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Teaching Thermodynamics Principle of Power Generation with Analogy for Electrical Power Engineering Students to Enhance Their Understanding

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Abstract. Most electrical engineering students must make an extra effort to understand non-electrical engineering concepts in their study. An analogy approach is commonly selected by lecturer to assist the students to understand the concepts. In this paper, an analogy by conducting practical work is proposed. The objective of this practical class is to enhance the students understanding of the work principle of the economizer and what advantages will be gotten by adding economizer in the boiler. This study has been started to be implemented in 2nd semester academic year 2022/2023. The research result shows that the students who conducted the proposal practical class in 2nd semester academic year 2022/2023 demonstrated 38.75% much higher in understanding compared to the students who took the same subject in previous academic year 2021/2022 (93.75% vs 55.00% in correctly identifying economizer). All these students showed exemplary level capability for given rubric assessments, except in system efficiency improvement assessment which half of students have capability at satisfactory level. Also, more than ninety percent of students could identify the economizer, one of important components in a boiler, correctly. Whereas only fifty five percent of students who could do the same in previous academic year.

Keywords: Thermal Power Plant, Economizer, Thermodynamics, Practical Analogy Class

INTRODUCTION

Electrical Power Engineering Study Program is one of undergraduate study programs in School of Electrical Engineering and Informatics, Institut Teknologi Bandung (ITB) that provides education in the field of generation, delivery, and use of electrical energy. In curriculum 2019 of the Electrical Power Engineering Study Program, the 3rd year students shall take Electric Power Plant subject. One of the specific learning outcomes of this subject is related to student capability in understanding the concept and designing a thermal power generation plant. Before taking this subject, the students should take thermal engineering and fluid mechanics subject and general chemistry subject in their 2nd year and 1st year studies, respectively, as their basic learning in thermodynamics principles.

In the electric power plant class, the students are, firstly, introduced to general power generation overview and some basic thermodynamic laws to review what they have learned in previous year level. Then, the students shall be focused on thermal power generation plant topics such as power plant cycle, fossil fuel, combustion process, steam generator, steam turbines, condensate-feedwater system, electrical & plant control systems and some environmental aspects of power generation plants as illustrated in a thermal power plant scheme in Figure 1.

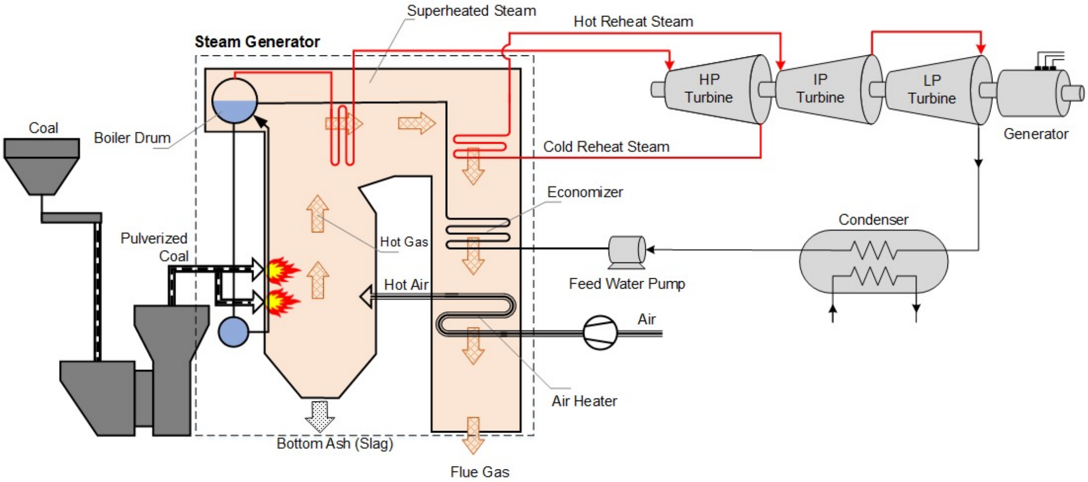


Figure 1: A Typical modern pulverized coal-fueled thermal power plant.

