Session 1333

Development of Web-based Tools for Energy Engineering

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Abstract

With increasing popularity of World Wide Web (WWW) as a teaching medium, more and more engineering educators have developed web-based teaching and evaluation tools to facilitate and improve the learning process of students. In this paper, the development of two web-based tools for use in Energy Engineering course was presented and discussed. One of the tools is an energy calculator that does unit conversion of different energy resources and fuel units, and estimates the cost of electricity generation using different fuels. The other tool is a cycle analyzer that conducts the first and second law analyses of power cycles for different ideal gases. These tools were beta tested in a senior elective class to evaluate their effectiveness. The students found the tools useful for their assignments and projects. Future improvements of the tools based on suggestions of the students were presented. These improvements are being incorporated in the tools to make them more useful for students.

Introduction

Increasing popularity of the Internet and information technology and widespread availability of computers have resulted in the use of World Wide Web (WWW) as a teaching medium in engineering education[1, 2]. Thus, more and more educators have developed web-based teaching and evaluation tools to facilitate and improve the learning process of students. In this paper, the development of two web-based tools for use in Energy Engineering course was discussed and presented.

Course Description

Energy Engineering is a multi-disciplinary subject that encompasses thermodynamics, fluid mechanics, engineering economics, energy conversion, energy conservation, energy audit and management, and environment. Energy Engineering course is a senior elective course in the department of mechanical engineering at Lamar University, offered in every other spring semester. The course consists of four parts: energy resources, energy conversion, energy conservation, and environmental impacts of energy generation.

In the first part of the course, two types of energy resources were covered in detailed: non-renewable and renewable energy resources. Non-renewable energy resources discussed in the course included petroleum, coal, natural gas, and nuclear while renewable energy resources are solar, biomass, wind, geothermal energy, and hydro. For each energy resource, the following topics were discussed:

- Current and future availability
- Production and consumption
- Advantages and disadvantages
- Technical and economic challenges
- Current and future uses
- Environmental impact

The main resources for this part of the course are Annual Outlook of Energy (AEO)[3] published yearly by the Department of Energy (DOE), and World and US Energy Statistics[4] published yearly by British Petroleum (BP). One of the main difficulties in this part of the course is that different energy resources have different forms (gas, liquid, solid) and different units associated with them. For example, the unit for petroleum (oil) may be in terms of barrels of oil, barrels per day, thousand barrels per day, tonnes of oil, million tonnes of oil equivalent (Mtoe), and million Btu (British Thermal Unit). The students therefore found it difficult to understand many different units as well as convert one unit of energy resource to the other, especially for energy resources in different forms (gas, liquid, solid). These conversions are essential in this course in order to compare and evaluate energy consumption and production patterns of different countries, and to compare different types of power plants utilizing gaseous, liquid, and solid fuels. Thus, the first web-based tool developed deals with the conversion of different forms and units of energy resources.

The second part of the course is about the energy conversion processes for different energy resources discussed in the first part. The energy conversion devices covered in the course include internal combustion engines, steam and gas turbines, photovoltaic cells, wind turbines, geothermal heat pumps, fuel cells, and microturbines. Most of these devices are based on thermodynamic principles so the first law analysis of power cycles was reviewed in this part of the course. For each energy conversion device, the following topics were covered:

- Basic thermodynamic principles and analysis
- Advantages and disadvantages
- Current technical status and future challenges
- Environmental impact

In this part of the course, first law analysis of the energy conversion devices is necessary to predict the performance of these devices. A quick and easy way to carry out the first law analysis is necessary in order to facilitate the learning and understanding of students. Thus, the second web-based tool was developed to conduct the first law analysis of thermodynamic power cycles.

Different types of energy conservation technologies were discussed in the third part of the course. Some of the energy conservation technologies covered were pinch technology, cogeneration or Combined Heat and Power (CHP), trigeneration, and waste heat recovery. For each energy conservation technology, the following topics were discussed:

- Second law analysis
- Advantages and disadvantages
- Current technical status and future challenges
- Environmental impact

Many conservation technologies are based on the second law analysis of thermodynamics cycles. Thus, the second web-based tool was extended to include the second law analysis of thermodynamic power cycles for use in this part of the course.

