Experiment 2

WORK TO HEAT TRANSFER

(Mechanical Equivalent of Heat)

1.0 OBJECTIVE

- To determine the relationship between energy transferred by heat and the energy transferred by work.

2.0 INTRODUCTION & THEORETICAL BACKGROUND

The principle of the conservation of energy tells if a given amount of work is transformed completely into heat, the resulting thermal energy must be equivalent to the amount of work that was performed. Since work is normally measured in units of Joules and thermal energy is normally measured in units of Calories, the equivalence is not immediately obvious. A quantitative relationship is needed that equates Joules and Calories. This relationship is called the Mechanical Equivalent of Heat. It was not until the experiments of Joule in 1850, however, that Joule performed a variety of experiments in which he converted a carefully measured quantity of work through friction into an equally carefully measured quantity of heat. For example, in one experiment Joule used falling masses to propel a paddle wheel in a thermally insulated water-filled container.

Measurements of the distance through which the masses fell and the temperature change of the water allowed Joule to determine the work performed and the heat produced. With many such experiments, Joule demonstrated that the ratio between work performed and heat produced was constant. In modern units, Joule's results are stated by the expression

(1 calorie = 4.184 Joule).

Joule's results were within 1% of the value accepted today.

(The calorie is now defined as equal to 4.186 Joule.)

Work is done on an object by force acting through a displacement. The energy transferred by work is measured by multiplying the force acting on an object times the displacement over which the force acted: W = F x d. The unit of energy transferred by work is the **joule**. Work done on an object may result in a change in its mechanical energy or a change in its internal energy, or both. A change in an object’s internal energy results in a change in its temperature.

Heat is transferred between an object and its environment when there is a temperature difference between the object and its surroundings. The energy transferred is measured as the product of the object's mass, its specific heat, and the temperature change which occurs within the object:

Heat = M x specific heat x ΔT. Specific heat is the amount of energy it takes to raise 1 gram of a substance by 1℃ , the unit of energy transferred through heat is the calorie.

If work is done on an object which results in a change in the temperature of the object, then the work done must be the same as the heat energy that is transferred to the object. The ratio of the work done (in joules) to the heat transferred (in calories) is the "mechanical equivalent of heat".

$$\boldsymbol{Mechanical\ equivaent\ of\ heat = \frac{work\ done\ in\ joules}{heat\ transferred\ in\ calories}}$$

3.0 APPARATUS

The apparatus incorporates a universal electric motor with variable speed control for driving a copper drum calorimeter, two sets of weights, heavy and light, a set of brake belts to encircle the drum, a spring balance, a thermometer and a counter for recording the revolutions of the drum. All items of equipment are mounted on the steel cabinet which contains the motor control gear. (See Figure 1)

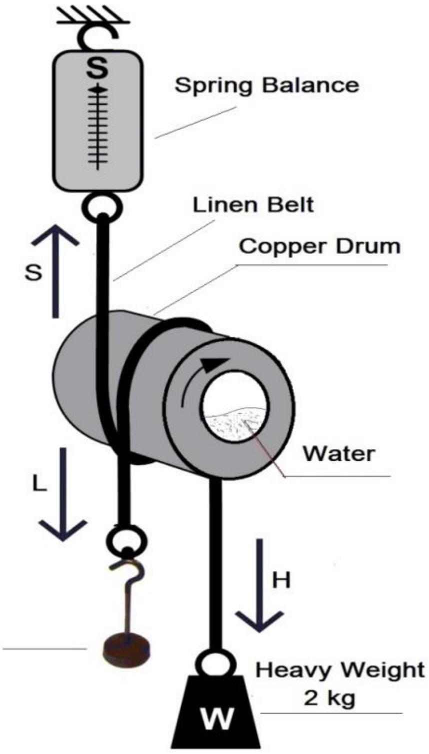

Fig. 1: Work to Heat Apparatus

4.0 PROCEDURE

1. Assemble the double part of the belts suspends the heavier weight of 2 kg, while the single part suspends the carrier for the light weights and the spring balance.
2. Amount of water, approx. 250g, at a temperature approximately 5 or 6 degrees below room temperature is then carefully inserted into the drum taking care not to wet the outside of the drum or the weights.
3. Rotation is then begun at a uniform speed of about 83 rev/min.
4. The light weights are adjusted to keep the heavy weight in floating equilibrium with the spring balance pointer near the center of the scale.
5. After a few revolutions the friction will become practically constant and the water temperature will rise at an approximate rate of 1C per 100 revolutions.
6. Take reading of water temperature at intervals of 100 revolutions of the drum.

