Thermal Management of Proton Exchange Membrane Fuel Cell by Air Cooling

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July 29, 2006

Prepared in partial fulfillment of the requirements of the Office of Science, U.S. Department of Energy Science Faculty and Student Team Program. Prepared under the directions of Dr. Hazem Tawfik, Director, IRTT Farmingdale State University and Dr. Devinder Mahajan, Group Leader, Advanced Fuels Group, Brookhaven National Laboratory, U.S. Department of Energy

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TABLE OF CONTENTS

ABSTRACT

The use of fossil fuel has become a major problem that has national security implications and environmental concerns. The emission of green house gasses and the need for clean renewable energy has led to the research into alternative energy sources. One of the options to replace fossil fuels is hydrogen fuel that can be utilized in a proton exchange membrane fuel cell (PEMFC). PEMFCs show optimum performance at an operating temperature of about 80ºC. The PEMFC produces heat energy as a byproduct of the chemical reaction needed to produce electrical energy. The production of heat by fuel cell is closely related to the current density output. The removal of excess heat produced at a rate that keeps the internal temperature constant at about 80ºC is a challenge. Monitoring and controlling the external temperature of the active area of the flow field at the bipolar plate or end plate can be an economic way to keep the fuel cell within an ideal temperature range. In this project, an array of fifteen thermocouples was dispersed across three bipolar plates in a fuel cell stack to monitor the internal temperature and the rate of heat production. An infrared heat sensing camera was also used to display the external surface temperature of an operating fuel cell. The outputs from the 15 thermocouples were connected to data acquisition software. Real-time temperature monitoring was automatically performed at predetermined time intervals. Two fans with variable air flow were used to introduce a steady stream of air to cool the external surface of the fuel cell stack. Two other sensors were used to measure temperatures up and down stream of the air flow used to cool the fuel cell. Data was collected with the fuel cell stack operating at various power levels while establishing the air flow required to keep the internal fuel cell temperature constant at safe operating level. The heat generated by the power stack spikes due to hot spots during periods of high demand, requiring an effective method of cooling. It is inferred from the collected data that

an economical air-cooling system could be designed for a fuel cell stack that would allow it to operate under isothermal conditions. Finding a relationship between active area, heat produced, and air flow required to remove excess heat can supply the design tool needed to configure the cooling system for any fuel cell size.

PROBLEM DESCRIPTION

Hydrogen fuel cell is the one of the available options to provide clean, reliable, and efficient alternative source of energy for commercial applications. The ability to generate clean energy with no emission of greenhouse gasses has made hydrogen fuel cells a prime candidate to replace inefficient internal combustion engines [1]. The simplicity of a hydrogen fuel cell concept is only complicated by strict adherence to temperature and humidity limitations necessary to achieve an optimum efficiency [2]. The electrochemical reaction of hydrogen and oxygen in a fuel cell produces electrical energy and also produces heat energy and water as byproducts.

Thermal management of a proton exchange membrane fuel cells (PEMFCs) is one of the main parameters that influences the cell’s performance [4]. The efficiency and durability of polymer membrane inside the fuel cell are maximized at about 80ºC, but the performance tends to decline significantly at temperatures above 80ºC. Due to the direct effect of temperature on humidity, it is also critical to maintain the proper temperature while controlling humidity at an optimum level. Ways to maintain constant temperature has become an important consideration in the manufacture of PEMFCs since even small temperature changes can have an adverse effect on power produced [5]. Total dehydration or flooding of the Membrane Electrode Assembly (MEA) can occur if careful temperature and humidity controls are not maintained at appropriate levels. Total dehydration will instantly decrease produced power, and flooding simply creates a short circuit since water is a good conductor of electricity. Temperature and humidity are also critical in the longevity of a membrane [6]. Analyzing and monitoring heat produced in a fuel cell stack has been the focus of many research projects. The temperature analysis and management using real time information can be a complimentary addition to the body of research already available in this area. [7]. The work in this project focused on devising pathways to operate the fuel cell under isothermal conditions.

