California State University, Long Beach

College of Engineering
Department of Mechanical Engineering

EXPERIMENT 2: Bomb Calorimeter

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Course: MAE 337-Thermal Engineering Lab

Section 9

Group 5
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Abstract:

The objective of the experiment is to find the higher heating and lower heating value of combustion of a sample of liquid diesel using a bomb calorimeter. The experiment was conducted in a mechanical engineering thermal lab and involved the use of a bomb calorimeter, which is a closed vessel designed to contain the diesel sample and an excess of oxygen. The fuel sample was burned in the calorimeter, and the heat released was measured by monitoring the temperature change of the surrounding water. The heat of combustion was then calculated using the mass of the fuel sample, the mass of water, and the temperature change. There is a minor burning mechanism that is on the top of the combustion chamber that is connected to a spark igniter to begin the combustion procedure. On the other hand, the thermometer is also placed inside the inner container to measure the change in temperature throughout the experiment.There is also an oxygen tank used to pressurize the combustion chamber with pure oxygen for the whole duration. A burette is used to titrate the collected chemical that is produced from the reaction. The volume of the acid created was obtained by titrating it to neutralize by Na2CO3 and also the orange color indicator. The wire that remained after the combustion was used to help ignite the fuel was measured after the experiment using a ruler.

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Objective

To determine the higher heating value (total calorific value, or gross heat of combustion) of a sample of liquid diesel fuel.

Introduction

In our world today the most important chemical reaction for producing energy is combustion. The process involves the oxidation of the constituents in the fuel. During this reaction energy is released from the fuel in the form of heat and is called the heat of combustion and the amount of heat per unit mass of the fuel is called the heating value. When doing thermodynamic analysis of power plants, the heating value is very important. Calorimetry is the art of measuring how much heat during the combustion of a substance and is an important test to determine the heating value of a fuel. The tools used for this test are known as calorimeters and there are two main types, one for measuring liquid and solid fuels (bomb calorimeter) and one for measuring gaseous fuels (gas calorimeters). Bomb calorimeters, which will be used in this lab because the fuel is a liquid, come in either adiabatic or non adiabatic depending on their construction and both have chambers which are held at constant volume and are filled with oxygen before the fuel is ignited. The way a calorimeter works is by measuring the temperature change in a known mass of water when a known amount of fuel is burned. When measuring the heating value of a liquid or solid fuel using a bomb calorimeter there must be some corrections applied discussed in the following. The radiation correction $\Delta T_{corrected}$ takes into account the if the used is not at room temperature and its equations are in detail under the calculations. The water in the bomb becomes acidified and a solution is used to measure the heat generated by the formation of the acids. The bomb washing is collected in a beaker and titrated and the correction e1 is calculated using this equation $e(cal) = V_{Na_2CO_3} \times \frac{5}{9}$. Because of difficult chemical analysis e2 can be assumed to be zero. The fuse wire correction e3 can be made with the following equation $e_3(cal) = (length\ of\ burnt\ wire) \times 3$. The next correction is due to the combustion happening at a constant volume instead of a constant pressure e4 and is calculated using $e_4 = V(P_f - P_i) = 0.35lit \times (23.6 - 26)atm \times 24.22cal/lit.atm = 23.3\ .cal/gram\ fuel$. The final correction is due to the combustion of products at higher temperature than the reactants e5 and the following equation is used $e_5 = 3.94 \times (T_f - T_i)$.

List of Apparatus

1. Parr calorimeter system including firing mechanism

2. A digital thermometer with $0.01^{\circ}C$ accuracy
3. Ignition wire
4. Oxygen cylinder
5. Sample liquid diesel fuel
6. Standard (2.032 grams/liter) anhydrous (Na_2CO_3) solution

