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Study of Effect on Cooling Correction Factor by Using Different Insulation Materials in the Outer Jacket of Bomb Calorimeter

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ABSTRACT: In the present work, we went through cooling correction factor and understood that cooling correction can be minimized or may be eliminated, if we increase the adiabaticity of any bomb calorimeter (which is plain jacket in our case), to the greater extent by using better insulating material in the outer jacket (which thermally insulates the entire apparatus) than water.
In this present work, Three common insulating materials is used which provides better insulation as they have lower thermal conductivity than water. (i.e. glass wool, cotton wool and expanded polyethylene).
Experiments were carried out with these four types of insulations which are water, wool, cotton wool and expanded polyethylene. Comparisons charts were made and calculations were done to estimate effects of insulating material on cooling correction factor of bomb calorimeter. Some modification work on existing bomb calorimeter also had done so that different insulations can be used in apparatus for evaluating the experimental values.

KEYWORDS: Cooling correction factor, Adiabaticity, Thermal Insulation, bomb caloriemeter.

I. INTRODUCTION

Bomb calorimeter is an isolated system and has constant volume. The bomb is a sealed container for the reaction occurring, and the heat of reaction will transfer to the water or oil in the inner container. The temperature changing of the water is used to calculate the heat of reaction. Bomb calorimeter is suitable for study of combustion reaction

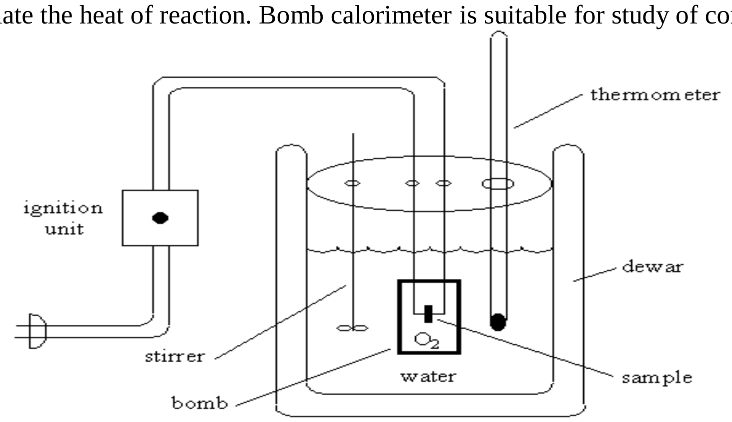

Figure 1.1 Basic bomb calorimeter

A bomb calorimeter consist of a bomb in which combustion of fuel takes place, a bucket in which bomb is kept surrounded by water, a thermometer to measure the temperature rise of the bucket water and a water jacket which acts as a shield and prevent any heat loss from bucket water to the surrounding. Among other accessories there is a stirrer which maintains uniform temperature distribution of bucket water, an ignition circuit or controller which provides electricity for fuel ignition and stirrer rotation. There is also provision for oxygen supply to the bomb. Calculation is

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done either by finding out energy equivalent or heat capacity of the calorimeter or by using standardization technique in which a sample is used with known heat of combustion.

II. THEORY OF BOMB CALORIMETER

The heat of combustion can be most conveniently measured using an **adiabatic bomb calorimeter**. In such calorimeter, the combustion reaction takes place in a closed chamber under constant volume ("bomb") so that no work can be transferred. Bomb calorimeters are used to determine the calorific value of solid and liquid fuels like gasoline or petrol, coke, coal, combustion waste, foodstuffs and building materials etc. the calorific value of the fuel is determined by the fuel's heat of combustion.

A. Construction of bomb calorimeter

Major parts of bomb calorimeter are bomb, bucket, water jacket, temperature sensor and current controller.

(i) Bomb:

Bomb is a cylindrical vessel in which fuel can be burnt. In a bomb, combustion of fuel takes place so it has to be a thick walled vessel. Material used for constructing bomb is stainless steel also capacity of any general bombs is 300 cm^3. Nickel chromium alloys can also be used as to prohibit damage due to after products during combustion of fuel. A bomb can be opened or closed according to the requirement. The lid of the bomb incorporates an insulated electrode, one return line electrode (body or earth) and two valves. One valve is for oxygen intake and the other is for discharging residual gases after combustion. An O-ring is provided at the oxygen intake valve for insuring no leakage of the gas. The residual gases which are filled up in bomb after combustion must be removed to release the pressure of the bomb. Otherwise it would be very difficult to open the bomb for further experiments. There is a provision for holding the fuel-crucible at the lid of the bomb. For attaching fuse wire to the fuel crucible there is a holes in rod attached to the inner side of bomb lid. A neoprene rubber O-ring is provided for sealing the threaded joint between the cover and the bomb.