5.0 OBSERVATIONS

Table 1: DATA OBSERVED

Initial water & drum temperature, T_i:______ ℃				
Drum revolutions (N)	**Water temperature T_f (°C)**	**Spring balance S (g)**	**Light weight L (g)**	**Heavy weight H (kg)**
100				2
200				2
300				2
400				2
500				2
600				2
700				2
800				2
900				2
1000				2
1100				2
1200				2
1300				2
1400				2
1500				2
1600				2
1700				2
1800				2
1900				2
2000				2

6.0 DATA ANALYSIS

1- Calculating W, the Work done (kJ)

$\boldsymbol{W = (H + S - L) \times g \times (2\pi r) \times N/1000}$	(1)

$H = heavy\ weight, 2\ kg$
$L = light\ weight, kg$
$S = spring\ balance, kg$
$g = acceleration\ due\ to\ gravity,\ 9.81\ m/s^2$

$r = drum\ radius, 0.075\ m$

$N = Total\ number\ of\ revolutions\ the\ motor\ was\ turned$

2- Calculating Q, the Heat produced (kcal)

The total heat Q_T produced by friction against the copper cylinder filled with water can be determined from the measured temperature change that occurred.

$\boldsymbol{Q_T = Q_d + Q_w = (M_d \times C_d \times \Delta T) + (M_w \times C_w \times \Delta T)}$	(2)

$Q_d = heat\ gained\ by\ drum, kcal$

$Q_w = heat\ gained\ by\ water, kcal$

$M_d: mass\ of\ drum = 0.7\ kg$

$C_d: specific\ heat\ of\ copper\ drum = 0.092\ \ kcal/kg.℃$

$M_w: mass\ of\ water\ in\ the\ drum = 0.250\ kg$

$C_w: specific\ heat\ of\ water = 1.0\ kcal/kg.℃$

$\Delta T = rise\ in\ water\ temperature\ after\ agiven\ revolutions = (T_f - T_i),\ ℃$

$T_f = final\ water\ temperature, ℃$

$T_i = initial\ water\ temperature\ just\ before\ motor\ turning,\ ℃$

3- Calculating J, the Mechanical Equivalent of Heat

$\boldsymbol{Mechanical\ equivaent\ of\ heat = \frac{work\ done\ in\ joules}{heat\ transferred\ in\ calories}}$ $\boldsymbol{J = W/Q \qquad kJ/kcal}$	(3)

4- Calculating the % error

$\boldsymbol{\%\ error = \frac{\lvert theoretical - Measured \rvert}{theoretical} \times 100\%}$	(4)

$Jtheor = 4.186\ \ kJ/kcal$

7.0 RESULTS & DISCUSSION

Table 2: SUMMARY OF RESULTS

Drum revolutions (N)	$Temp.diff.,$ ΔT °C	$Work\ done,$ W kJ	$Heat\ Produced,$ Q $kcal$	$Joule\ Factor$ $J = W/Q$	**Error%**
100					
200					
300					
400					
500					
600					
700					
800					
900					
1000					
1100					
1200					
1300					
1400					
1500					
1600					
1700					
1800					
1900					
2000					

1. Plot the graph of work and heat (W versus Q) and calculate the slope (J value).
2. All the results were recorded and tabulated under the results table.
3. Compare (J value) from graph plotted to that calculated from equations.
4. Discuss any discrepancy and the possible causes of errors of the experiment.
5. Write your own opinions about the results. What might be? Discuss about whether the results are acceptable or not?

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