portion of the screen is cut off at the bottom).

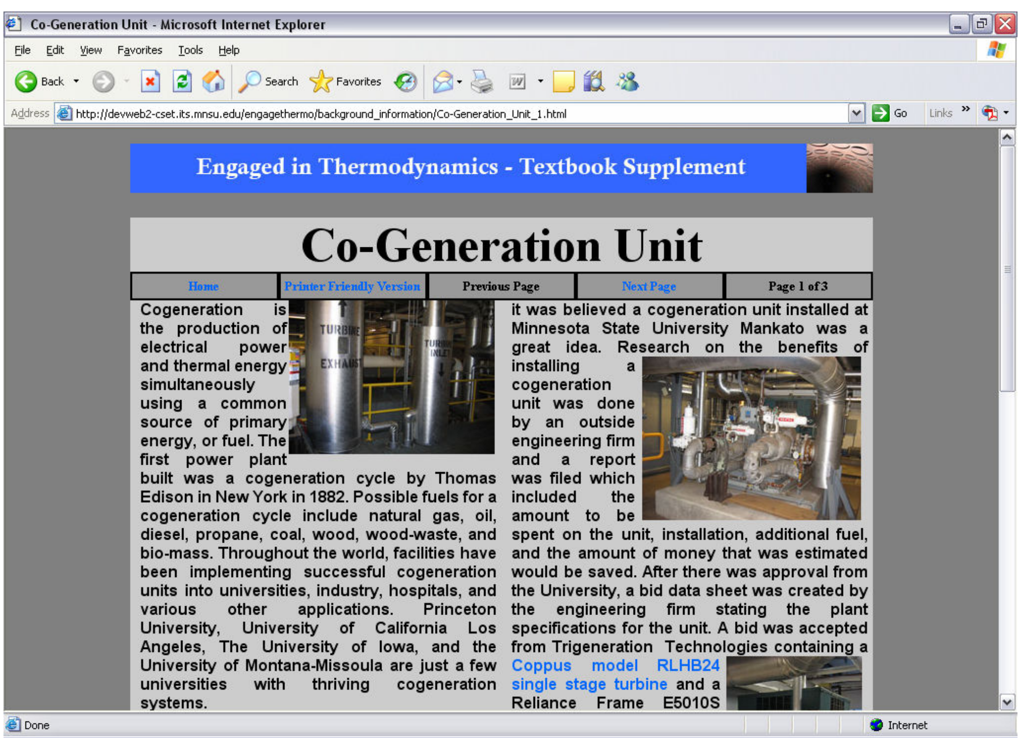


Figure 2: Top of the Co-Generation narrative demonstrating use of equipment photographs and linked manufacturer data.