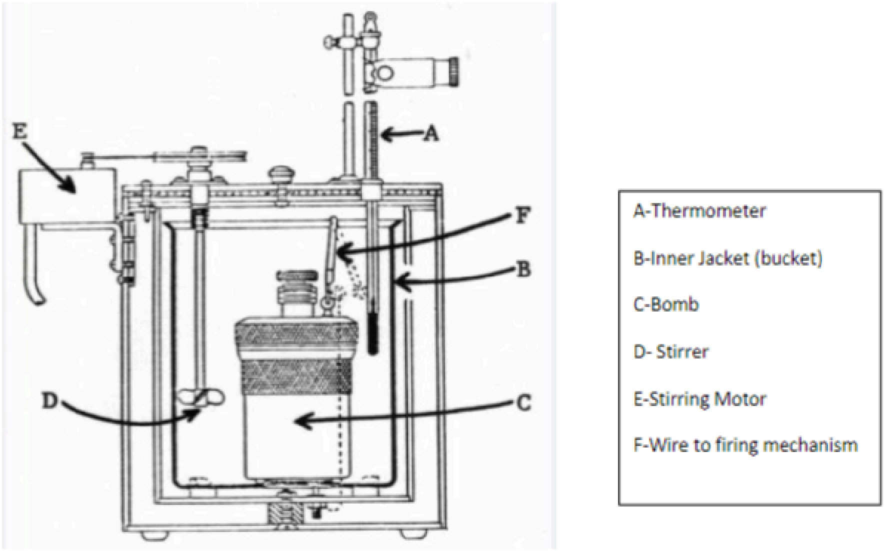


Figure 1-Cross Section view of 1300 Series Parr Bomb Calorimeter

Procedure

The first step in this experiment was to weigh an empty fuel capsule to the nearest 0.001 gram and then add about 1 gram of fuel and weight again to the nearest 0.001 gram and then subtract to find the weight of the fuel. After that a 10 cm long wire was attached to the fuel capsule where the wire just touched the sample and was not fully immersed. The 1 ml of distilled water was placed in the bob cylinder using a pipet. The bomb was then assembled with care to make sure no fuel was spilled and the bomb cap was screwed on hand tight. The oxygen was then loaded into the bomb by connecting its inlet valve to the oxygen supply and the needle valve opened slowly. Once pressure in the bomb reached 25 atm the supply valve was closed and pressure valve slowly released. Bomb is then disconnected and the screw is replaced screwing down twice. The bomb was then placed in a steel bucket with 2000 ml of distilled water and the bucket was then placed in the calorimeter. Before the bomb was electrically connected, the circuit was tested. The wire was then connected to the electrode, the calorimeter was closed and the stirring mechanics started. The calorimeter ran for 2 minutes before taking the first first temperature reading. The temperature was then read at every minute for 5 minutes. The bomb was then ignited by pressing the ignition button for 7-8 seconds. The temperature was read one minute after ignition and in 15 seconds intervals for two minutes. After that the temperature was read at one minute intervals until the difference was constant for a ew minutes. The calorimeter was then opened and the bomb was removed and the residual pressure was released. The unburned pieces of fuse wire were measured and the bomb was cleaned appropriately with proper washing solutions.