Figure 2.1 Parts of bomb

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(ii) Bucket:

The bucket is filled with water and the bomb is submerged in that. For determining calorific value of any fuel temperature difference of the water has to be noted. The assembled bucket comprises water, bomb, stirrer and thermometer. They are made up of stainless steel or chrome plated copper sheet. For minimizing absorption and emission of radiant heat buckets can be made of brass with a highly polished finished outer surface

Figure 2.2 Buckets

(iii) Calorimeter jacket:

It is the most outer part of the calorimeter; it carries bomb and bucket inside it. Its main function is to insure to prevent any heat loss from bucket to the surroundings. It is dual walled stainless steel container with two coaxial cylinders and water is filled in between the two cylindrical walls. The bucket with the bomb is kept inside the inner cylinder.

These jackets are broadly of three types:

(a) Adiabatic:

In this type, water in the calorimeter jacket is kept in same temperature with bucket water, for that external heater and coolers are provided. In an adiabatic jacket, ideally no heat transfer is take place between bucket and jacket. Only two temperature reading has to be taken for the calculations which are initial water temperature and water temperature after combustion of the fuel. No cooling corrections are required.

(b) Isoperibolic:

Literal meaning of isoperibolic is “almost isothermal” that means temperature of the jacket-water is maintained same throughout the experiment using external means. In this type of calorimeter jacket a small amount of heat transfer between bucket- and jacket-water takes place. And a correction factor is introduced after the experiment that takes care of this heat transfer.

(c) Plain insulating:

In this case it is assumed that the jacket temperature will remain constant throughout the test. No auxiliary temperature control systems is provided in this type of jacket . So this is low cost design. Temperature reading has to be noted every now and then in this system and also cooling correction is involved.

(iii) Controller:

It provides electricity to the bomb for firing the sample and for the stirrer unit for rotation of stirrer. Now a day’s microprocessor based controllers are used widely which have provision for recording of data, data processing, maintaining jacket temperature and also receiving information on the content of acids and sulphur in combustion products.

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(iv)Temperature measuring device

It is the most important and very crucial part of the bomb calorimeter as overall results for the calorific value of any fuel based on reading noted from it only. A plain mercury based thermometer can be used for this purpose but now-a-days metastatic thermometers with .01 K scale divisions are used because more temperature sensing device is accurate the better will be the results. Some bomb calorimeters use platinum resistance thermometers along with metastatic thermometers. More advanced calorimeters are using a high accuracy electronic sensor with a resolution of .0001 K.

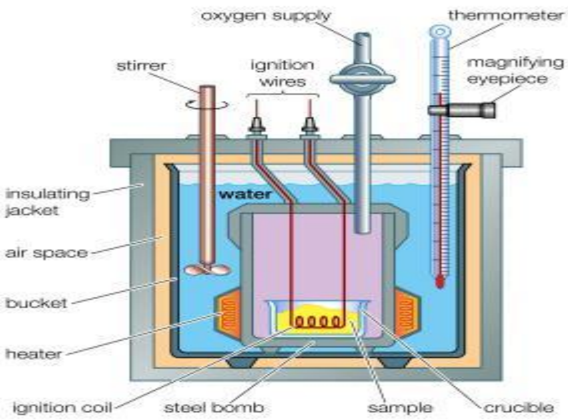

Figure 2.3 Nomenclature of various parts of bomb calorimeter

III. WORKING

The bomb calorimeter is set up as shown in Fig. above.

