Objective

To find out the relationship between work energy and heat energy .

Experimental Setup

The experimental setup is shown in figure1 . The apparatous consists of a brass drum around which is wrapped a belt with weights attached to it , and a thermometer to measure the temperature of water inside the drum.A control box contains a switch botton and angular speed control botton used to adjust the speed of the electric motor.Furthermore , A revolution counter is connected to the motor to count its revolutions

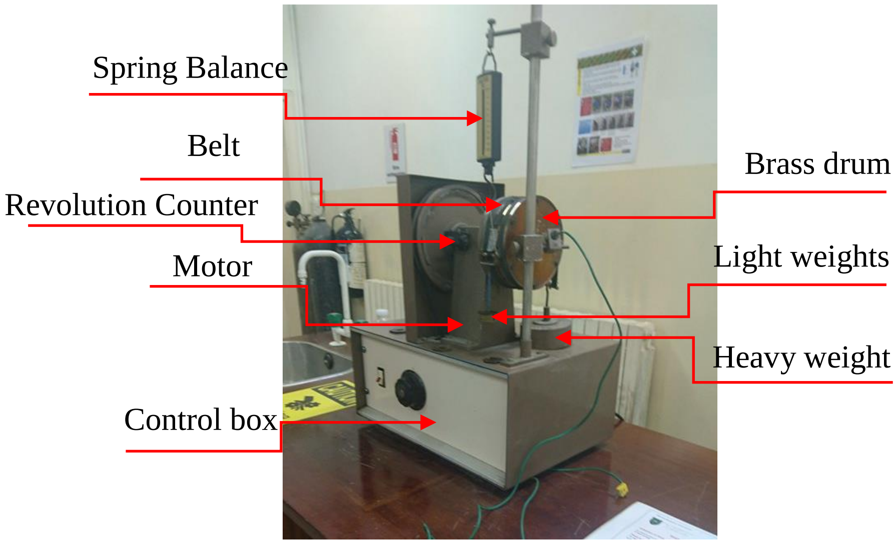

Figure1:Mechanical Equivalent of Heat Apparatous

Procedure

1. Obtain about 250g of cold water in a clean, dry beaker, at a temperature approximately 5-6 degrees below room temperature.
2. Pour the cold water into the drum carefully.
3. Insert a thermometer with its bulb in the water and record the intial temperture of water.
4. Connect the plug of the apparatous into a wall socket, and adjust the angular speed of the electric motor to a uniform speed within the range 60-120rev/min.
5. Set a suitable mass of light weights , so that the heavy weight is held in floating position in equilibrium.As a result , the belt will be tightly tied around the drum (In this way you will be sure that friction force is acting on the drum)
6. Record the water temperature every 100 revolutions of the drum up to 2000 revolutions .

Given Data

- Drum Data
  - Mass m_d = 0.7 kg
  - Specific heat C_d = 0.092 kcal/kg.^oC
  - Radius r_d = 0.075 m
- Water Data
  - Mass m_w = 250 gm
  - Specific heat C_w = 1 kcal/kg.^oC
  - Initial temperature T_i =16 ^oC
- Mass Data
  - Big mass W = 2 kg
- Room Temperature T_{amb} = 23 ^oC

Data Observed

Drum Revolurions (N)	Water Temperature (^oC)	Spring Force (gm)	Small Mass (gm)
0	16	65	60
100	19.2	65	60
200	20.1	65	60
300	21	65	60
400	21.9	65	60
500	22.7	65	60
600	23.5	65	70
700	24.2	65	70
800	24.9	65	70
900	25.6	65	70
1000	26.2	65	70
1100	26.8	65	70
1200	27.4	65	70
1300	28.0	65	70
1400	28.6	65	70
1500	29.1	65	70
1600	29.6	65	60
1700	30.1	65	60
1800	30.5	65	60
1900	31.0	65	60
2000	31.4	65	60

Sample Calculations

Step (1) : Calculate the work done by the friction force
Take reading N=100 as a sample for calculations :

$W = F\times d = (W + p - w)\times g \times 2\pi r\times N$
$= (2 + 65/1000 - 60/1000) \times 9.81\times 2\pi\times 0.075 \times 100$
$= 926.88$ J = 0.9269 kJ

Drum Revolutions(N)	100	200	300	400	500	600	700	800	900	1000
Work Done (kJ)	0.9269	1.854	2.781	3.708	4.634	5.533	6.455	7.378	8.300	9.223