As shown in Figure 1, energy of the coal fuel will be converted to heat energy for heating up the working fluid (water) to produce superheated steam in the steam generator. Then, this high energy steam will be delivered to steam turbine systems for producing mechanical energy to rotate the generator for generating the electricity. From the steam turbine systems, the working fluid will go to the condenser system for changing its phase to liquid one. By changing the working fluid to liquid phase, the power plant system requires less energy for increasing the pressure level of working fluid. This increase in work pressure will be handled by the feed water pump to make a complete Rankine cycle by sending it to the steam generator for, again, generating the superheated steam.

As one of the biggest and most critical parts in a thermal power plant, steam generator is also frequently referred to as boiler (Black & Veatch, 2005). A boiler mainly consists of some important components such as furnace, drum, convection pass, air heater, burners and some apparatuses that deal with the coal fuel processing to support combustion process as described in Figure 1. The convection pass is a crucial part to transfer the thermal energy in the boiler furnace to the working fluid. This thermal energy is produced by converting pulverized coal fuel chemical energy via combustion process. Then, the hot gas will be produced and travel all over the boiler as indicated in Figure 1. This hot gas will heat up all convection pass tubes. In a steam generator, there are generally three convection pass types i.e. superheater, reheater and economizer. The first heat absorption unit in boiler is the economizer. It absorbs the energy from hot flue gas which raises the high-pressure liquid's temperature. Thus, the temperature of the working fluid becomes much higher before it passes through the narrow tubes (water wall) via downcomers. The superheater works to produce superheated steam which will stream to the high-pressure (HP) steam turbine. From the HP turbine, to increase the working fluid temperature, it is resent to the steam generator via the reheat to get the hot reheat steam before going to the intermediate pressure (IP) turbine. Almost all these processes deal with energy conversion, heat transfer and thermodynamics knowledge which might require extra efforts to understand for electrical engineering students.

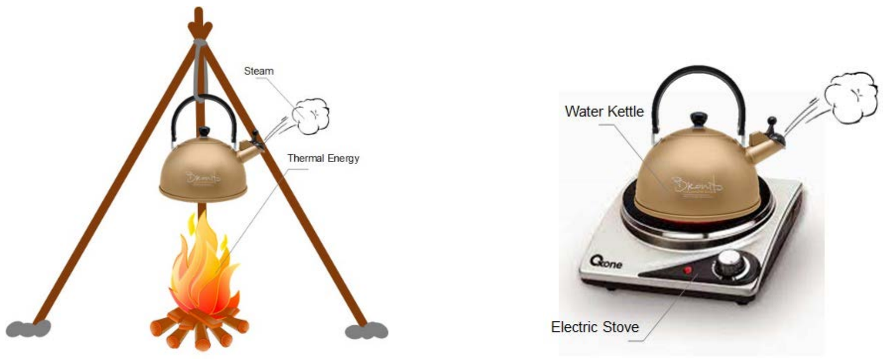
Conversely, Electrical Engineering (EE) Education in the world is nowadays focusing on enhancing education quality and quantity of graduates (Vleeshouwers, Baltus, & Raz, 2023). This concern motivates EE educators to provide a class which is more attractive and easier to understand for students. An integrated learning activities management based on the MIAP learning model might be as one of alternatives to provide a professional teaching practice for supporting electrical engineering education in a simple way (Chumchuen, N., Klinbumrung, K., & Meesomklin, S., 2020). Most students are used to adopting analogy approaches to understand many physics or electrical engineering concepts more easily (Libres, 2023). Moreover, analogy approaches are effectively proven for helping students to understand the chemistry concepts (Sriboonruang, Suwannoi & Treagust, 2022). By applying analogies which commonly adopt well known or simple models or approaches, it will help students to more easily understand any difficult and abstract concepts during the class (Harrison & Coll, 2008). Many university level textbooks also adopted analogies or equivalencies to make their contents more obvious for the book readers (Moran, M. J., Shapiro, H. N., Munson, B. R., & DeWitt, D. P., 2003; Alexander, C. K. & Sadiku, M. N. O., 2009; Chapman, S. J., 2012). Moreover, for engineering students, conducting practical work in an appropriate sequence is essential for students' concept building (Singh & Singh, 2023; Vleeshouwers, Baltus, & Raz, 2023). For providing the best practical experience for the students, a collaborative project involving industries and academic institutions become one of the solutions for enhancing EE education (Martins, M. J., Lopes, F., Fonseca, I., Ferreira, C. M., & Barbosa, F. M., 2014).