The bomb is opened and cleaning of required parts is done. Fuse wire of measured length and weight is taken and the ends of the wire are attached to the holes slots given in the bomb. Fuel sample has been palletized with the help of pallet and then small measured mass of it is taken in the crucible (about 1 gm). The crucible is kept in the crucible holder of the bomb such that the fuse wires passes through the fuel. The lid of the bomb then fastened manually. After that with the oxygen intake valve not more than 2 Mpa of oxygen is supplied to the bomb. Now all the electrical connections are made. Lead wires connect the fuse wire inside bomb with the controller. Stirrer is placed in the bucket water for maintaining throughout even water temperature. Temperature sensor is then inserted in the bucket water such that there is adequate space between stirrer, thermometer, bomb and lead wires. Now the apparatus is fully assembled and prepared for experiment.
Stirrer is turn on and temperature of the water is noted every minute and if temperature remains constant for 3 consecutive readings then that reading is noted down (T initial) now we press fire button for almost 3 seconds and temperature of bucket water is observed. After the ignition, temperature rises rapidly to the maximum, and temperature readings are to be noted down (T final) when no further increase in temperature is observed. After some time, temperature starts to decrease. This decrement in temperature is noted down in every 1 minute interval. Now the stirrer got turn off, lead wires are got removed and thermometer/sensor is taken out. Bomb is removed from the bucket and the residual gases of the bomb are discharged. The bomb is then opened, If any amount of fuel is present in the crucible that means combustion of fuel was not completed and we have to weigh the remaining fuel. If there is no fuel found in the crucible that means combustion is completed and if any residual fuse wires are found then get them collected and weighed.

A. Thermal Insulation

To explain thermal insulation, we first need to understand the theory of heat transfer.

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Overview of heat transfer phenomena:

Heat transfer is the transfer of thermal energy from a heated object to a cooler object. When an object or fluid is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat transfer, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium. Heat transfer always occurs from a hot body to a cold one, a result of the second law of thermodynamics. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed down. Classical transfer of thermal energy occurs only through conduction, convection, radiation or any combination of these. Heat transfer associated with carriage of the heat of phase change by a substance (such as steam which carries the heat of boiling) can be fundamentally treated as a variation of convection heat transfer. In each case, the driving force for heat transfer is a temperature gradient.

Thermal insulation is the depletion of heat transfer (the exchange of thermal energy between objects of different temperatures) between objects in thermal contact. Thermal insulation can be achieved with especially engineered and suitable materials.
The insulating capability of a material is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value). In thermal engineering, other important properties of insulating materials are product density (ρ) and specific heat capacity (c)

B. INSULATION MATERIALS AND PROPERTIES

Insulations are defined as those materials or combinations of materials which slow down the flow of heat energy.

Following are some of functions of insulation materials:

1. Conserve energy by reducing heat loss.
2. Modulate or control temperatures for particular process.
3. Check vapor flow and water condensation on cold surfaces.
4. Increase operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power systems found in commercial and industrial installations.
5. Prevent apparatus from corrosive atmospheres and fire exposure. .
6. Prevent discharge of pollutants to the atmosphere.

C. Generic types and forms of insulation

The type indicates composition (i.e. glass, plastic) and internal structure (i.e. cellular, fibrous). The form implies overall shape or application (i.e. board, blanket, pipe covering).

Types

1. **Fibrous Insulation**
Fibrous insulation as name suggested are constitute of small diameter fibers which finely divide the air space. The fibers may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together. Silica, rock wool, slag wool and alumina silica fibers are used. The most widely used insulations of this type are glass wool. Glass fiber and mineral wool products usually have their fibers bonded together with organic binders that supply the limited structural integrity of the products.

2. Cellular Insulation
Cellular insulation composed of small individual cells separated from each other. The cellular material may be glass or foamed plastic such as polystyrene (closed cell), polyisocyanurate and elastomeric.

3. Granular Insulation
Granular insulation is composed of small nodules which may contain voids or hollow spaces. It is not considered a true cellular material since gas can be transferred between the individual spaces. This type may be produced as a loose or

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pourable material, or combined with a binder and fibers or undergo a chemical reaction to make a rigid insulation. Examples of these insulations are calcium silicate, expanded vermiculite, perlite, cellulose, diatomaceous earth and expanded polystyrene.