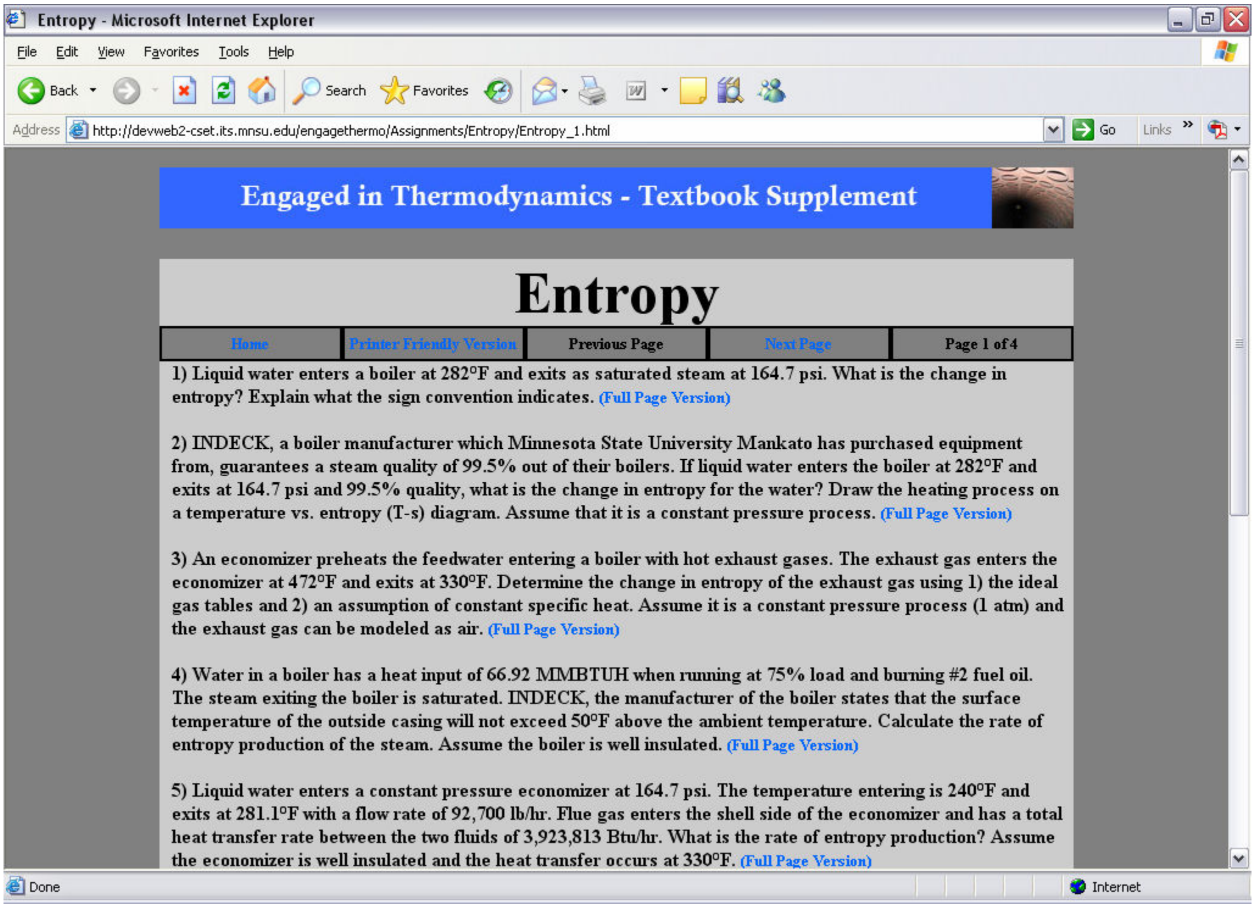
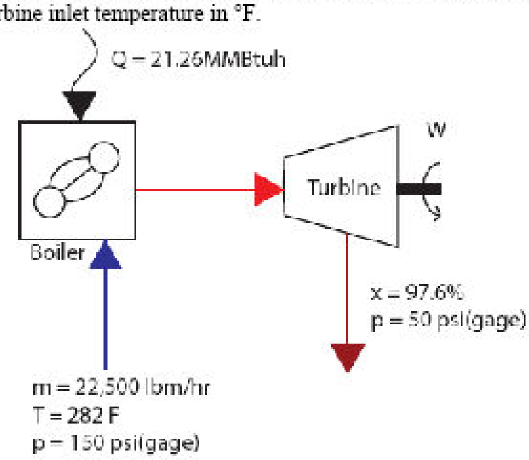


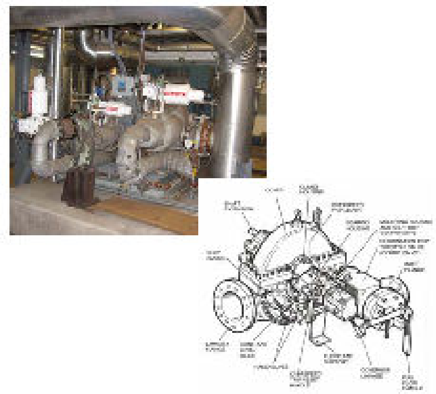
Figure 3: Screen shot of skill based problem list for the Entropy section.

Engaged in Thermodynamics - Textbook Supplement

Name: Course: ID #:
Due Date: Problem No.

Consider the MSU boiler and cogeneration turbine together as a system (as shown below). The flow rate through the system is 22,500lbm/hr with an output quality of 97.6%. The boiler supplies 21.26 MMBtuh of heat transfer to the water. The inlet conditions of the boiler are a pressure of 150 psi(gage) and temperature of 282 °F and the outlet pressure is 50 psi(gage). In order for the Director of Facilities to determine if the turbine is cost effective the amount of work produced must be known. Determine the amount of work in kW produced by the turbine and the turbine inlet temperature in °F.