MATERIALS AND METHODS

A 10 cell power stack shown in fig 1 was constructed using in-house and commercially available components. Graphite bipolar plates, Nafion®ionomer, and platinum catalyst were used along with aluminum end plates, which were also designed and manufactured at the Institute for Research and Technology Transfer (IRTT) at Farmingdale State University of New York. The custom made bipolar plates shown in fig 2 were designed to allow embedding of thermocouples directly into the plates. An airtight enclosure shown in fig 3 was built to house the fuel cell stack to allow controlled air flow parallel to the plates of the fuel cell. The airflow was supplied by two fans mounted at either end of the enclosure. Each fan had an on/off switch and three variable speeds giving six different CFM ratings by combining both fans.

Each of the three aluminum bipolar plates used in fig 2 was embedded with five thermocouples. A total of fifteen K-type thermocouples were installed on the three bipolar plates and numbered as follows: numbers 1-5 on bipolar plate 1, numbers 6-10 on bipolar plate 2 and numbers 11-15 on bipolar plate 3. An infrared camera was aimed at the outside of the fuel cell stack to monitor the temperature on the outside surface. There were two electronic temperature sensors shown in fig 3 installed in the housing: in the air flow field to monitor air temperature before and after cooling the fuel cell stack. Air pressure and flow gages were installed on both hydrogen and air lines entering the fuel cell. A humidification system was used to humidify air entering the fuel cell stack. An electronic dynaload shown in fig 4 was used to simulate a real world loading conditions and to measure the power generated. A state-of-the-art data acquisition system shown in fig 5 was used to measure and record temperature data in real time while the fuel cell was in operation.

The pressure of air and hydrogen entering the system was kept at 10 psig each. The power generated was controlled at 2,4,6,8 and 10 Watts using the dynaload shown in fig 4. The fan remained off until the cell reached a temperature of 40ºC, then was run at the lowest speed to keep the temperature constant. Temperatures data collected through the 15 thermocouples were recorded automatically and were used as the internal temperatures for this research project. The readings of the infrared camera were also recorded automatically by the data acquisition system and used as the external surface temperature of the fuel cell [8]. The average of the five temperature readings on each bipolar plate was used in calculating the cooling load required (in BTU units). The average difference in temperature across the air flow field was measured by two electronic temperature sensors. The PEMFC was successfully maintained at about 40ºC (Figure 6) while the data were collected for parameters under consideration.

RESULTS AND DISCUSSION

The ability to monitor the temperature changes at multiple ports showed, in real time, the performance of the fuel cell membrane with increased power demand. The temperature increase was instantaneous with increase power demand. The temperature distribution across the entire fuel cell stack consistently showed the middle plate to be the hottest plate, see Fig 7. The heat flow pattern propagated and showed an increase in the direction of the flow of reactant gasses from plate to plate inside the power stack. For example, the heat generated from the reaction on the first bipolar plate was transferred with the gasses causing an increased heating effect on the second plate, and so on. The pattern that showed the outermost plate to be cooler can be explained by considering the cooling effect of the fan air flow on the outer surfaces. There was also a thick piece of aluminum on the two outer ends of the fuel cell stack, as shown in fig 1, acting as a heat sink and increasing the cooling effect of the fan on the these ends.

The change in temperature seen by turning off the fans and thereby suspending its cooling effect was used to confirm the cooling effects of the fan. The increase in temperature seen at 10W was about 1ºC per minute; this is shown in fig 6. However, there was no cooling required at relatively low power such as 2W, since the cell operated at about 35 ºC, which is below the experimental limit set at 40 ºC.

The graph in Figure 6 was plotted to show the internal temperatures along with the cooling effects of the fan, versus the internal temperatures without the cooling effects of the fan. This graph was plotted to ascertain that the fan had a significant cooling effects on the fuel cell stack. A second graph, as shown in Fig 8, was plotted to show the relationship between the CFM of the airflow of the fan and the power demand of PEMFC. The curve generated in this graph established a relationship between power produced and CFM that was required to maintain a constant temperature of 40ºC on the middle plate of the PEMFC. The infrared thermal imaging camera, with its results displayed in Figure 7, showed that we were able to effectively cool the outer surfaces of the fuel cell to about 4 ºC below the hottest recorded internal surface. The graph in Figure 9 showed the relationship between power produced and the cooling load required per square feet to maintain a constant temperature.

