Energy: Properties and Policy Issues

Abstract

Students following a curriculum designed to provide a degree in mechanical engineering (ME) inevitably take one or more courses in *Thermodynamics* along the way. One of the many keys being addressed in such courses is the Principle of Conservation of Energy, otherwise known as the First Law of Thermodynamics. Whereas one of the program accreditation requirements specifically addresses the need to incorporate design of components or processes of thermal systems[1] into the curriculum, does this necessarily include all (or any) of the following: fossil fuel combustion, greenhouse gas production, alternative energy sources, energy conservation, or energy policy?

It is our contention that, in light of the demand for global solutions to environmental problems which include unsanitary drinking water, inappropriate recycling of heavy-metal laden used electronics, and the free release of toxic gases due to the combustion of mixed-waste streams (just to name a few), mechanical engineering students should be required to incorporate energy policy issues into their required thermal designs.

This paper assumes that the reader has an introductory knowledge of *Thermodynamics* and thus understands the definitions of heat, work, internal energy, enthalpy, and entropy. Though textbook examples and end-of-chapter problems are designed to move students from knowing the principles to problem-solving, components such as the piston-cylinder device or the adiabatic compressor are isolated from their power sources. In an effort to complete the picture for our students, design of power plants was added to the course content of thermodynamics for mechanical engineering students (MEs). The Single Rankine Reheat power plant will be considered here for our discussion. Efficiencies along the energy conversion path are computed and projections are made for the use of alternative fuels in the supply chain.

Students, rather than simply learning how to compute entropy changes for individual process steps, learn how to place a "value" on their thermal systems. By design, the "value" is based both on economics and ethics.

Introduction

Mechanical Engineers are facing a challenge in today's marketplace in areas of energy production and delivery. Coal power plants are being considered major polluters due to their large carbon dioxide (CO_2) output.[2] Nuclear power plants, though "carbon-free", are seen by some as potentially dangerous to the environment due to the lack of a proper burial site for spent fuel rods.[3] Thus, alternative energy sources such as solar, wind, biomass, or even natural gas are being considered more highly favored for their "green" nature.

But what are the trade-offs? Cost is clearly on the minds of persons across the globe due to the tough economic times in which we find ourselves. How much will converting to green technologies push those already struggling to survive past their limit to afford energy and goods?

Food for the hungry is another consideration. A strong outcry has erupted over the use of food products (such as corn) for the production of ethanol to be used as a fuel.[4] Thus, discussions of both ethics and economics should clearly be part of any decision to convert from the use of coal to alternative fuels in new designs for power plants.

Project Specifications

Junior MEs taking *Thermodynamics* are introduced to many of the fundamental principles (work, heat, quality, enthalpy, entropy, and efficiency) and components (piston-cylinder, throttle, nozzle, diffuser, compressor, pump, boiler, condenser, and turbine) which are incorporated into energy production. Energy-producing cycles such as Carnot, Otto, Diesel, Brayton, Stirling, and Rankine are proposed as models and analyzed so that students can address how alterations improve or reduce the efficiency of each. Our course is a five semester-hour course whose topics range from introductory concepts of energy through refrigeration cycles and concludes with an introduction to the psychometric chart.

This paper reports on a power plant design project which relies on the Single Rankine Reheat Cycle powered by the burning of coal used as the baseline for alternatives. On the Wednesday when students took their Rankine cycle quiz, the project was distributed to the students who were able to ask questions about the project during class time the following day. Class time was suspended for the following two days, creating a four-day weekend over which students would get together in their groups and work through the project which was collected one week from the day it was assigned. Each group of five (5) students was provided the following information: net plant power output, pressure (P) of high-P turbine, inlet temperatures of both high-P and low-P turbines, and net plant efficiency (based on percent Lower Heating Value — %LHV — of the fuel). Students were asked to identify reasonable values of the quality of the steam in each of the turbines as well as pump and turbine adiabatic efficiencies. From this collective information, they were tasked to compute the cycle thermal efficiency. Given that the net plant efficiency could be written as the product of three contributing factors:

$$\eta_{net} = \eta_{th} \bullet \eta_{fc} \bullet \eta_{ec} \qquad \text{(EQ 1)}$$

where η_{th} is the cycle thermal efficiency, η_{fc} is the fuel conversion efficiency, and η_{ec} is the electrical conversion efficiency, students were asked to find at least one of the non-computed values on the right-hand-side (RHS) of equation EQ 1 and compute and compare the remaining unknown efficiency.

Students were then given an alternative fuel source to research. When the alternative fuel was a "heat producer" (i.e. either a hydrocarbon or nuclear), students were asked to assume that their coal plant could be simply converted for use of their alternative fuel. Clearly, this approach would not work for direct electricity producers (wind, solar, and hydrogen fuel cell).[5] All groups were required to research the literature to gather information about comparable plant construction cost, electricity generation cost, and CO_2 output. The costs were to be compared apples-to-apples with coal. That is, the mining, refining, and transporting of each fuel was to be considered embedded in the power plant electricity production costs quoted by the students.

Results

Table I reports the students' findings. Each group was asked to analyze a different power plant,[6] thus the computed thermal efficiencies (η_{th}) are uniquely determined for the specifications of the particular Single Rankine Reheat Cycle used at their given facility. The cost column is electricity generation cost and thus varies with location due to fuel availability and transportation surcharge costs for a given fuel. Student comments are summaries of their findings and not direct quotes.