Description of Web-based Tools

The web-based tools were developed with the following objectives:

- To facilitate and improve the learning process of students
- To provide web-based teaching tools to the educators dealing with energy

The tools were developed for them to be made available on the web, so Hyper Text Markup Language (HTML) and JavaScript languages were used in developing these tools. Both tools made use of the different elements of Graphical User Interface (GUI) available to HTML and JavaScript languages to provide ease of use for the users.

The first web-based tool, an energy calculator, deals with the conversion of different forms and units of energy resources. There are many unit conversion tools available on the Web. One example would be the conversion tool at the web site of BP[4]. Many of these unit converters can only convert from one thermal unit to another such as conversion from British Thermal Unit (Btu) to kilo joules (kJ). A few of these converters can provide the thermal (heat) content of different forms of energy resources such as Btu content of a barrel of oil. However, the real shortcoming of these tools is that they do not provide conversion from thermal (heat) energy to electricity or vice versa. Electricity generation is the main use of all energy resources so it is critical to have the conversions from electricity to thermal energy and thermal energy to electricity available. The main parameter for this conversion is known as the heat rate in industry and thermal efficiency in academic. The present tool was therefore developed in order to provide thermal energy unit conversion, electricity to thermal conversion, and thermal to electricity conversion. The present tool also provides thermal efficiency and the capital cost of different power plants using natural gas and coal.

The tool has three distinct parts on a single web page. The first part is the pure unit converter between different units of energy such as conversion from quadrillion Btu to million kJ. Some of the available units are Btu, million Btu, quadrillion Btu, kJ, MJ, GJ, hp, etc. The second part of the tool converts units among different forms of energy resources including thermal energy to electricity and electricity to thermal energy. The conversion is based on the heating content of each energy resource. Some examples are conversion from cubic meter of natural gas to kW-hr of electricity and a billion barrels of oil to the million metric tons of coal. In order to do the calculations, heating (thermal energy) content of each energy resource is necessary. These heating contents and unit conversion factors were taken from the World and US Energy Statistics published yearly by British Petroleum (BP). The third part of the tool provides the thermal (energy conversion) efficiency of various energy devices such as coal power plants, and gas turbine combined cycle and their capital cost per kW of electricity generated. These values were taken from current literature and energy handbooks. The GUI interface of the tool and some examples of the calculator are shown in Figs 1 and 2.

