Introduction

Objectives

The objectives of this experiment were to understand equivalence of electrical and heat energy, learn techniques of calorimetry and how to measure both electrical energy and joule equivalent of electrical energy.

Theory

Joule equivalent of electrical or mechanical heat is the quantity of electrical energy contained in a unit of heat energy. The two forms of energy are measured in joules (J) . Heat energy is measured in kilocalories. Sir James Joule studied electrical and mechanical energy and found that between the two there is a constant of proportionality. This constant is the Joule equivalent of heat, denoted by J. In this experiment the factor was to be determined.

Power is the rate of doing work. Electrical power refers to electrical energy transferred by an electric circuit per unit time. Its S.I unit is the watt (W). Work ΔW required to move an electrical charge ΔQ through a potential difference V is given by;

$\Delta W = \Delta Q * V$ ………………………………………………………………………………………1

Power (P) is given by; $P = \Delta W/\Delta t = (\Delta Q/\Delta t) * V$

……………………………………………………. 2

Therefore, $P = V * I$ ………………………………………………………………………………… 3

Where I is current in amperes, Δt is change in time in seconds.

The electrical energy ΔW after an increase in time Δt is given by,

$\Delta W = P*\Delta t$ ………………………………………………………………………………….. 4

By substituting P with V*I we get;

$\Delta W = V*I*\Delta t$ ……………………………………………………………………………………

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The change in heat energy ΔQ in a substance is given by;

$\Delta Q = m*c*\Delta T$ ……………………………………………………………………………. 6

Where m is mass of substance in kilograms, c is specific heat of a substance in Kcal/Kg/°C, and ΔT is change in temperature given in °C. When electrical energy is converted into heat energy, the equivalence of heat energy and electrical energy is given by;

$\Delta W = J*\Delta Q$ ………………………………………………………………………………….. 7

Where J = 4186 Joules/kilocalorie

In this experiment a constant current (I) flowed through a resistive heating element and a constant voltage drop V was determined. Temperature is measured as a function of time. The electrical energy which was expected in this element was transformed to heat energy. This heat energy was to heat water and container in which it was kept. Heat energy change in this case is given by;

$\Delta Q = m_w * c_w * \Delta T + m_c * c_c * \Delta T$ ··· 8

Where m_w, c_w, m_c, c_c are masses and specific heats for water and container respectively.

By combining equation 5 and 8 into 7, we have;

$VI * \Delta t = J(m_w * c_w * \Delta T + m_c * c_c * \Delta T)$ ·· 9

This implies that; $J = \{VI/(m_w * c_w + m_c * c_c)\} * \{1/(\Delta T/\Delta t)\}$ ···

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This shows that, temperature is a linear function of time. $\Delta T/\Delta t$ is equal to slope of the linear fit to data. (c_w = 1.0 kcal/kg/ °C, c_c = 0.21 kcal/kg/ °C.

Materials and apparatus

This included: an assembly with resistive heating coil, electrical connector posts, stirrer, Styrofoam and an aluminum calorimeter cups, double walled calorimeter, low voltage, high current power supply, voltmeter, ammeter, electrical leads, temperature sensor and Pasco 850 Universal Interface data acquisition system.

Procedure

The Pasco 850 Universal Interface was turned on and from the start menu the Capstone software program was started. The hardware set up icon was clicked. On the hardware set up window, Add Sensor/Instrument button was then clicked to elicit another menu after which Science Workshop Analog Sensors were then selected. Temperature sensor ansd stainless steel were then chosen under Sensor/Instrument list.

The sample rate was then adjusted in the controls palette so as to take a reading every two seconds by setting the sample rate adjustment icon. The hardware setup panel was minimized by clicking on the hardware setup icon. Under the display panel, the Table and Graph icons were double clicked to display the temperature in a table and graph as a function of time. After this, the rest of the experimental devices were set up, including the calorimeter and the power supply and circuit. The mass of aluminum insert can was recorded before adding water and again after water was added. Then current was then adjusted upto about 1 amperebut not over the knife switch closed. The switch was then opened to cancel current flow before measurements started. Voltage and current values were then recorded on a data sheet.

The time for recording temperature was then set. After this, the probe and heater were then placed in water while the switch on the circuit was off. Recording button was hit and the switch flip at the same time while stirring continuously.

Calculations

Question 1

Given; mass of water, m=150g, T1=20 °C, T2=30°C, $c_{w=}$1.0 kcal/kg/° C =4186 J/kg/° C, V=10volts, I=2A, Δt=?

Solution

$\Delta Q = mc\Delta T$

$= 0.15kg * 4186\ J/kg/°C * (30-20)°C$

$= 6279J$

Also, $\Delta W = P*\Delta t$

$= 10*2*\Delta t$

$= 20\Delta t\ J$

But $P*\Delta t = mc\Delta T$

Therefore, $\Delta t = 6279J/20W$

Δt= 313.95 seconds. This is the time taken to raise water temperature to 30° C.

Question 2

Given; mass of ethylene glycol, m=150g, T1=20 °C, T2=30°C, c=0.57 kcal/kg/° C =2386.02 J/kg/° C, V=10volts, I=2A, Δt=?

Solution

$\Delta Q = mc\Delta T$

=0.15kg* 2386.02 J/kg/°C*(30-20)°C

= 3579.03J

Also, ΔW = P*Δt

=10*2*Δt

=20Δt J

But P*Δt= mcΔT

Therefore, Δt=3579.03J/20W

Δt= 178.95 seconds. This is the time taken to raise ethylene glycol temperature from to 30° C.

Works Cited

Glover, J. Duncan, Mulukutla S. Sarma, and Thomas Overbye. *Power System Analysis & Design, SI Version*. Cengage Learning, 2012.

Hubert, C., et al. "Simulation of continuum electrical conduction and Joule heating using DEM domains." *International Journal for Numerical Methods in Engineering* (2016).