DESIGN, CONSTRUCTION AND TESTING OF A LOW COST MINI ELECTRIC STEAM GENERATOR

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ABSTRACT

This study aimed to design, construct and test a Low Cost Mini Electric Steam Generator for Physics Laboratory with the following components: the AC power supply, heater, boiler, water pump, water level controller, temperature indicator, and steam exhaust. The AC power is a 220 V/60Hz that is used to supply the heater for the boiler to produce steam. The water is automatically fed via a submersible water pump with a water level controller to maintain the correct level of water and avoid its shortage inside the boiler. The boiler was also connected to a temperature sensor. The maximum power line voltage is 227 V while the total resistance of the heater and the transformer is 51.5288 ohms, with a load current of 4.42 amperes and power equivalent to 1000 watts. After a series of tests, it was found out that the Low Cost Mini Electric Steam Generator is capable of producing steam at the rate of 225.2 gm/min. The maximum temperature generated is 1000C, which is the boiling point of water. It can be concluded that the low cost mini electric steam generator was satisfactorily made and can meet the needs of the Physics Laboratory for experiments in thermodynamics.

INTRODUCTION

Background of the Study

A steam engine is a mechanical device used to transfer the energy of steam into mechanical energy for a variety of applications, including propulsion and generating electricity. The basic principle of the steam engine involves transforming the heat energy of steam into mechanical energy by permitting the steam to expand and cool in a cylinder equipped with a movable piston. Steam that is used for power or heating purposes is usually generated in a boiler. The simplest form of boiler is a close vessel containing water, which is heated by a flame so that the water turns to saturated steam. The ordinary household-heating system usually has a boiler of this type, but steam-generating plants used for power purposes are more complex in design and are equipped with various auxiliary devices. The efficiency of a steam engine is generally low, and therefore, in most power generation applications, the steam engines have been replaced by steam turbines.

The steam generator consists of two major parts: the top half or the combustion chamber and the bottom half which contains the coil stack. Air is delivered from a blower through an air jacket to the top of the combustion chamber. The air jacket provides cooling for the inner skin of the combustion chamber and preheats the air as it flows to the combustion chamber. The fuel is dribbled onto a spinning cup that vaporizes the fuel into a very fine spray. Only 12 watts of electric power is required to vaporize the fuel with the spinning cup. This is less than what would have been required to vaporize the fuel with a pressure pump or compressed air. The coil stack is usually made of finned tubing. The finned tubing has 8 to 10 times the heat transfer surface of bare tubing. The coil stack with finned tubing is considerably smaller than a bare tube coil stack. The coil stack contains stainless tubing in which all joints are welded. As such the coil stack can withstand a considerable amount of abuse without damage. If the burner is turned on with a dry boiler, the over heat control will turn off the burner and no damage will occur to the coil stack (from http://www.firedragon.com/~kap/Barrett/SteamGenerator1.html).

On the other hand, the Electric Steam Generator Corporation SPEEDYLECTRIC electrode type steam generators are designed to work with artificially increased boiler water conductivity. This greatly reduce the cycling up effect as additional electrolytes are carried in with the makeup water.

Conventional fuel fired boilers and electric boilers of the immersed resistive heating element type must utilize heat transfer surfaces at a temperature substantially higher than the desired steam temperature. The efficiency of such units depends on the efficiency of the conversion of fuel into heat and the efficiency of heat transfer. These efficiencies are highly dependent on heat transfer surfaces. Minerals are left behind and deposited on the hot heat transfer surfaces (scale) as the water flashes into steam. These deposits can greatly reduce heat transfer efficiency. With an electrode type electric boiler, heat is generated directly in the water itself. No part of the boiler is at a temperature higher than the steam being produced.

Electric steam generators of the electrode type are constructed with a vertical pressure vessel thereby resulting in a relatively small footprint, occupying less valuable floor space. Because of their small footprint, SPEEDYLECTRIC steam generators can be located close to the load, reducing long, heat wasting runs of pipe. There is no requirement for fuel handling space or equipment. As an electric boiler has no stack, there is no related stack heat loss and there is no problem with air pollution due to incomplete combustion of fuel. The hazards associated with the combustion of fossil fuels are eliminated.