Providing a high-quality education is very challenging for educators. To check whether the education program is in high quality level or not, an assessment should be performed. In year academic 2020/2021 and 2021/2022, the students of Electrical Power Engineering Study Program ITB who taking the Electric Power Plant subject were required to do similar assessments regarding components of a typical steam generator. Unfortunately, the results showed that the student had difficulties to solve the given problem. Considering this issue, a new proposed analogy by conducting practical work will be discussed in this paper. The objective of this practical class is to enhance the students understanding of the work principle of the economizer and what advantages will be gotten by adding economizer in the boiler.

METHODOLOGY

In this study, the students of Electrical Power Engineering Study Program ITB who were taking the Electric Power Plant subject in year academic 2021/2022 and 2022/2023 were required to do similar assessments regarding components of a typical steam generator. Only the students in the year academic 2022/2023 class were requested to perform the proposed practical work before the assessment. Based on the assessment results, both classes will be compared and analyzed.

The proposed practical work adopts one of the common analogies of power plant steam generator is by adopting water kettle as illustrated in Figure 2. In Figure 2(a), thermal energy is produced from wood chemical energy (biomass energy) which is same as in typical biomass boiler. A similar analogy is much simpler by adopting electric stove where the consumed energy is much easier to be measured as depicted in Figure 2(b).



(a) (b)

Figure 2: Boiler analogy

To provide a simple illustration of the working principle of economizer in a boiler, an analogy of Figure 2(b) is adopted by adding additional another daily life stuff i.e. electric water kettle as shown in Figure 3. In the class, students are grouped into four students (maximum) for each group. All groups shall do step by step of two experiments as follows:

A. Experiment I
   a) Material and equipment:
      1. One liter of water
      2. Electric stove
      3. Water kettle
      4. Wattmeter
      5. Infrared thermometer gun
   b) Procedure
      1. Fill the water kettle with 1 liter of water!
      2. Check and note the water temperature by using the infrared thermometer gun!
      3. Heat up the water by turning on the electric stove as illustrated in Figure 3(a)!
      4. When the sound comes out from the water kettle, note the energy consumption that is indicated by the wattmeter and check the water temperature by using the infrared thermometer gun!

B. Experiment II
   a) Material and equipment:
      1. One liter of water
      2. Electric stove
      3. Water kettle
      4. Electric water kettle
      5. Wattmeter
      6. Infrared thermometer gun
   b) Procedure:
      1. Fill the electric water kettle with 1 liter of water!
      2. Check and note the water temperature by using the infrared thermometer gun!
      3. Heat up the water by turning on the electric water kettle for 3 minutes as illustrated in Figure 3(b)!
      4. After 3 minutes, note the energy consumption that is indicated by kWh meter and check and note the water temperature by using the infrared thermometer gun!
      5. Pour the water into the water kettle!

6. Reheat up the water by turning on the electric stove as illustrated in Figure 3(a)!
7. When the sound comes out from the water kettle, note the energy consumption that is indicated by the wattmeter and check the water temperature by using the infrared thermometer gun!

(a) **(b)**

Figure 3: Proposed analogy of boiler economizer

RESULTS AND DISCUSSION

The delivery method of steam generator lecture topic with the proposed analogy has been started to be implemented in 2^{nd} semester academic year 2022/2023. In academic year 2021/2022 and 2022/2023, a same test was given to class students (20 students and 16 students, respectively). Students were asked to distinguish components of a typical steam generator. As described in Figure 4, students of academic year 2022/2023 can correctly identify the superheater, the economizer and the air heater of steam generator much better compared to the previous academic year students. In academic year 2021/2022, the students who could not correctly identify the superheater, the economizer and the air heater are 20%, 45%, and 20% of the total students, respectively. Most of these students have still confused the economizer and the air heater of boiler. These numbers are much improved in the academic year 2022/2023.