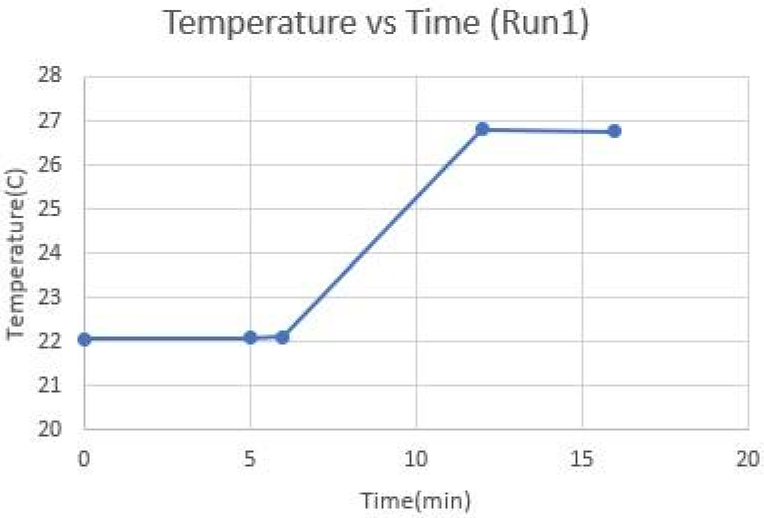
Table of Data and Results

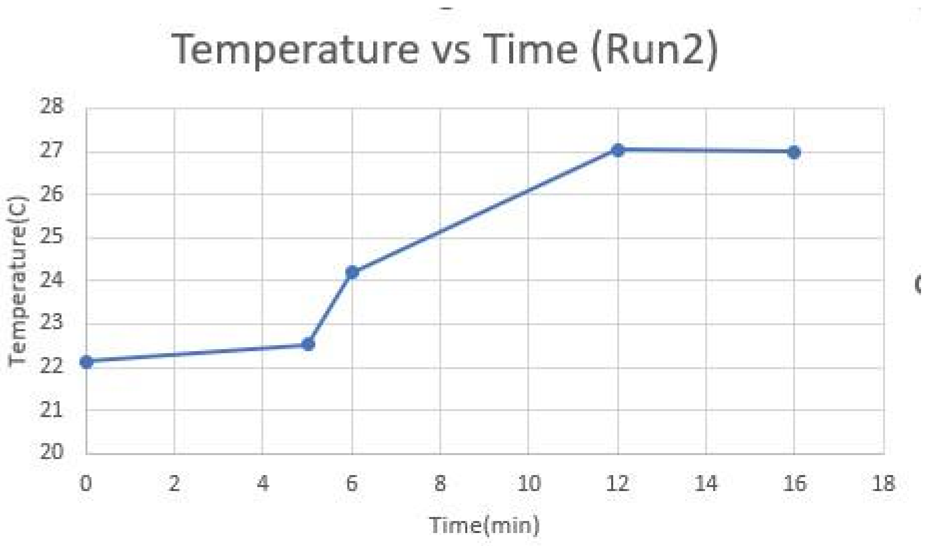
Theoretical HHV: 19594 Btu/lbm

Theoretical LHV: 18320 Btu/lbm

Data Table

Temperature vs Time Plot





Old:

	Run 1	Run 2
r_1 (℃/min)	0.002222	0.005556
r_2 (℃/min)	0.010317	0.011111
$\Delta T_{corrected}$ (℃)	4.625794	4.756546
e_1 (cal)	8.055556	14.72222
e_3 (cal)	9.2	8.165
e_4 (cal)	-22.2075	-22.2075
e_5 (cal)	19.55221	20.27726
HHV (Btu/lbm)	20127.91	20689.03
% error	2.725%	5.589%
LHV (Btu/lbm)	18722.04	19283.15
% error	2.195%	5.257%

New:

	Run 1	Run 2
r_1 (℃/min)	0.0065	0.078996

r_2 (°C/min)	0.010933	0.011243
$\Delta T_{corrected}$ (°C)	4.741219	4.552772
e_1 (cal)	7.861111	8.722222
e_3 (cal)	11.9503	11.9503
e_4 (cal)	-22.2075	-22.2075
e_5 (cal)	15.5166	16.05773
HHV (Btu/lbm)	20858.01	20026.51
% error	6.451%	2.207%
LHV (cal/g)	19452.14	18620.64
% error	6.18%	1.641%

Result

<u>Sample Calculations</u>

Old calorimeter run 1:

$T_b = T_a + 0.6(T_c - T_a) = 23.21667+0.6(27.79444-23.21667) = 25.96333$ °C

$6<t_b<6.25$

Interpolate:

$t_b = 6 + \Delta T((T_b - T_{@6})/(T_{@6.25} - T_{@6})) = 6+(6.25-6)*((25.96333-25.6)/(26.44444-25.6)$

$t_b = 6.107566$ min

$r_1 = (T_a - T_i)/(t_a - t_i) = (23.21667 - 23.22778)/(5-0) = -0.002222 \rightarrow |-0.002222| = 0.002222$