Conventional fuel fired boilers and electric boilers of the immersed resistive heating element type are subject to failure with potentially disastrous results if the water level falls below some minimal point. There is no unsafe water level in an Electric Steam Generator Corp. SPEEDYLECTRIC electrode type electric boiler because, if for any reason the water supply is interrupted causing the water level in the pressure vessel to fall below normal levels, the electrode tips will become completely exposed. No current will pass between the electrodes, no steam will be produced and no hazardous temperatures can occur. In an electrode type steam generator, 100% of the electrical energy is converted to heat.

Electricity has always been considered a safe, clean, and efficient form of energy. In the past however, it was also expensive, particularly when compared to natural gas and cheap oil. In recent years, with the rapidly rising cost of using natural gas and oil-fired boilers, electricity is increasingly becoming a practical alternative source of energy. For the future, electricity enjoys one very important advantage over other forms of energy-it can be generated from a number of power sources including hydro, nuclear, fossil fuels, tidal, solar, geothermal and wind. A great deal of time, effort and money are being devoted to developing new technologies and sources of electric power (ESG Corporation, 2009).

In the Physics laboratory of Central Philippine University, a steam generator was developed by PASCO Scientific, Inc. The steam generator includes many convenience and safety features, namely: extra wide base, rubber stopper for a tight seal and safety pressure release, dual steam ports, internal electric heater, low water warning light, and six variable power (0 400 watts) with an adjustable steam flow. This steam generator boils three-fourths liter of water in 10 minutes and provides continuous steam up to 10 g/min. A baster is also provided for removing hot water for experiments. The steam generator provides steam to change the temperature of the metal sample for the study of thermal expansion (from http://www.pasco.com.html).

The result of tests using this equipment shows a significant effect in thermodynamics particularly in conducting coefficient of linear expansion experiment. The room temperature reading before the rod was subjected to heat was 260C. The final temperature attained as the steam continuously flowed reached to 1000C giving a 740C change in temperature. The maximum scale reading it attained was 0.04 cm which contributes 0.04164 cm change in the length of the rod (L). The coefficient of linear expansion of the metal was 0.0000093784/0C which means that for every 10C rise in temperature, the temperature of the metal rises at the rate of 0.0000093784/0C.

In the second semester of school year 2005-2006, the Physics Stockroom of the Department of Mathematics and Physics, Central Philippine University (CPU) served twenty two (22) Physics 6 Laboratory Classes. Twenty sections came from the College of Nursing with a total of 870 students. One section was from the College of Education for their Bachelor of Science in Nutrition and Dietetics with nine students listed in the classroll. On the other hand, the College of Arts and Sciences has one section for their Bachelor of Science in Medical Technology with a total of 29 enrollees (UCSC Data, 2nd Sem. 2005-2006).

Physics 6 laboratory experiments include: Precision Measurement, Motion, Forces, Simple Machines, Electricity and Heat. Coefficient of Linear Expansion, Specific Heat and Latent Heat of Fusion of Ice are the experiments that fall under the category of Heat. In these three experiments, an electric steam generator is used to produce steam in order to determine the coefficient of linear expansion of a metal, the specific heat of a metal, the latent heat of fusion of ice and the temperature of the substance.

As per Physics Stockroom Inventory Records for school year 2005

2006, only three electric steam generators were in the list. Out of these three electric steam generators, only one was in good working condition. This equipment was purchased from a reputable supplier with high standard product qualities. It was imported from the USA thus, was expensive. With only one equipment available, it cannot cater to the needs of 908 students to conduct experiments in thermodynamics. Then, with a minimal budget allocated every year for the equipment alone, the Department cannot purchase all the equipment needed in the Physics laboratory. As a result, experiments cannot be performed individually but rather in groups. At present, a class has a maximum of nine groups with five students per group. With this number of students per group, not all of them can manipulate the equipment, hence a low cost electric steam generator was designed.

The Low Cost Electric Steam Generator was simple in design. It costs P15, 000.00 with the same features and functions as compared to the previous one. Furthermore, it has a special feature that the previous steam generators do not have, the temperature indicator.

Objectives of the Study

The main objective of the study was to design, construct and test the Low Cost Mini Electric Steam Generator for Physics Laboratory experiments.

Specifically it aimed:

1. to draw the basic Block Diagram of the system and to integrate each discrete component based on the block diagram;
2. to identify the basic components needed in setting up the system;
3. to construct an electric steam generator that will use local and available materials; and,
4. to conduct final testing and evaluation of the system in terms of the temperature, and the volume flow rate of the steam at specific temperature.