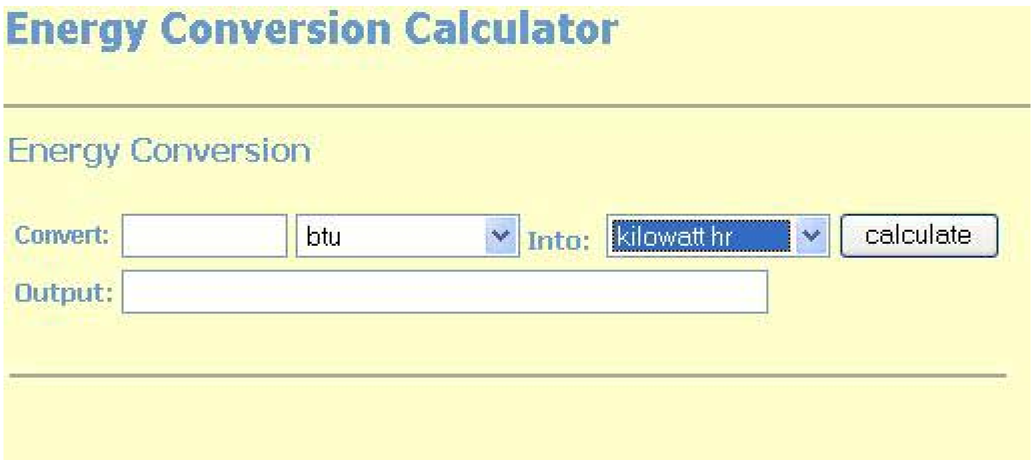

Figure 1 The Opening Screen of the Unit Conversion Tool

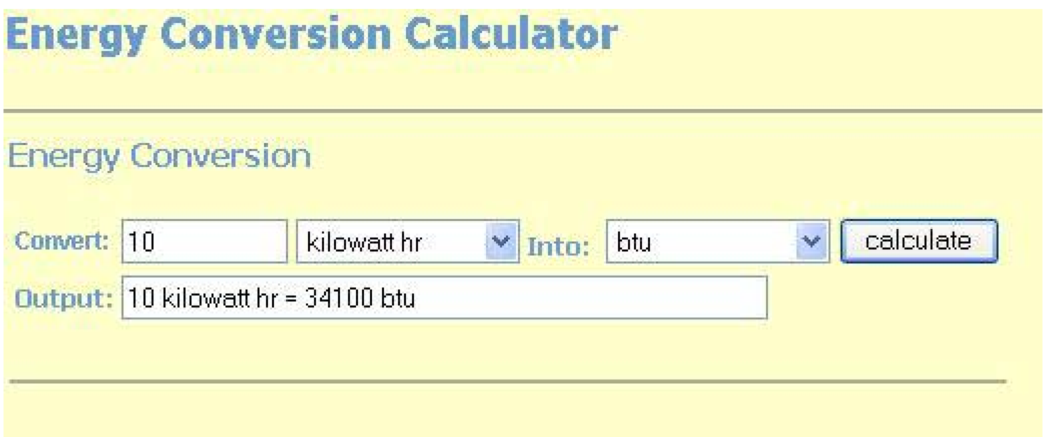

Figure 2 The Sample Result Screen of the Unit Conversion Tool

The second tool is the first and second law analyses of thermodynamic power cycles. The tool was intended to use in the energy conversion and energy conservation sections of the course. There are similar tools available for the first law analysis of cycles, and one of them is CyclePad. All the students who took the Energy Engineering class used CyclePad in their Engineering Thermodynamic class, which was a prerequisite for the Energy Engineering course. However, CyclePad was not intended for use on the web. In addition, CyclePad does not provide the second law analysis of the thermodynamic cycles, which is essential for discussing energy conservation technologies. Thus, the second tool was developed to provide both first and second analyses of power cycles with graphical visualization (Sankey diagrams) of energy and exergy flows of the cycles.

The first law analysis is used for the energy balance and calculation of thermal efficiency while the second law analysis provides estimation of the irreversibilities in the cycle and calculation of the second law efficiency. The second law analysis is based on the change in availability (exergy) of each individual process. The cycles included in the tool were a diesel cycle, an Otto cycle, and a gas turbine cycle. At present, the tool allows the analysis of air-standard cycles with air, oxygen, nitrogen, carbon monoxide, and carbon dioxide as working fluids. For the diesel and Otto cycles, three types of problems can be analyzed: given maximum pressure, given maximum temperature, and given heat input. These choices were made available so that the tool could be used to evaluate the effects of main cycle parameters, namely maximum pressure, maximum temperature, and heat input, on the cycle performance. This is one of the main advantages of the present tool compared to other available tools. Some of the results of the diesel and Otto cycles include the net work output, cutoff ratio, cycle heat input, thermal efficiency, and second law efficiency. For the gas turbine cycle, only a simple Brayton cycle analysis is included. Some of the results of the gas turbine cycle include the net work output, cycle heat input, thermal efficiency, and second law efficiency. The theoretical equations and the properties of working fluids were taken from the book by Sonntag, Borgnakke, and Van Wylen[5]. The sample screen shots of the tool GUI interface were shown in Figs. 3, 4 and 5.