CONCLUSIONS

The real time analysis of temperature variations within the fuel cell stack in a PEMFC was determined to establish the air flow necessary to maintain a constant operating temperature. The temperature change due to a change in the power demand was monitored in real time, and controlled by external air cooling. The temperature distribution across the entire fuel cell stack was noted as the cell reacted to power demand changed. The data analysis showed the middle plate (plate #2) being the hottest plate in all experiments. The external cooling effect of the air stream provided by the fans was quantified. A graph of cooling load versus power produced was generated. The graph of cooling load per square feet versus power Fig 9 generated by the fuel cell could essentially supply the parameters needed to design a cooling system for the external and internal surfaces of a fuel cell stack.

ACKNOWLEDGEMENTS

National Science Foundation

United States Department of Energy

Brookhaven National Laboratory

State University of New York Farmingdale

IRTT Institute for Research and Technology Transfer

Power Service Concepts

John De Angelo

Bob Kern

AMP Corporation

Kamal Mahajan

Jeff Hung PhD. Student.

Dr. Kamel El-Khatib PhD.

Dr. Hazem Tawfik

Dr. Devinder Mahajan

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[8] Power Service Concepts, data acquisition software

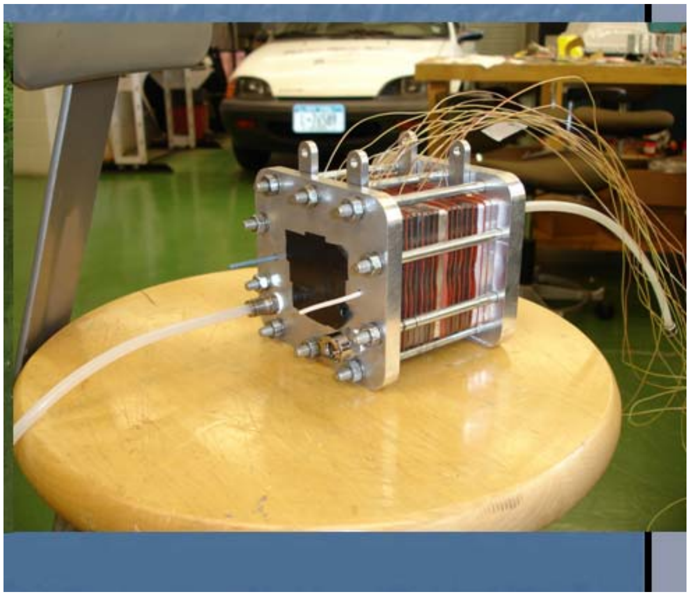
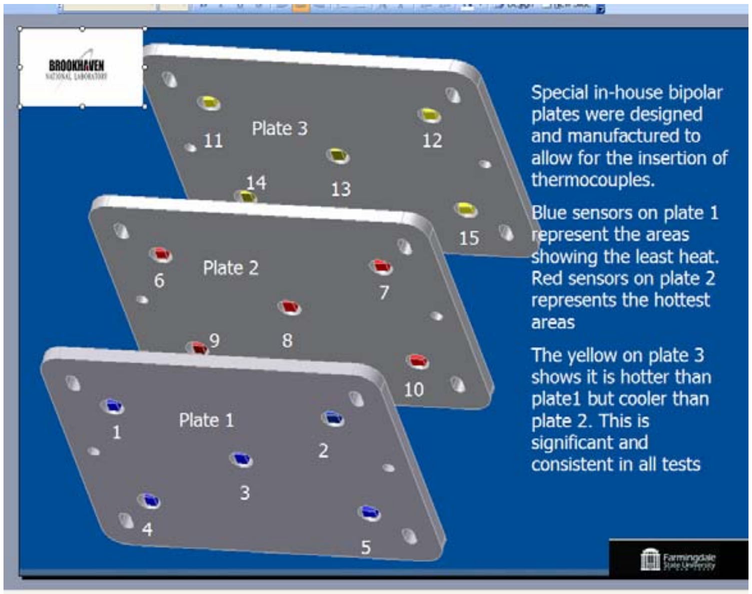


Figure 1. Fuel cell stack with embedded thermocouples



Special in-house bipolar plates were designed and manufactured to allow for the insertion of thermocouples.

Blue sensors on plate 1 represent the areas showing the least heat. Red sensors on plate 2 represents the hottest areas

The yellow on plate 3 shows it is hotter than plate1 but cooler than plate 2. This is significant and consistent in all tests

Figure 2. Bipolar plates with embedded sensors.