Scope and Limitation of the Study

This Low Cost Mini Electric Steam Generator was primarily designed for Physics Laboratory experiment specifically on the Thermodynamics laboratory experiment. The system capacity is approximately 1.5 liters of water for steam distillation unit and 2 liters of water for reserve water tank. The temperature was set to boiling point of water; which is controlled by the temperature indicator built-in in the system. The feeding mechanism of water is automatic using a submergible water pump and controlled by the water level controller. This system was designed based on the requirements and needs in thermodynamics experiments in the Physics Laboratory.

This system was also designed based on its specifications and limitations. The supply voltage was set to 220 VAC/60Hz line source with AC voltage controller to control the current through the heater using quadrac. The temperature ranges from -100 C to 1100 C indicated automatically by a temperature indicator attached to the system.

This study was limited only to the design, construction and testing of the low cost mini electric steam generator. Revision or upgrading of the system was beyond the scope of this study and is included in the recommendation for further studies. Testing and evaluation were conducted by the Stockroom Coordinator, Stockroom Assistants of the Physics Laboratory, Faculty of the Department of Mathematics and Physics, College of Engineering, and the Designer.

Significance of the Study

The low cost mini steam generator is advantageous to the University specifically to the Department of Mathematics and Physics because this equipment is much cheaper compared to the one used in the Physics Laboratory. The finished device is also advantageous to the students because it can provide them hands-on experience in their thermodynamics experiments.

Time and Place of the Study

The study was conducted in School Year 2005-2006 up to School year 2007-2008 at the Physics Stockroom, En203, College of Engineering, Central Philippine University, Jaro, Iloilo City.

METHODOLOGY

Conceptualization of the Design Trainer

The design is based on the block diagram of a given system shown in Figure 1 below. The simplified block diagram of the steam generator system is composed of seven blocks labeled with a name that corresponds to its specific function and operation, namely: the AC power supply, heater, boiler, water pump, water level controller, temperature indicator, and steam exhaust. The AC power is a 220V/60Hz that is used to supply the heater to heat the boiler to produce a steam. The water is automatically fed via a submergible water pump and it was controlled by a water level controller to ensure the correct level of water and to avoid shortage of water inside the boiler. The boiler was connected with a temperature sensor and indicator to properly monitor its temperature.

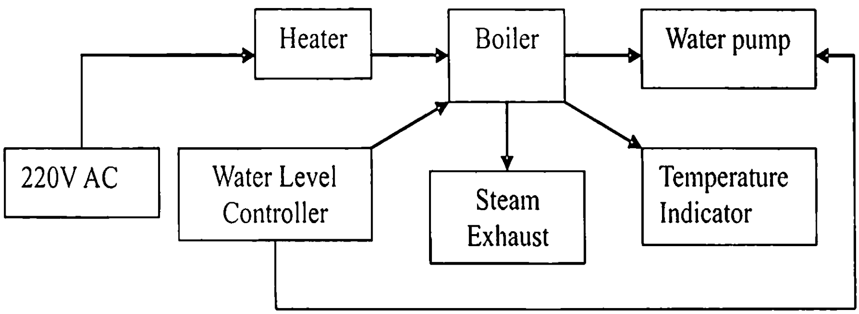

Figure 1. Block diagram

Construction of the Steam Generator

The construction of the steam generator was done at the Physics Stockroom, EN203 by the designer and the work students assigned in the laboratory.

Testing the Circuit Design and Pre-evaluation

The testing of the design was done at the EN203 Physics Stockroom, College of Engineering, Central Philippine University. The parameters tested were the volume of the steam generated per unit time, and the minimum and maximum temperature.

Final Evaluation and Testing of the Finished Design

The final evaluation of the steam generator was again done at the EN203 Physics Stockroom. It was tested by the personnel from the Math and Physics Department during the week of continuous operations. During the evaluation and testing of the steam generator, the following instruments were used:

DMM (Digital Multimeter). METEX model M380 is a multimeter instrument used in measuring voltage, current, and resistance of a given circuit and component.

Power source. This is a line voltage that provides supply to the generator, connected to a 220VAC line.

Thermometer. This is used in the measurement of temperature to ensure accuracy of the control system.

Data Gathered

During the performance evaluation of the steam generator, the following data were gathered:

1. Power line voltage and load current
2. The minimum and maximum temperature
3. Steam flow generated per unit time

Parameters Analyzed

The parameters analyzed were the temperature, and the volume flow rate of the steam at specific temperature. Temperature was obtained using the built-in laboratory thermometer. On the other hand, the volume flow rate was obtained by confining the steam in a container for a certain period of time.