D. FORMS

Insulations are produced in a variety of forms suitable for specific functions and applications. The combined form and type of insulation determine its proper method of installation. The forms most widely used are:
1. Rigid boards, blocks, sheets, and pre-formed shapes such as pipe insulation, curved segments, lagging etc. Cellular, granular, and fibrous insulations are produced in these forms.
2. Flexible sheets and pre-formed shapes. Cellular and fibrous insulations are produced in these forms.
3. Flexible blankets. Fibrous insulations are produced in flexible blankets.
4. Cements (insulating and finishing). Produced from fibrous and granular insulations and cement, they may be of the hydraulic setting or air drying type.
5. Foams. Poured or froth foam used to fill irregular areas and voids. Spray used for flat surfaces.

E. Properties of Insulation

Not all properties are suitable for all materials or applications. The following properties are referenced only according to their significance in meeting design criteria of specific applications.

1. Thermal Properties of Insulation

Thermal properties are the primary consideration in choosing insulations.

a. Temperature limits: Upper and lower temperatures within which the material must retain all its properties.
b. Thermal conductance "C": The time rate of steady state heat flow through a unit area of a material or construction induced by a unit temperature difference between the body surfaces.
c. Thermal conductivity "K": The time rate of steady state heat flow through a unit area of a homogeneous material induced by a unit temperature gradient in a direction perpendicular to that unit area.
d. Thermal resistance "R": Resistance of a material to the flow of heat.

2. Mechanical and Chemical Properties of Insulation

Properties other than thermal must be considered when choosing materials for specific applications:

a. Alkalinity (pH) or acidity: Significant when moisture is present. Also insulation must not contribute to corrosion of the system.
b. Appearance: Important in exposed areas and for coding purposes.
c. Breaking load: In some installations the insulation material must "bridge" over a discontinuity in its support.
d. Capillarity: This must be took in account when material is in contact with fluids.
e. Chemical reaction: Potential fire hazards exist in areas where flammable chemicals are present. Corrosion resistance must also be considered.

F. Theory of cooling correction

If we add heat to a perfectly insulated body at a steady rate then a graph of the temperature of the body against time will be a straight line (Figure a).

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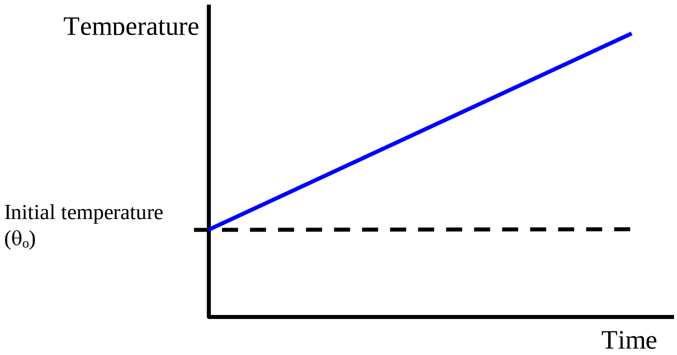

Figure 3.6: Ideal Graph between Temperature Vs Time

Clearly the final temperature in Figure 3.6 shows the needs to be corrected for loss of heat in final temperature.

Figure 2.5 shows the cooling of the body after the supply of heat has been cut off at t_o. Now to calculate the true rise of temperature we can use the Newton's law -
It shows that:

$$\Delta\theta = \phi S_1/S_2$$

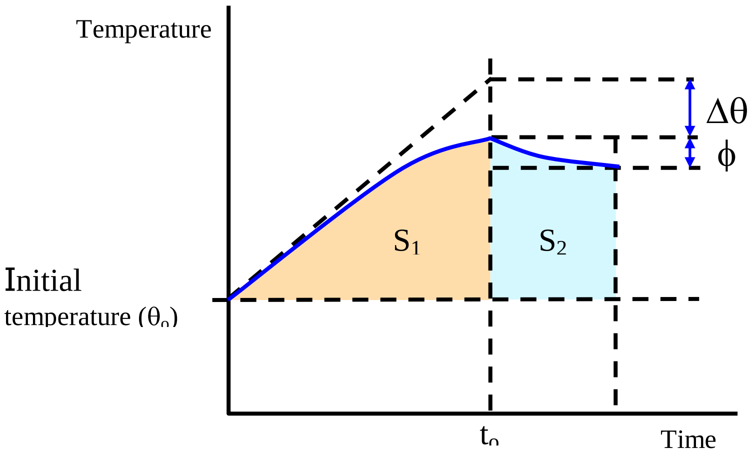

Figure 3.6.1: Actual Graph between Temperature Vs Time

Where $\Delta\theta$ is the cooling correction, and hence the true final temperature due to heating can be calculated.