MSU NSF

Figure 4: Example of a control volume skill based problem which uses the co-generation steam turbine as its basis (shown in student printable pdf version).

Engaged in Thermodynamics - Textbook Supplement

Name: Course: ID #:
Due Date: Problem No.

The refrigerant (R-134a) within the McQuay chiller operates at 37.0 psi (gage) in the evaporator and 116.2 psi (gage) in the condenser. The water side of both the evaporator and condenser operates at 150 psi (gage). Water enters the evaporator at a temperature of 52.9°F and exits at 44°F at 2,000 GPM. The R-134a refrigerant leaves the condenser as a saturated liquid and leaves the evaporator as a saturated vapor. An ideal chiller of this type using R-134a has a coefficient of performance of approximately 6.2. To evaluate the performance of this chiller determine the mass flow rate of R-134a in lbs/s and the work input to the compressor in kW. NOTE: A refrigeration cycle consists of a condenser, throttling valve, evaporator, and compressor in series.

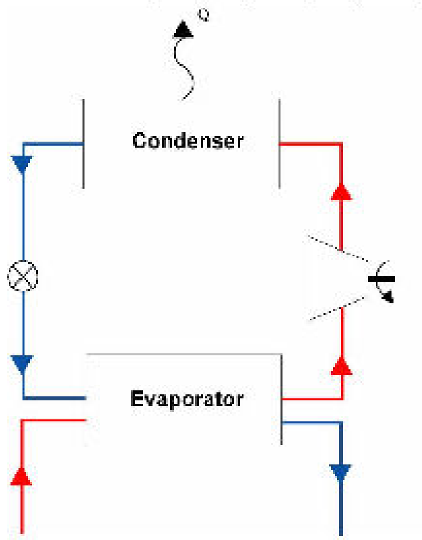


Figure 5: Example of a control volume skill based problem which uses one of the vapor compression chillers as its basis (shown in printable pdf version).

Engaged in Thermodynamics - Textbook Supplement

Plant Assignment: Evaluating Refrigerant Options for Use on the Minnesota State Mankato Campus

The Task in Perspective

The Minnesota State University campus in Mankato employs three centrifugal chillers. These chillers produce cold water which is used for air conditioning across campus. With the building expansions currently planned these three chillers may prove to be insufficient to produce enough chilled water. Therefore, the MSU Facilities Department is currently considering the addition of a fourth chiller. These are referred to as high/medium and low pressure chillers, respectively. Typically a bidding process is used where possible vendors propose units which will satisfy the stated needs. However, it is the Facility staff's responsibility to critically evaluate the bids and determine which is actually best for the University.

Work Assignment

The existing equipment includes chillers which use R-134a (HFC-134a) or R-123 (HCFC-123) as the refrigerant. Assume the Chief Engineer has determined that a R-134a chiller is preferable. Prepare a report for the Physical Plant Director which evaluates the two refrigerant options (i.e. a R-134a or R-123 based chiller) and justifies this recommendation based on the positive and negative considerations of 1) environmental impact, 2) refrigerant availability, and 3) thermodynamics. For item #3 produce a system schematic, a Pressure-Enthalpy (P-h) process diagram, and calculate generic motor horsepowers for the two possible chillers.

Additional Information

Typical coefficients of performance for R-134a and R-123 chillers are 6.28 and 6.76 respectively. In both cases subcooling and superheating are ignored (i.e. the quality out of the condenser is zero and the quality out of the evaporator is unity). An equipment life of 30 years and a nominal refrigeration capacity of 1000 tons can be assumed. A table of thermodynamic properties for R-123 is available in the Engaged in Thermodynamics Additional Documents section. Information on the existing Trane and McQuay chillers is also included. Typical pressures for each refrigerant can be found in the Centrifugal Chillers and Centrifugal Chillers Advanced sections of the Background Information.

MSU

NSF

Figure 6: Short design problem used in introductory thermodynamics course based on the selection of a new campus chiller (shown in student printable form).