RESULTS

Operation

The power supply provides electricity of the proper voltage and current to the steam generator which operates at 220VAC/60Hz. The heater operated at 220V, 1000W with a current equivalent of 4.42A. The water level controller was supplied by 220VAC and was stepped down to 12V DC. The water level sensor detects the lower and upper level of water. It also controls the submersible pump. Once the water is below the water level, the submersible pump automatically turns ON and fills the boiler with water. Once the water reaches the upper level of the water sensor, the submersible water pump automatically turns off. The designed Low Cost Mini Electric Steam Generator is shown in Figure 2.

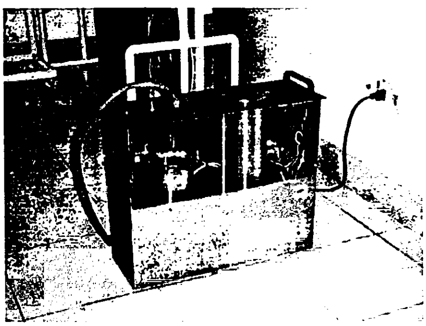

Figure 2. The designed low cost mini electric steam generator

Power Line Voltage and Load Current

Results of Testing and Evaluation show that the Low Cost Mini Electric Steam Generator operates at 227V AC power line voltage and with load current equivalent to 4.42A. The current was measured using a clamp meter and it shows that the current reading was 4.42A. This indicates that the heater is working properly. The power consumption of the heater was determined by multiplying the current reading with source voltage (P = IV). The computation reveals that power consumption is 1003.34W. The larger the power, the higher the energy consumption and the larger the steam it generated.

Minimum and Maximum Temperature

The pre-boiling temperature of 1.25 liters of water confined inside the stainless boiler was 280C. After 25 minutes of boiling, the temperature reached 1000C. At maximum temperature of 1000C, the steam flows to the steam outlet.

Steam Flow Generated per Unit Time

The average steam flow generated by the Low Cost Mini Electric Steam Generator after 3 trials was 225.2 g/min.This means that for every minute of operation, 225.2 g of steam flows out in the steam outlet. This steam flow is higher than the steam flow of the currently used steam generator which has an average rate of 28.4 g/min.

Table 1. Steam Flow Generated per Unit Time

Trials	Steam Generator Currently Used	Mini Electric Steam Generator
1	25.8g/min.	224.9g/min.
2	29.2g/min.	225.2g/min.
3	30.2g/min.	225.5g/min.
Average	**28.4g/min.**	**225.2g/min.**

DISCUSSION

The results of this study show a significant improvement as to the features and design compared to the equipment developed by PASCO Scientific, Inc. (from http://www.pasco.com.html). The result of the test using this equipment shows that in terms of the steam flow generated per unit time, the output of the newly designed equipment is almost nine times more than that of the currently used steam generator. In the coefficient of linear expansion experiment, the maximum scale reading was 0.6 cm which contributes 0.0625 cm change in the original length of the rod. The coefficient of linear expansion of the metal was 0.000014076/0C. In addition, the outcome of the design was also comparable to the design of the Barrett Steam Generator (from http://www.firedragon.com/~kap/Barrett/SteamGenerator1.html).

However, the Barrett Steam Generator can only be procured abroad while the newly designed equipment was made using locally available materials.

CONCLUSION

After three trials, the Low Cost Mini Electric Steam Generator is capable of producing steam at the rate of 225.2 g/min. That amount of steam generated is enough to meet the steam needed in the coefficient of linear expansion apparatus and other experiments related to the study of heat. The maximum temperature generated is 1000C, the boiling point of water. The controller can detect well the water level automatically with the water level sensor attached to the system preventing the overheating of the boiler. It can be concluded further that it was satisfactorily made and can meet the needs of the Physics Stockroom for experiments in thermodynamics.

RECOMMENDATION

Based on the results of tests, it is recommended that:

1. The water capacity of the boiler be reduced to make the boiling process fast. The circumference of the boiler must be as big as the hot plate in order to prevent heat loss.
2. It is also recommended that an insulator be placed outside the chamber of the reserve tank in order to prevent the submersible pump to deform because it gets hot once the hot plate is turned on.
3. A ¼ hp water pump with one way valve is also recommended for high pressure application such as in the Department of Mechanical Engineering of this University which uses high pressure of steam in their experiments related to Heat.
4. It is highly recommended to use aluminum chamber instead of stainless steel in order that the time needed to heat and boil will be shortened.

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