The above discussed theory can be directly applied to the case of bomb calorimetric. For this we assumed a bomb calorimeter which is not perfectly insulated and we draw a Time Vs Temperature graph for the experiment performed on the apparatus.

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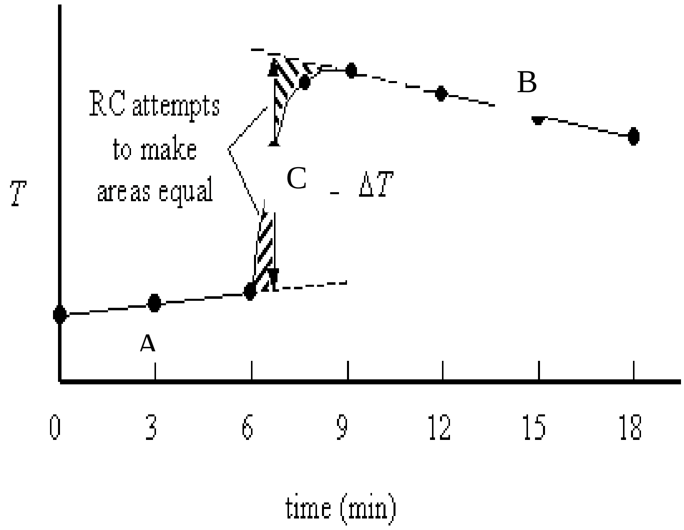

Figure 3.6.2 General Graph between Time Vs Temperature for bomb calorimeter heating and cooling process

Slope 'A' is a pre firing slope which shows temperature increment of bucket water due to heat transfer from jacket. When the difference between two successive readings with same time interval becomes almost same then at that point ignition of fuel is done denoted by the arrow head in graph. After ignition the temperature rises slowly initially then rapidly up to a maximum. Then there will be a small drop in temperature and after some time at point B, temperature gradient is constant again. Now, to calculate cooling correction, the initial heating rate (Slope A) and final cooling rate (Slope B) is extrapolated to a common vertical line. For locating this line, Dickinson method is used in which point C is chosen on the heating curve so that the temperature rise is almost 60% of total. Vertical line shows that the process is instantaneous in adiabatic system. For the above graph, ignition starts at $t = 7$ minutes. Thus, the temperature at $t = 6$ minutes must be extrapolated forward 1 minute by the pre-firing slope, and the temperature at $t = 12$ minutes must be extrapolated backward 5 minutes by the post-firing slope. For calculating the inadiabaticity of the system the cooling correction factor we have to bring the actual firing temperature to the T(initial) and post firing to T(Final).

It can also be done by following formula given by Dickinson:

$cc= v^1(t_a – t_o) + v^2 (t_n –t_a)$

cc = cooling correction

v^1= rate of fall in temperature / min in the preliminary period (when temperature rises, v^1 is negative)

v^2 = rate of fall of temperature /min in the after period.

ta = time at temperature [$T_o + .60 (T_n – T_o)$] mins

T_o = temperatute in ^oC at which firing is done.

T_n = temperature in ^oC after which rate fall of temperature is constant.

t_o = time at temperature T_o in minutes.

t_n = time at temperature T_n in minutes

IV. METHODOLOGY AND EXPERIMENTS

We had performed the experiments to find out the effect of using different insulating material on cooling correction factor of bomb calorimeter –

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Apparatus:

1. Benzoic acid (weighed) 1 gm
2. Oxygen bomb calorimeter;
3. Fuse wire (nichrome);
4. Thermometer;
5. 1.75 liters of water;
6. Supply of oxygen;
7. Power source;
8. Stop watch.

