Technology-Hospital Collaboration in Thermodynamics

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Abstract

In order to provide a real example of applied thermodynamics, the Purdue School of Technology located in Columbus, Indiana and the Columbus Regional Hospital have agreed to work together to demonstrate and investigate the various thermodynamic systems operating at the hospital.

During a junior-level Applied Thermodynamics class in the spring of 2003, the students were given a tour of the hospital facilities; although no specific projects were attempted using the hospital's systems. This paper will outline specific projects at the hospital that may be assigned to students to supplement the classroom material. These projects will be presented to the junior-level Applied Thermodynamics class in the fall of 2004.

Quantities such as power, heat flow, energy and efficiency will be explored along with the various thermodynamic cycles utilized throughout the hospital. Pressure, temperature, and volume data will be recorded and compared, especially between heat exchanger components.

Examples of systems to be investigated include the water chiller with its cooling tower and associated air handling capabilities; the boilers, which produce high, medium and low pressure steam for various uses throughout the hospital; the oxygen-delivery system that starts with liquid oxygen and is converted to oxygen gas for patients.

While this look at a real business and its utilization of thermodynamic principles will certainly benefit the students, the hospital facilities' staff can expect highly detailed reports of their systems including analysis and potentially some recommendations for improvements. These reports may be used by the staff for training and learning activities that might help them understand why the corrective actions specified in their troubleshooting manuals are successful.

Introduction

During the past several years, the Purdue University School of Technology at Columbus/Southeast Indiana has joined with Columbus Regional Hospital to offer two or three *Technology in Action* days for local high school students. The focus of this effort has been to introduce young people to careers at the hospital or in the medical profession that are unrelated to training in medicine. Indeed, careers in computer technology and mechanical engineering technology are emphasized.

A short presentation is given by representatives from both the hospital and Purdue University informing the students of what they will see during the hospital tours that comprise the majority of the students' visit. There are four separate tours:

1. the computer networking facilities
2. the computer technology section that provides hardware update/repair, software update/installation and other associated services to the hospital staff
3. the mechanical repair section whose purpose is to make repairs to hospital equipment such as beds, IV machines and other mechanical devices.
4. the hospital facilities management section

The high school students are divided into four groups and each group tours each of the four areas.

Typically, the tour of the facilities management section is led by co-author David Lenart. During the tour, the students have an opportunity to see areas of the hospital that much of the general public never sees, including the boilers that produce heat and steam, and the associated piping. Other highlights of the facilities tour include the system used to deliver gaseous oxygen to individual patient rooms; systems to heat and cool the hospital; power generating systems to provide back-up power in the event that power from the local utility is lost.

Co-author Dr. Fuehne joined the students on these tours during 2003 and recognized the potential for active learning for thermodynamic and fluid power students by engaging them to investigate these systems with group projects. In order to judge how students might receive these projects, an Applied Thermodynamics class in the spring of 2003 was taken on a tour of the hospital facilities, emphasizing the thermodynamic systems. This tour did not involve specific group projects but gave the students an opportunity to observe the various thermodynamic systems of the hospital. Students generally found the tour of the systems interesting and enjoyed the opportunity to see real applications of the fundamental concepts they were studying.

Specific Potential Projects

1. Liquid/Gas Oxygen Handling System[1]
   A critical hospital system is the delivery of gaseous oxygen to patient rooms. The Columbus Regional Hospital (CRH) uses a system with one tank continuously supplying the piping system while a secondary tank containing at least an average day's supply is held in reserve. Specifically, the system is a 3000/11000-gallon primary system with a 350/1500-gallon reserve. Brazed copper pipes are used for the piping network delivering the oxygen because of their increased resistance to ignition and lower combustibility than other materials. Similar oxygen compatible materials are used for other parts of the system.

   The oxygen starts as a liquid in an outside tank at a pressure of 150 psi. By undergoing a volumetric expansion to 90 psi, the liquid oxygen is evaporated and controlled by a pressure regulator set at 52 psi. Pressure limit switches are utilized at each zone to warn of low pressures.