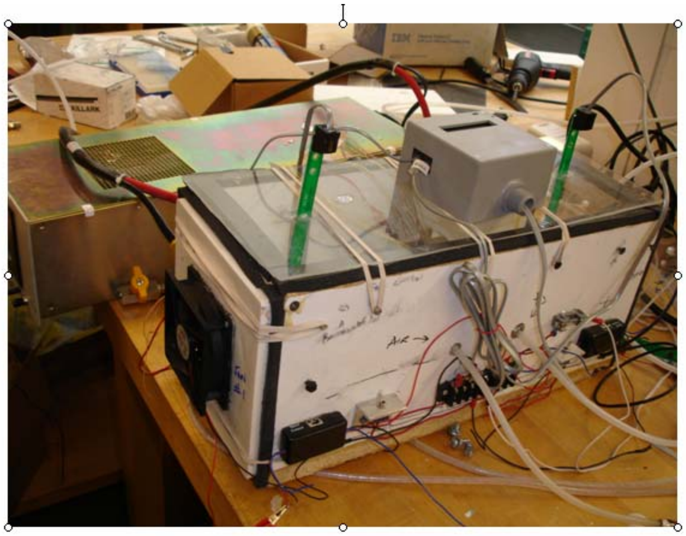
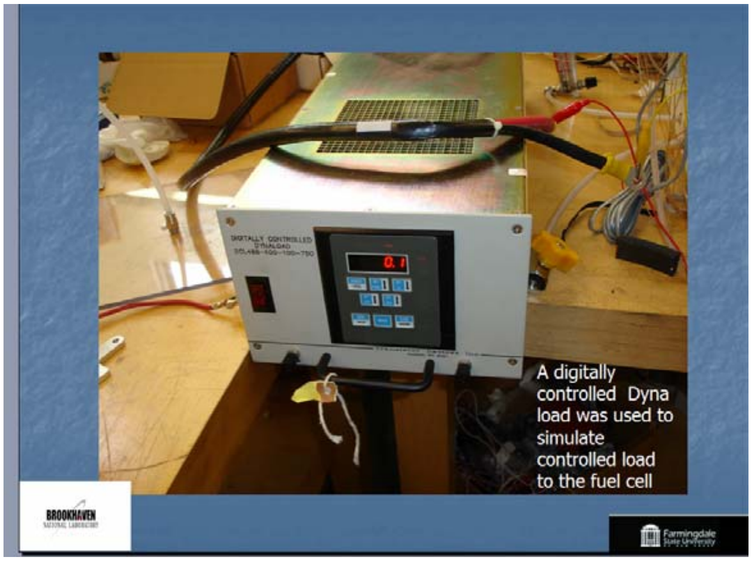
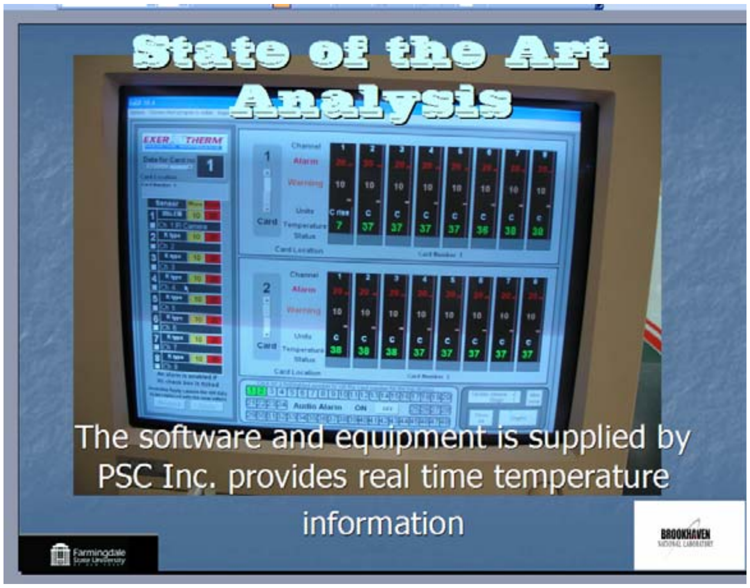


Figure 3. Airtight enclosure for the fuel cell.