List of thermal insulating materials used in experiments:

S. no.	Insulating material	Thermal conductivity (k)
1	Water	0.56
2	Glass wool	0.04
3	Cotton wool	0.029
4	Expanded polyethylene	0.4

<u>Experiment # 1</u>

Our first is with entire apparatus is insulated with water jacket:

Having the apparatus discussed above and following the general procedure mentioned in the introduction with water jacket we observed the temperature readings while using benzoic acid as a fuel. We took 1 gram (approx) of benzoic acid for each experiment and experimented 3 times with water jacket and note down the average readings of temperature on each point of time and plotted graph with those readings.

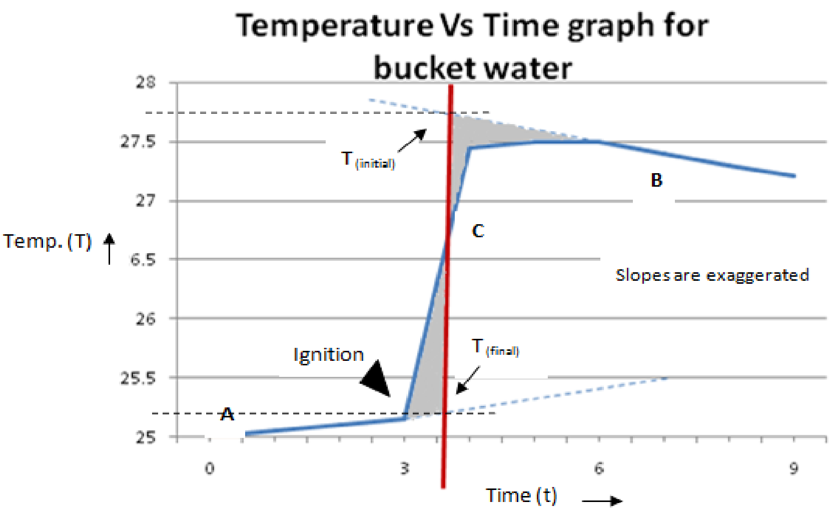

Figure 4.1 Graph between Time Vs Temperature for bucket water for Water jacket

Graph between time and temperature of the bucket water during experiment is plotted. 'A' shows pre firing slope , at t = 3 minutes firing started and temperature increases initially very rapidly then slowly to the 27.5 ^{o} C and started decreasing which can be seen in slope 'B'. To estimate cooling correction for this experiment we have to draw a vertical line which can be located by locating point 'C', which is 60 % of the total rise of temperature (According to Dickinson). Now we have two areas just after ignition and another after point 'C', for estimating cooling correction factor, we have to minimize the areas of these portions in graph for which we have a formula given by Dickinson, with this we can calculate the cooling correction factor. In any adiabatic system these areas will be nill and ignition process would be instantaneous so for calculating cooling correction factor any deviation from adiabaticity has to be observed. As much as adiabacity would increase areas will be decreased.

Experiment # 2

Our second experiment is with when apparatus is insulated with glass wool jacket:

Having the apparatus discussed above and following the general procedure with glass wool jacket we observed the temperature readings while using benzoic acid as a fuel.
We slightly modified our existing bomb calorimeter for this experiment so that glass wool can be inserted in the jacket instead of water.

Figure 4.2 – bomb calorimeter jacket after removing back cover.

Figure 4.3 – bomb calorimeter jacket filling with glass wool

We took 1 gram (approx) of benzoic acid for each experiment and experimented 3 times with water jacket and took average readings of temperature on each point of time and plotted graph with those readings.

Graph between time and temperature of the bucket water during experiment is plotted. 'A' shows pre firing slope , at t = 3 minutes firing started and temperature increases initially very rapidly then slowly to the 24.7^{o} C and started decreasing which can be seen in slope 'B'. To estimate cooling correction for this experiment we have to draw a vertical line which can be located by locating point 'C', which is 60 % of the total rise of temperature (According to Dickinson method). And in this case Point C is located on 23.6^{o}C. Now we have two areas just after ignition and another after point 'C', For any fully adiabatic system these areas would be nil and ignition process would be instantaneous so for calculating cooling correction factor any deviation from adiabaticity has to be observed. As much as adiabaticity would increase areas will decrease.