   In patient rooms, centrifugal pumps create a vacuum of 20 mm of mercury. By using the equation below and noting the appropriate unit conversions,

   $$\boxed{\text{Pressure} = \{\text{density of fluid}\} \times \{\text{gravitational constant}\} \times \{\text{height of fluid}\}}$$

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   this vacuum represents about 0.39 psi. Flow meters are used to control the flow of oxygen to the patient. The system is designed to handle about 20 patients simultaneously.

   The study of the evaporation process of the oxygen is an outstanding project related to tracking the oxygen as it moves through the vapor dome with changing pressure, volume and temperature. Figures 1 and 2 show the pressure-volume vapor dome and the pressure-enthalpy vapor dome for oxygen. On both plots the left side each curve up to the peak is the liquid line and the right side is the gas line.

   The boiling point of liquid oxygen under atmospheric pressure is -297.4 °F. When subjected to 150 psia pressure, the boiling point increases to -243.3 °F since additional heat is needed to overcome the pressure. In both of the figures, constant temperature lines run across the vapor dome. During evaporation, the pressure and temperature of a liquid-gas mixture remain constant as all the heat input to the system is used to change the phase of the oxygen from liquid to gas.

   As an example, in Figure 2 the difference between the enthalpies between state A and state B represents the heat required to convert all of the liquid oxygen to gas at 125 psia pressure and -235 °F. Under the vapor dome, the pressure and temperature are not independent, meaning that a change in pressure will produce