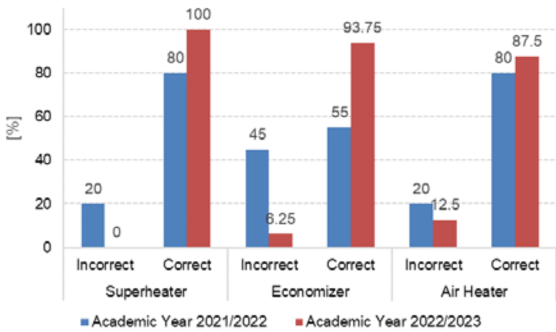


Figure 4: Students capability assessment

In academic year 2022/2023, after having performed the experiment, students were asked to discuss within their group and analyze the experiment results. The objective of this experiment is to provide more understanding for students related to the work principle of economizer and what advantages will be gotten by adding economizer in the boiler. During the group discussion, most students looked very enthusiastic to discuss the given issues. Then, the group discussion results had to be summarized in a written report.

Table 1: Rubric of student assessment

Working Principle	
Unsatisfactory (U)	Student cannot explain the working principle of the economizer
Developing (D)	Student can explain how the fluid temperature in the economizer raises, but he/she cannot explain the advantage of this temperature increase
Satisfactory (S)	Student can explain how the fluid temperature in the economizer raises and the advantage of this temperature increase
Exemplary (E)	Student can explain how the fluid temperature in the economizer raises, the advantage of this temperature increase, and its improvement to system efficiency
Energy Consumption Calculation	
Unsatisfactory (U)	Student cannot calculate the system energy consumption
Developing (D)	Student can identify all parameters for the calculation of system energy consumption, but he/she cannot finish the calculation
Satisfactory (S)	Student can identify all parameters for the calculation of system energy consumption and finish the calculation
Exemplary (E)	Student can identify all parameters for the calculation of system energy consumption, finish the calculation and apply the calculation results to show the system improvement
System Efficiency Improvement	
Unsatisfactory (U)	Student cannot calculate the system efficiency
Developing (D)	Student can identify all parameters for the system efficiency calculation, but he/she cannot finish the calculation
Satisfactory (S)	Student can identify all parameters for the calculation of system efficiency calculation and finish the calculation
Exemplary (E)	Student can identify all parameters for the calculation of system efficiency calculation, finish the calculation and apply the calculation results to show the system improvement

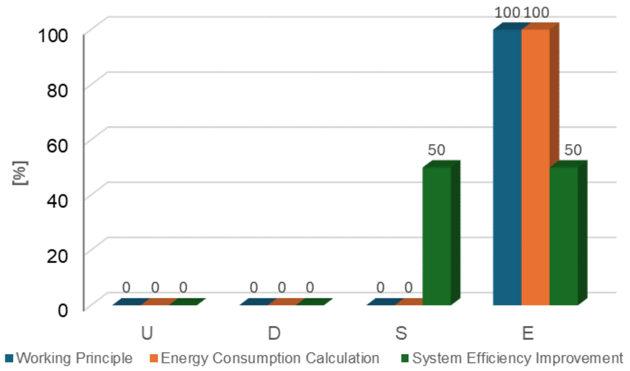


Figure 5: Students assessment results

To assess the student's capability, a special rubric was developed as described in Table 1 based on group reports. The assessment results are described in Figure 5. It shows that all students have capability at exemplary level for the given assessments, *except* for system efficiency improvement assessment which half of students have capability at satisfactory level (instead of 100% in exemplary level).

CONCLUSION

An analogy by conducting practical work was proposed in this paper. The students who conducted the proposal practical class have demonstrated much better understanding compared to the students who took the same subject in the previous academic year. Almost all students showed exemplary level capability for given rubric assessments. The rubric assessments were designed to check the student's capability in recognizing the working principle, the energy consumption calculation, and the system efficiency improvement of boiler economizer. All assessment criteria were fulfilled very well by all students. Moreover, more than ninety percent of students could identify the economizer, one of important components in a boiler, correctly. Whereas only fifty five percent of students who do the same in previous academic year.

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