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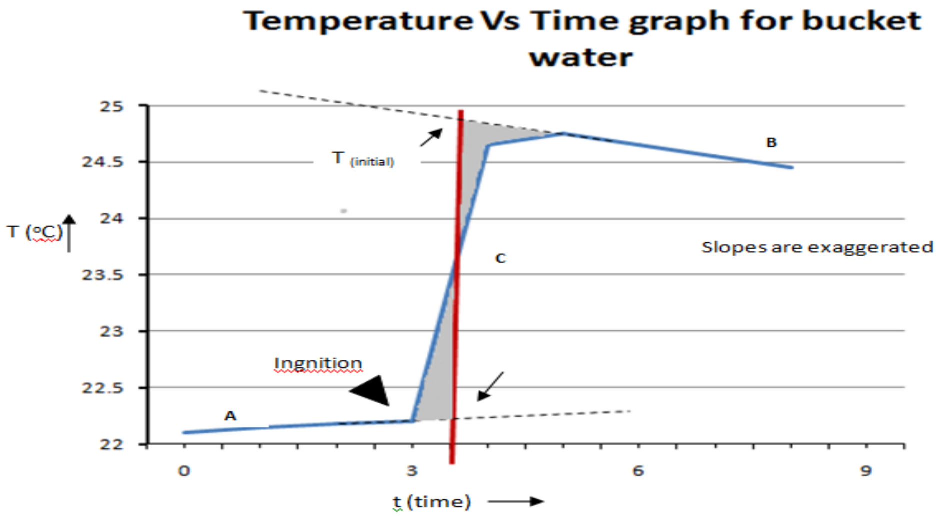

Figure 4.4: Temperature Vs Time graph for bucket water for Glass wool jacket

Experiment # 3

Our third experiment is with when apparatus is insulated with cotton wool jacket:

Having the apparatus discussed above and following the general procedure with cotton wool jacket we observed the temperature readings while using benzoic acid as a fuel.

For this experiment we used our modified bomb calorimeter which was used for previous experiment, we just removed glass wool and filled jacket up with cotton wool.

Figure 4.5: Bomb calorimeter jacket filled with cotton wool

We took 1 gram (approx) of benzoic acid for the experiment and experimented 3 times with water jacket and took average readings of temperature on each point of time and plotted graph with those readings.

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Graph between time and temperature of the bucket water during experiment is plotted. ‘A’ shows pre firing slope , at t = 3 minutes firing started and temperature increases initially very rapidly then slowly to the 26.7^{o} C and started decreasing which can be seen in slope ‘B’. To estimate cooling correction for this experiment we have to draw a vertical line which can be located by locating point ‘C’, which is 60 % of the total rise of temperature (According to Dickinson method). And in this case Point C is located on 25.8^{o}C. Now we have two areas just after ignition and another after point ‘C’, For any fully adiabatic system these areas would be nil and ignition process would be instantaneous so for calculating cooling correction factor any deviation from adiabaticity has to be observed. As much as adiabaticity would increase areas will decrease.

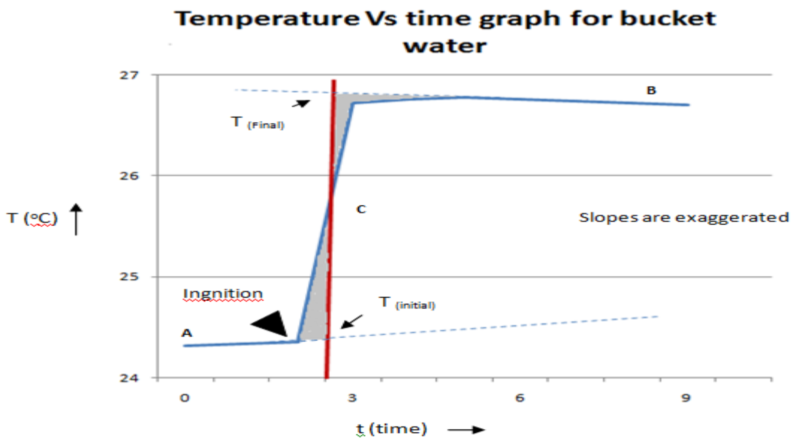

Figure 4.6: Temperature Vs Time graph for bucket water for Glass wool jacket

Experiment # 4

Our fourth experiment is with when apparatus is insulated with expanded polyethylene jacket:

Having the apparatus discussed above and following the general procedure with **expanded polyethylene jacket** we observed the temperature readings while using benzoic acid as a fuel.
For this experiment we used our modifies bomb calorimeter which was used for previous experiment, we just removed cotton wool and filled jacket up **expanded polyethylene**We took 1 gram (approx) of benzoic acid for each experiment and experimented 3 times with water jacket and took average readings of temperature on each point of time and plotted graph with those readings.