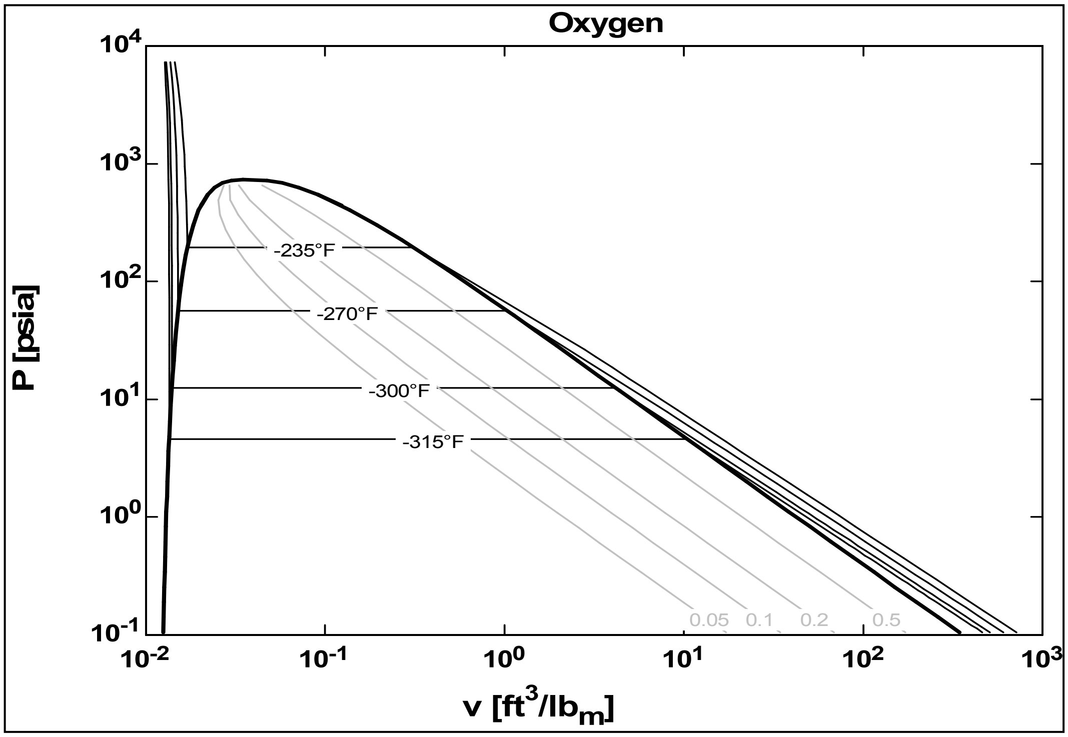

Figure 1. The pressure-volume vapor dome for Oxygen

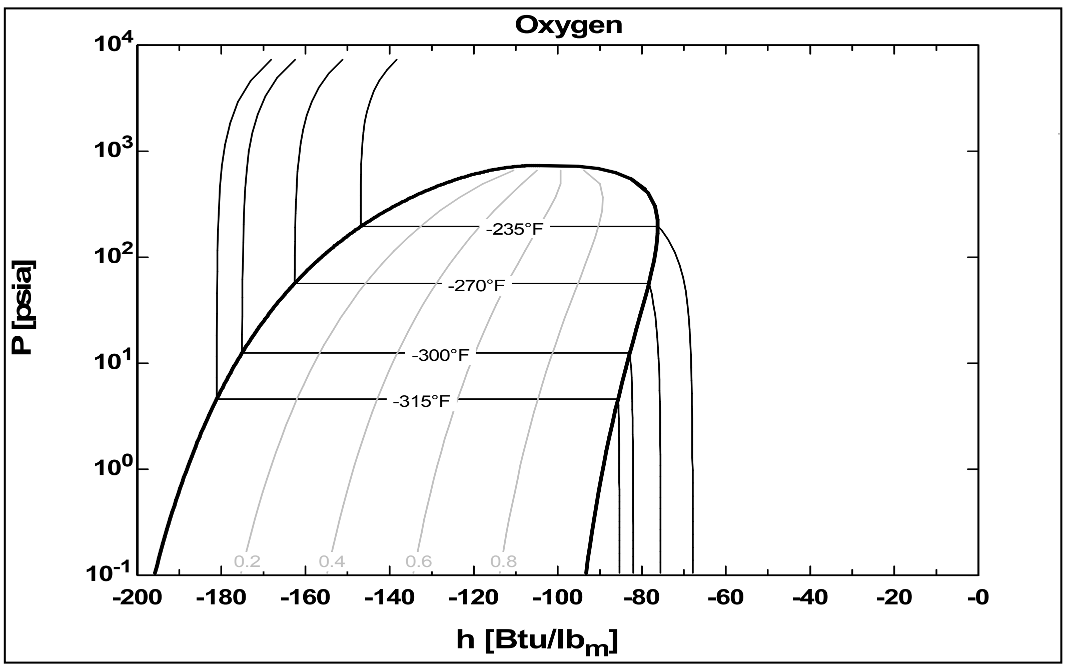

Figure 2. The pressure-enthalpy vapor dome for Oxygen

a corresponding change in temperature. Outside of the dome when only gaseous oxygen exists, pressure and temperature are independent and temperature increases as the pressure is decreased through the pressure regulator. That the external oxygen tanks are coated with ice year-round suggests significant heat is pulled from the surroundings of the liquid oxygen to produce the gas. A project to quantify the interactions would be fascinating.

Although pressurizing the tank requires energy and minimizing energy expended is always a reasonable goal, this goal must be balanced with material requirements that prevent embrittlement and functional requirements that require the use of liquid oxygen to keep tank volumes small. A student project could investigate the ramifications of using a higher or lower pressure on the liquid oxygen.

In Figure 1, it's evident that as the oxygen is evaporated its volume increases anywhere from 100 to 1000 times, emphasizing the practicality of storing oxygen as a liquid rather than a gas.

2. Other gas and vacuum systems similar to oxygen may also be studied. Those include compressed nitrogen to drive various medical tools; nitrous oxide for use with anesthetic systems; carbon dioxide that is piped to open-heart operating rooms; and normal air that is delivered to patient rooms.