A digitally controlled Dyna load was used to simulate controlled load to the fuel cell

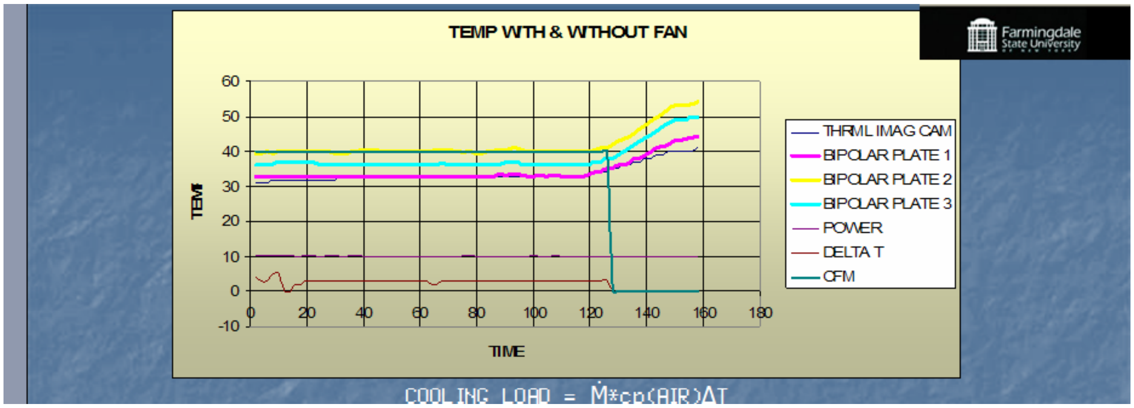
Figure 4. Dynaload used for load simulation**.**



State of the Art Analysis

The software and equipment is supplied by PSC Inc. provides real time temperature information

Figure 5. Data acquisition system for the fuel cell.



COOLING LOAD = $\dot{M}*c_p(AIR)\Delta T$

Figure 6. Fan on & fan off effects on temperature during fuel cell operation.

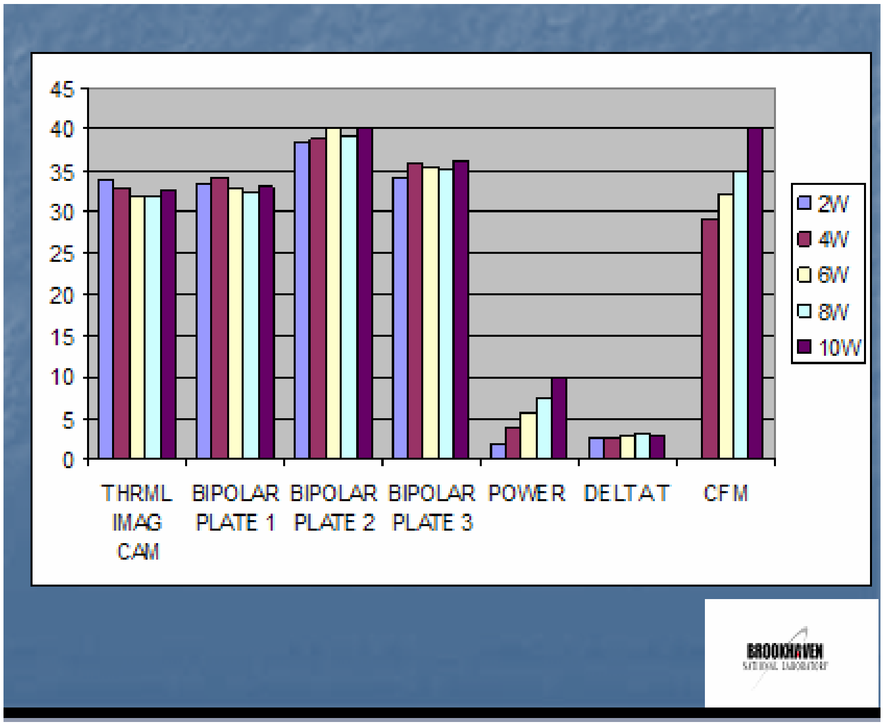


Figure 7. Temperature (in ºC; Y-axis) comparison on bipolar plates.