Figure 4.7: Bomb calorimeter jacket filled with cotton wool

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Graph between time and temperature of the bucket water during experiment is plotted. 'A' shows pre firing slope , at t = 2 minutes firing started and temperature increases initially very rapidly then slowly to the 25.6^{o} C and started decreasing which can be seen in slope 'B'. To estimate cooling correction for this experiment we have to draw a vertical line which can be located by locating point 'C', which is 60 % of the total rise of temperature (According to Dickinson method). And in this case Point C is located on 24.9^{o}C. Now we have two areas just after ignition and another after point 'C', For any fully adiabatic system these areas would be nil and ignition process would be instantaneous so for calculating cooling correction factor any deviation from adiabaticity has to be observed. As much as adiabaticity would increase areas will decrease.

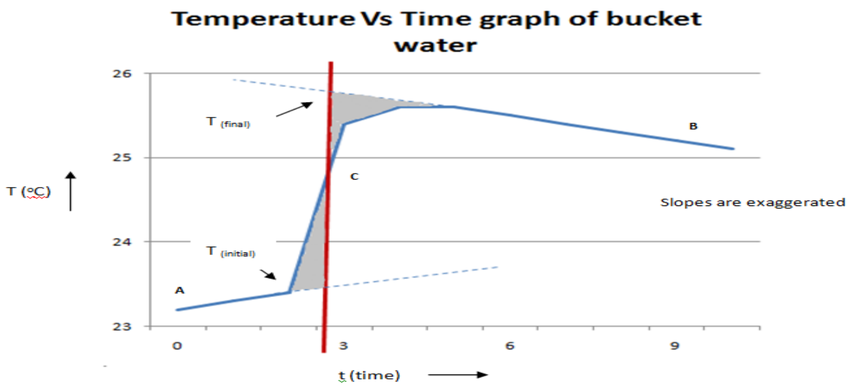

Figure 4.8: Temperature Vs Time graph for bucket water for EPE jacket

V. RESULTS AND DISCUSSION

In this section results observed from the above experiments and plotted graphs have been discussed.
We calculated cooling correction factor from the data attained in the above section of the work and tabulated below:

S.no.	Insulation used	Δ T	Cooling correction factor
1	Water	2.3	0.22
2	Glass wool	2.5	0.11
3	Cotton wool	2.4	0.036
4	Expanded polythylene	2.2	0.18

From the above table we can clearly find out that there is a slight difference between cooling correction factors if we change the insulation in the outer jacket of bomb calorimeter.
For cotton wool the value of cooling correction factor is minimum so it makes the system more adiabatic than water.
Authors are expected to conclude their presentation comprehensively in the conclusion. Authors have to freedom to include future research details as part of the conclusion or as a separate section before the conclusion, depending on the appropriateness. Conclusion should not repeat the main text; instead it should try to help the reader to have a strong view on the article's claims. Following a critical approach on own research methods and experiments can show maturity and impartial evaluation, which enhance the quality of your article.

VI. CONCLUSION

We have used our existing bomb calorimeter which have water jacket to get results with different insulation materials i.e. glass wool, cotton wool and expanded polyethylene. For this we had to get apparatus slightly modified. We experimented with four different types of jackets and observed the difference using same fuel and same quantity which is benzoic acid. Observing the entire graph plotted for four insulations we can say that there is slight difference in the trend of heating and cooling portions of graphs from each other and this difference in trend is occurred due to different

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conductivities of insulations. From the above work we can say that if we use better insulation than water we can improve the adiabaticity of apparatus and further can nullify the requirement of cooling correction. Among the insulations what we have used in the experiments cotton wool gave best results in terms of cooling correction factor , For cotton wool cooling correction factor came out as 0.036 which is far better than that of for water which is 0.22 . For making the existing calorimeter fully adiabatic or in other words to eliminate the requirement of cooling correction we have to use much better insulating material than we have used.

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