Drum Revolutions(N)	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Work Done (kJ)	10.14	11.07	11.99	12.91	13.83	14.83	15.76	16.68	17.61	18.54

Step(2) : Calculate the heat transferred to the drum and water
Take reading N=100 as a sample for calculations :

$Q = m_d\times C_d\times \Delta T + m_w\times C_w\times \Delta T = m_d\times C_d\times (T-T_i) + m_w\times C_w\times (T-T_i)$
$= 0.7\times 0.092\times(19.2 - 16) + 0.25\times 1\times(19.2 - 16)$
$= 1.006$ kCal

Drum Revolutions(N)	100	200	300	400	500	600	700	800	900	1000
Heat Generated (kCal)	1.006	1.289	1.572	1.855	2.106	2.358	2.578	2.798	3.018	3.207

Drum Revolutions(N)	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Heat Generated (kCal)	3.396	3.584	3.773	3.961	4.119	4.276	4.433	4.559	4.716	4.842

Step(3) : Find Joule's Factor (J)
Take reading N=100 as a sample for calculations:

$J = W/Q = 0.9269/1.006 = 0.9214$ kJ/kCal

Drum Revolutions(N)	100	200	300	400	500	600	700	800	900	1000
Joule's Factor(kJ/kCal)	0.9214	1.438	1.769	1.999	2.200	2.346	2.504	2.637	2.750	2.876

Drum Revolutions(N)	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Joule's Factor(kJ/kCal)	2.986	3.089	3.178	3.259	3.357	3.468	3.555	3.657	3.734	3.829

Average
2.778 kJ/kCal

Results & Discussion

According to first law of thermodynamics which is a version of the law of conservation of energy, the total energy of an isolated system is constant; energy can be transformed from one form to another, but can be neither created nor destroyed.Thus, a given amount of work would generate the same amount of heat.The exact value of Joule's Factor J = 4.186 kJ/kCal . That indicates , for every 4.186 kJ of work done , 1 kCal of heat must be generated . The value of Joule's Factor in this experiment = 2.778 kJ/kCal , which means more heat is generated than expected (The expected value for generated heat = 0.6636 kCal for 2.778 kJ of work done).

The reason beyond this error , is that the recorded intial temperature is not accurate. This is obvious in the data sheet , where the intial temperature $T_i = 16\ ^oC$ and the recorded temperature after 100 rev of drum revolutions $T = 19.2\ ^oC$. The change in temperature for the first reading $\Delta T = 19.2-16 = 3.2\ ^oC$ which is a great value relative to the successive changes in temperature . From the data sheet, it is clear that for every 100 rev of drum revolutions , the temperature was increased within a range of 0.6-0.9. So , the recorded intial temperature must be greater than 16 ^oC .

Since the value of the heat generated is given by

$$Q = m_d \times C_d \times \Delta T + m_w \times C_w \times \Delta T = m_d \times C_d \times (T-T_i) + m_w \times C_w \times (T-T_i)$$

then , as T_i decreases , the value of Q increases .This is why the calculated values of the generated heated are greater than their expected values .

Moreover, it is noticeable that there is an upward trend of both values of work done and heat generated , which is consistent with the fact that energy can not be destroyed.

Regarding the heat exchanged between the drum and the ambient air , it can be neglected and not to be taken into consideration , because for effective heat transfer to occur , the difference between the two bodies must be greater than 10 ^oC .Since $T_{amb}=23\ ^oC$ and the temperature of the drum is within the range 16-23.4 ^oC , heat transfer between them is ineffective .

Uncertainty Analysis

The precision of Joule's Factor value obtained in this experiment can be determined using the following percent error formula :

$$\text{Percent error} = \left| \frac{\text{Experimental Value} - \text{Theoretical Value}}{\text{Theoretical Value}} \right| \times 100\%$$

$$= \left| \frac{2.778 - 4.186}{4.186} \right| \times 100\% = 33.64\%$$

Sources of Errors

Errors in this experiment are caused by several factors such as :the intial temperature was wrongly recorded (probably because temperature was measured before pouring the water into the drum) ,the worn belt and computational errors due to approximation

Summery & Conclusion

Overall, The experiment showes that mechanical work W can be transformed into heat Q . The relationship between work and heat is investigated by determining the value of Joule's factor , which represnts the amount of work that must be performed to produce a unit quantity of heat . Differences existed between the experimental value and the theoretical value due to experimental errors .

References

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