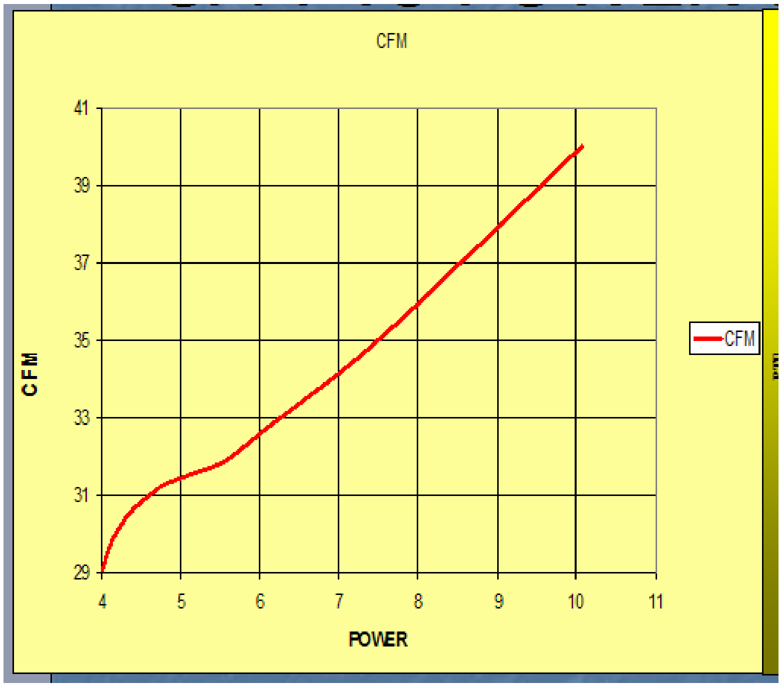


Figure 8. CFM versus Power

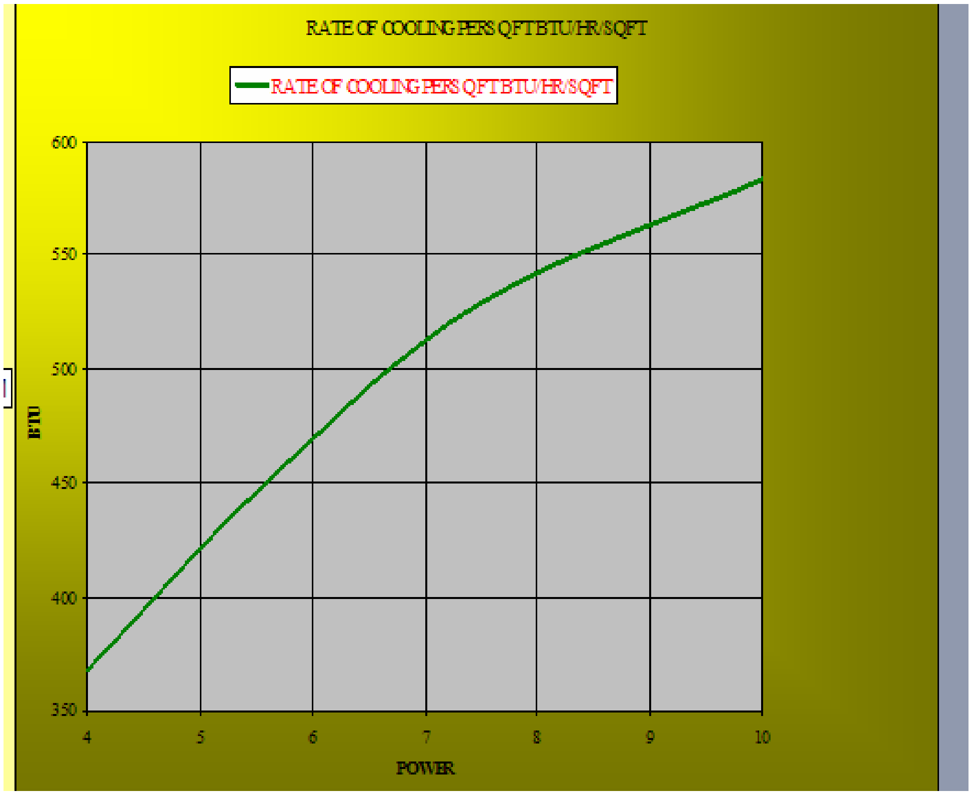


Figure 9. Cooling rate Btu/hr per sq feet