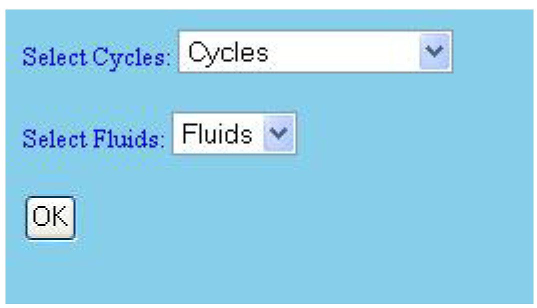

Figure 3 The Opening Screen of the Cycle Analysis Tool

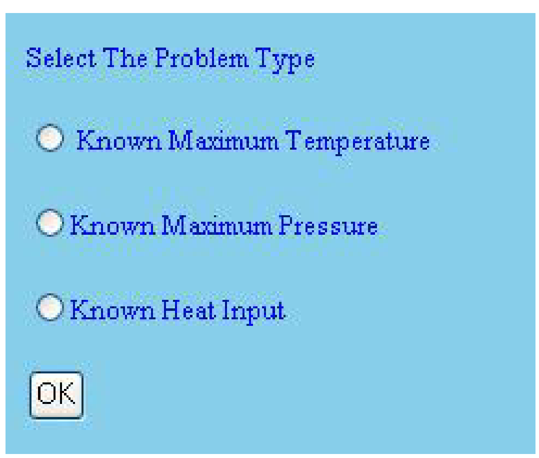

Figure 4 The Problem Type Screen of the Cycle Analysis Tool

Intake Temperature	: 300 K
Intake Pressure	: 100 kPa
Maximum Temperature	: 2200 K
Maximum Pressure	: 5719.81 kPa
Compression Ratio	: 18
Cut Off Ratio	: 2.31
Compression Work	: 468.74 kJ/kg
Expansion Work	: 1242.22 kJ/kg
Net Work	: 773.47 kJ/kg
Heat Input	: 1252.93 kJ/kg
Heat Output	: 479.17 kJ/kg
Neat Heat	: 773.76 kJ/kg
First Law Efficiency	: 0.62
Second Law Efficiency	: 0.71

Figure 5 The Sample Result Screen of the Cycle Analysis Tool

The tool also provides the visualization of energy and exergy flow of each cycle in the form of Sankey diagrams. Based on the discussion above, main advantages of the two web-based energy tools can be summarized as follows:

- The unit conversion tool provides not only unit conversion between different energy thermal) unit but also electricity to thermal energy, and thermal energy to electricity conversions based on heat rate/thermal efficiency.
- The unit conversion tool also provides typical thermal efficiency and capital cost of different types of power plants, including coal-fired power plants, and natural-gas gas turbine power plants.
- The cycle analysis tool conducts first and second law analyses of power cycles for different problem types including specified maximum pressure, maximum temperature, and heat input.
- The cycle analysis tool can use different ideal gases as working fluids in the analysis of power cycles.
- The cycle analysis tool uses Sankey diagrams to provide the visualization of energy and exergy flows of each power cycle.

Discussions

The web-based tools developed for Energy Engineering can be used for other courses related to energy and thermodynamics. These tools were developed as teaching tools and had been used only once in the course for beta testing. The web-based tools were made available to the students through the class web page. Students were asked to use these tools for completing their weekly assignments and group projects. The students were also asked to provide their opinions on the use of these tools. The responses of the students found that these tools facilitated greatly in their assignments and projects. However, the students also pointed out shortcomings of the tools, such as lack of Rankine cycle in the cycle analyzer tool.

Therefore, some of the improvements are being incorporated into the tools, based on the suggestions of the students, and they are listed below:

- To provide current prices of different energy resources in the energy calculator
- To include estimate of the cost of electricity generation using different fuels in the energy calculator
- To include more power cycles such as Rankine cycle and Combined cycle in the cycle analysis tool
- To take into account variation of specific heats with temperature in the cycle analysis tool

The tools discussed in this paper are all Web-based tools so the students can only use these for their assignments and projects. One purpose of these tools is to facilitate the students in doing their assignments and projects so these tools fulfil their intended use. It is the authors' opinion that the students must be able to do the required calculations and computations without the aid of these web-based tools. Therefore, the tools discussed in this paper are not available to students for use in their tests, quizzes, and exams. The ultimate goal of the authors is to develop a web-based interactive text of Energy Engineering where these tools will form an essential part of the text. Both the text and the tools will then be made available to all educators by hosting them on a web site.

Conclusions

This paper discussed the development of web-based tools for use in the Energy Engineering course offered as an elective in the department of mechanical engineering at Lamar University. The detailed description of the course and the capabilities of the web-based tools were presented. The main differences and advantages of these tools compared to similar tools were discussed. The students found that these tools facilitated greatly in their assignments and projects. The student also pointed out some shortcomings of the tools. Improvements of the tools based on the suggestions of students are being implemented.

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Biography

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