$r_2 = |(T_f - T_c)/(t_f - t_c)| = |(27.72222 - 27.79444)/(18-11)| = 0.010317$

$\Delta T_{corrected} = [T_c + r_2(t_c - t_b)] - [T_a + r_1(t_b - t_a)]$

$= [27.79444 + 0.010317(11 - 6.107566)] - [23.22778 + 0.002222(6.107566 - 5)]$

$= 4.625794\ ^{\circ}C$

$e_1 = V_{Na2CO3} \times 5/9 = 14.5 * 5/9 = 8.055556$ cal

$e_2 = 0$ cal

$e_3 = 2.3 \times \Delta L = 2.3(10-6) = 9.2$ cal

$n_i = PV/Rt = (30)(0.35)/(0.08205)(298) = 0.429432$ mol

1 gram diesel (14.1 g/mol) = 0.0709 mol diesel

$CH_{2.1} + 1.525\ O_2 \rightarrow CO_2 + 1.05\ H_2O + O_{2,\ excess}$

0.0709 mol $CH_{2.1} \times 1.525$ mol $O_2 = 0.1084$ mol $O_{2,\ consumed}$

mol O_2 remaining $= n_i - 0.1084$ mol $O_2 = 0.321032$ mol

n_f = # mol O_2 remaining + # mol CO_2 produced $= 0.321032 - 0.0709 = 0.391932$ mol

$P_f = (n_f / n_i) \times P_i = 30(0.391932 / 0.429432) = 27.38026$

$e_4 = V_{bomb}(P_f - P_i) = 0.35(27.38026 - 30) = -0.917 \times 24.22$ cal/L-atm $= -22.2075$ cal

$M = n \times MW$

$M_{CO2} = 0.0709*44 = 3.1196$

$M_{H2O} = 0.0745*18 = 1.341$

$M_{O2} = 0.321032*32 = 10.27303$

$e_5 = [(M \times C_v)_{CO2} + (M \times C_v)_{H2O} + (M \times C_v)_{O2}](T_f - T_i)$

$= [(3.1196)(0.227) + (1.341)(1) + (10.27303)(0.224)](27.72222 - 23.22778)$

$= 19.55221$ cal

$HHV = ((W \times \Delta T_{corrected} - e_1 - e_2 - e_3) / m_f) + e_4 + e_5$

$= [(2423)(4.625794) - 8.055556 - 9.2) / 1.016] + (-22.2075) + 19.55221$

$= 11188.39$ cal/g

$11188.39 \times 1.799 = 20127$ Btu/lbm

$100 \times (20127 - 19594) / 19594 = 2.725$ % error

LHV = HHV - $h_{fg,\ H20,\ @25\ C}$ x $m_{H20,\ produced}$ = 11188.39 - 583.19(1.34) = 10406.9 cal/g

10406.9 x 1.799 = 18722 Btu/lbm

100 x (18722 - 18320) / 18320 = 2.195 % error

Discussion and Analysis of Results

The calculated Higher Heating Value and Lower Heating Value of both old calorimeter and new calorimeter are significantly different from the theoretical HHV and HHV, which can be indicated by the percentage error ranging from 2 to 6 percent. However, the overall results are reasonably aligned with the given values. The potential errors can come from both human errors and equipment malfunction. First of all, heat can be lost from the calorimeter to the surrounding, which can result in the fluctuation in the recorded temperature. The human can occur during the experiment, which include incorrect reading of the instruments and also not following the proper procedures. In this particular experiment, some water was spilled during one of the runs which can cause significant influence on the result. Furthermore, the calorimeter cannot be perfectly insulated, therefore heat can enter or escape the system. Moreover, there may be a possibility of chemical reactions existed because of the combustion. The incompletion of the sample combustion can also be a contributing factor to the error.

Conclusion and Recommendations

In conclusion, the overall results and the calculated HHV and LHV in particular are similar to the predicted/theoretical values and the experiment in general is conducted successfully. Although there is a significant error within the theoretical values, it can be predicted by recognition of improper experimental procedure. Also, there are certain factors (heat loss, unideal lab condition) that are unavoidable and real life is different from the ideal condition.. But we can learn from the mistakes by implementing proper lab procedures, using accurate measurement techniques, and estimating the heat loss and the incomplete of the combustion process.

References

Çengel, Yunus A. Thermodynamics : an Engineering Approach. Boston :McGraw-Hill Higher Education, 2008.

Member's Contribution

Hung Ngo: Abstract, Discussion and Results, Conclusion and Recommendations

Paul Yousefian: Introduction, List of apparatus, Procedure

Ricardo Jimenez: calculations, sample calculations