3. Pump Efficiencies in the Chilled Water System[2]
A schematic of the chilled water system in use at the CRH showed numerous pumps used throughout the hospital. Simple pressure taps at the inlet and outlet of the pumps would produce an actual pressure head using the equation below:

$$\boxed{\text{Pressure Head} = \frac{\{\Delta\text{Pressure}\}}{\{\text{gravitational constant}\}\times\{\text{density of fluid}\}}}$$

Knowing the measured pressure head leads to calculation of the actual power transmitted from the pump to the fluid. The equation is

$$\boxed{\text{Actual Power}=\{\text{pressure head}\}\times\{\text{specific weight of fluid}\}\times\{\text{Volume Flow Rate}\}}$$

This value can be compared to the rated pressure head of the pump which leads to its efficiency. The equation to compute efficiency is

$$\boxed{\text{Efficiency}=\frac{\{\text{Actual Power}\}}{\{\text{Rated Power}\}}}$$

Although simple in concept, this project is challenged by having to gather the data for each pump. Problems such as the inability to shut down the system in order to install the pressure taps are possible.

4. Air Handling System Boiler
   Another example of a good thermodynamic project is the air-handling system of the hospital. The system starts at the boilers which are producing superheated steam at 10 psi. An investigation of the boiler includes determining the heating value of the fuel used and the amount of fuel required to produce the needed steam. This leads to a calculation of efficiency and to an economic analysis to establish if there are better ways to generate steam.

5. Air Handling System
   The superheated steam from the boiler is used in a counter-flow heat exchanger to heat glycol from 135°F to 155°F. This heated glycol, which exits the heat exchanger at 82 psi, is then used to heat the air that is brought in from the outside and subsequently circulated around the facility.

   Steam is not used to directly heat the air because the steam condenses and produces a water hammer effect in the coils. Corrosion difficulties are also possible with water remaining in the bottom of coils.

6. Water Chillers
   A cooling tower outside of the hospital acts like a condenser in a refrigeration cycle extracting heat from the refrigerant. Piped back into the hospital, the refrigerant removes heat from water that is continuously supplied at 55°F throughout the hospital. Defining the refrigeration cycle and determining the Coefficient of Performance for the cycle as well as efficiencies is another excellent project. Isentropic simplifications and their accompanying error may also be investigated.

Benefits to Students

The benefits of project work such as this are several.

1. The students' exposure to real systems with real components in a fairly ordinary place as a hospital emphasizes that technology and, particularly, thermodynamics is everywhere. Certainly, these types of projects demonstrate to students the principles of thermodynamics in systems that are not just in a text book.

2. Much of industry currently places great importance on teamwork. While grouping students to do class projects is not a new or unique idea, it does build the soft or people skills that organizations desire. Furthermore, accreditation agencies are emphasizing these skills in their requirements[3].

3. Likewise, all organizations value effective communications skills. Again, while this idea is not new, projects that require written reports and oral presentations help to build those skills and these proposed projects would require both. As before, technology accreditation agencies are increasingly pointing to improving communication skills as an essential part of technology programs.

4. Students appreciate a break from classroom work and enjoy hands-on activities that are important to engineering technology programs. These projects aim to increase those opportunities to students, particularly in a sometimes challenging subject like thermodynamics.

Benefits to Hospital

The hospital will receive copies of all the project reports and will be invited to the final presentations. The students' work may find inefficiencies or problems that hospital staff may not have resources to investigate. In fact, the students' reports may likely become a resource for the hospital staff, helping to increase their understanding of the complex workings of the thermodynamic systems that they maintain and troubleshoot.

Conclusions

An engineering technology-industry collaboration is described including the Purdue School of Technology in Columbus/Southeast Indiana and the Columbus Regional Hospital in Columbus, Indiana. Numerous projects for thermodynamics classes are outlined with benefits to both students and the hospital. Projects will be initiated in a junior-level applied thermodynamics class during the fall semester of 2004. Written reports and oral presentations will be required to emphasize communication skills. This collaboration between Purdue School of Technology and the Columbus Regional Hospital promises to be a win-win for all concerned.

References

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