Table I Student-reported results

Team	Fuel	η_{th}*	$/MWh**	CO_2	Student Comments
1	Coal	44%	60	High	Co-Fired plants replace 15% of coal and reduce emissions by 18%; Renewable and thus carbon-neutral
	Biomass	44%	50-100	Moderate	
2	Coal	46%	50	High	Plant construction and supply costs are lower for Nat Gas while it combusts more cleanly than coal; Win-Win
	Nat Gas	46%	45	Moderate	
3	Coal	42%	50	High	Nuclear plant construction cost prohibitive due to government regulations; Must identify proper disposal for nuclear waste
	Nuclear	42%	130	Zero	
4	Coal	44%	60	High	Solar has very low environmental impact except for land usage; Cost for solar over coal must be abated
	Solar	NA	180	Zero	
5	Coal	43%	60	High	Life cycle of wind technology is unlikely to recover capital costs; Unpredictability of energy supply forces back-up systems
	Wind	NA	30-70	Zero	
6	Coal	42%	50	High	H_2 production too expensive; H_2 delivery in cold climates problematic; CO_2 recovery and burial seems most promising
	Hydrogen	NA	175	Zero	

* Rankine thermal efficiencies are Not Applicable for direct-conversion energy sources
** $/MWh are in 2008 dollars and represent fuel cost passed along to the consumer

Discussion

One of the objectives for the project was to have students expand their problem-solving minds, which usually close shortly after they have computed a numerical answer to a problem. Clearly, encouraging students to think more about the problems they are solving is worthy of their time. Even the computational component of this project provided an excellent source for an "ah-ha" moment in the minds of the students. Classroom discussion which took place over the week during which this project was assigned included remarks such as the following:

> If my net plant efficiency is 40%, and if my calculation for the thermal efficiency of the cycle is 44%, that requires the fuel conversion and electricity conversion efficiencies to be on the order of 95% each...that can't be possible, can it?

Since the students had solved many problems computing the efficiency of engine cycles (Otto, Diesel, and Brayton) and recorded the dismal results for the efficiency of these internal combustion work-supplying devices, the thought that any combustion process could yield up to 95% of the fuel's available energy was astounding.

Another objective for the project was to require students to address the issue of Climate Change from an energy-supply perspective. As seen from the Student Comments section in Table I, CO_2 output was a major part of their discussion as they delved into an alternative fuel as compared with coal. The impact upon the student as citizen can not be understated. The students understood that, independent of whether or not CO_2 in any way affects the climate, certain fuels produce certain amounts of CO_2. Their research brought them face-to-face with the amount of CO_2 delivered to the atmosphere by coal-fired plants as the following quote suggests:

> for every million BTUs of energy produced by a coal power plant, 205 pounds of carbon dioxide are released into the environment.[7]

The cost-benefit analysis performed for this project was also a common focus among the students as they compared two fuels. Though the *Engineering Economics* module taught to our MEs is integrated into their senior-year *Manufacturing* course, the students stepped up and made economic evaluations without the formal understanding of cost basis, capital investment, or depreciation. By working through the details of this project, students were able to move past the simple delivery charges of goods and delve into plant construction and transportation costs associated with alternative energy systems.

Discussion of ethics in engineering practice are rarely integrated into engineering curricula. This project provided an opportunity for students to make "value" judgements as they contemplated their trade-off analysis. As seen from their comments in Table I, many see cost as the most problematic negative when considering an alternative fuel. Though most suggest that the reduction of carbon dioxide is important, very few would be willing to have this reduction at any cost. For example, those students who were given solar energy to consider expressed the following concerns:

If money is the main motivator, coal power is hands down the winner. Solar power costs three times as much to produce on a day to day basis. Solar power is also a tough sell to a businessman since a 600 MW coal plant costs $500 M less than a comparable solar power plant. Money isn't everything, though. The shift in thinking towards environmentally friendly power plays to solar power's strength over coal.[8]

Conclusion

A mechanical engineering (ME) education includes many topics which are essential to the problem-solving career MEs are known for. The ABET requirement for "design of components or processes of thermal systems" might be satisfied by a course or other experience during which all students design and fabricate a pump or compressor or heat exchanger. We have chosen to integrate energy production and policy into a project through which students are encouraged to become more active as citizens. Our hope is that future generations of MEs will be more globally aware than their predecessors. Wouldn't it be wonderful if clear-thinking, problem-solving, unbiased MEs would become involved in developing our nation's energy policy?

1. *Criteria for Accrediting Engineering Programs*, 2008-2009 Evaluation Cycle, pg. 15. (http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2008-09%20EAC%20 Criteria%2012-04-07.pdf) last visited 11/10/2009.

2. Matthew Brown, "Coal-fueled power plants being put on trial," *Dayton Daily News*, Cox Publishing, Sunday, January 20, 2008.

3. Associated Press Release, "Official: Nuclear waste won't go to Nevada site," *Xenia Gazette*, Greene County Dailies Publishing, Friday, March 6, 2009.

4. Ben Sutherly, "Ethanol use hitting home," *Springfield News-Sun,* Cox Publishing, Saturday, June 2, 2007.

5. Plants designed for direct electricity generation (solar, wind, and hydrogen fuel cell) would not have Rankine cycle thermal efficiencies.

6. "Advanced Power Plant Using High Efficiency Boiler/Turbine," DTI Best Practices Brochure #10, January, 2006. http://www.berr.gov.uk/files/file30703.pdf, last visited 03/16/10.

7. Jillanne Conway, et. al., "Thermodynamics Group Project," [Left Blank for Review], Fall 2009 and U.S. Energy Information Administration, "Voluntary Reporting of Greenhouse Gases Program Fuel and Energy Source Codes and Emission Coefficients," http://www.eia.doe.gov/oiaf/1605/coefficients.html, last visited 01/07/10.

8. Ibid.