California State University, Long Beach

College of Engineering
Department of Mechanical Engineering

EXPERIMENT 1: Continuous Flow Gas Calorimeter

Instructor: Ryan Moffit

Course: MAE 337-Thermal Engineering Lab

Section 9

Group 5
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Abstract:

The objective of this lab is to analyze the heat of combustion of natural gas by using the continuous flow calorimeter method. In this experiment, water was flown through the calorimeter and a heated burner was fueled with natural gas to heat up the combustion chamber. After 10 minutes, the water flow, temperature, condensate drip would be steady, then students would be ready to set to record the data. First of all, one would start the timer and collect the data for water inlet, water outlet, and water exit temperature at 5 readings intervals. The gas pressure and temperature would also be recorded within each run. After obtaining the data, the students would start calculations with the final goal of obtaining the Highest Heating Value and Lowest Heating Value. After that the relative percentage errors of those data would be calculated using the standard values for natural gas. The big difference in percentage error could be due to user error, or malfunctioning equipment.

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Objective:

To determine the heat of combustion of natural gas by the continuous flow calorimeter method and to become familiar with the calculations and corrections used in precision calorific work.

Introduction

One method of determining the energy content of a fuel is to use a calorimeter which is an apparatus for measuring the amount of heat involved in a chemical reaction or other process. The main objective here is to find the higher heating value (HHV) and lower heating value (LHV) of natural gas in BTU/ft^3 using the continuous flow calorimeter method. The HHV of a gas is the number of Btu evolved by the complete combustion at constant pressure of one standard cubic foot of gas with air, if the temperature of the gas, air, and products of combustion are all $60^{\circ}F$ and if all the water formed by the combustion reaction is condensed and the LHV of a gas is the number of Btu evolved by the complete combustion at constant pressure of one standard cubic foot of gas with air, if the temperature of the gas, air, and products of combustion are all $60^{\circ}F$ and the water formed by the combustion reaction would remain in the vapor state. In the flow calorimeter method a fuel in a gaseous state, in this case natural gas, is burned at a steady rate in a chamber at atmospheric pressure while water flows through the chamber at a steady rate collecting the heat. This water is then poured out of the chamber into graduated cylinders over a specified amount of time. The volume of water of these cylinders as well as the temperature change and time are recorded so the total amount of heat transfer can be calculated.

List of Apparatus

- Gas calorimeter
- Gas supply
- Water supply
- Gas burner
- Two 2000 ml graduated cylinders
- Small graduated cylinder to collect condensate
- Thermocouple
- Stop watch
- 4 channel K SD Logger

Procedure:

The gas was first fed to the burner, which was then placed inside the calorimeter. The gas was at a steady rate with a metered volumetric flow, allowing us to determine the total quantity that was used. The gas was burned at a constant pressure. The heat from the combustion was transferred to a stream of water that was flowing through the calorimeter. This water was then collected in graduated cylinders, measuring the total mass of water coming out of the apparatus. The water was poured out of the cylinders and refilled when needed. The temperature of the water in and out of the calorimeter and the temperature of the exhaust were measured at 1 minute intervals. The condensate that accumulated during the run was also collected, weighed, and its temperature was recorded once finished. The gas pressure, volume of gas, and the shell temperature were recorded for each run. These steps were repeated for 3 runs. The gas temperature, room temperature, and the pressure of the room were recorded but remained constant for all runs.

Table of Data and Results

Data Table

	T H2O In	◦F	
Run	1	2	3
0	66.1	67.3	67.9
1	66.3	67.3	68
2	66.3	67.4	68
3	66.5	67.4	68.1
4	66.5	67.5	68
5	66.6	67.5	68.1
Average	66.38333333	67.4	68.01667

	T H2O Out ◦F		
Run	1	2	3
0	100.4	100.4	100.1
1	100.2	100.5	100.1
2	100.2	100.8	100
3	99.9	100.6	99.6
4	100	100.7	99.3
5	100.1	100.8	100
Average	100.1333	100.6333	99.85

	T Ex	°F	
Run	1	2	3
0	69.6	69.6	69.8
1	66.8	69.6	69.8
2	68.3	69.6	69.8
3	69	69.6	69.9
4	67.5	69.7	69.9
5	68.9	69.7	69.9
Average	68.35	69.63333	69.85

Run	1	2	3
Gas Pressure (in H2O)	0.7	0.6	
Gas Temperature (oF)	69	69	
Volume of gas used (ft3)	0.252	0.332	0.324
Weight of condensate (mL)	3	14	13
Weight of heated water (mL)	4860	3345	4485
emperature of condensate (oF	70	69.1	68.5
Shell Temperature (oF)	71	71.3	71.3
Temperature room (°F)	62	62	62
Pressure room (°F)	29.99	29.99	29.99

Result

	Run 1	Run 2	Run 3
$W_{Heated\ water}$ (lbm)	10.692	7.359	9.8758
$W_{Condensate}$ (lbm)	0.0066	0.0308	0.0286
h_f @ T_{in}	34	35	36
h_f @ T_{out}	68.05	68.5	67.9
$C_{p\ H20,\ avg}$ (Btu/lbm ℉)	1.008889	1.008024	1.002094
P_{sat} @ T_{gas} (in Hg)	0.712607	0.712607	0.712607
P_m (in Hg)	29.32888	29.32153	29.32153
V_s (ft^3)	0.24644	0.324594	0.316772
C_e (Btu)	7.87185	8.134245	8.484105
C_t (Btu/lbmole)	878.3497	963.8742	962.7914

C_t (Btu/ft^3)	2.313882	2.539184	2.536331
HHV (Btu/ft^3)	1506.914	782.013	1018.772
HHV (% error)	38.38%	28.2%	6.45%
LHV (Btu/ft^3)	1478.542	681.4889	923.1234
LHV (% error)	50.41%	30.67%	6.09%

Sample Calculations

First run:

- $W_{heated\ water}$= 4860mL = 10.692 lbm
-
- $W_{condensate}$ = 3mL = 0.0066 lbm
-
- Cp $_{H2O}$ = $(hf\ Tout\ -\ hfTin)/(Tout\ -\ Tin)\ =$ (68.05-34) / (100.13 - 66.38) = 1.008889 Btu/lbm ℉
-
- Pm = P_{gas},absolute– $P_a$at at tm = ((0.8*0.07355)+29.12) - 0.3633*2.036= 29.328 in Hg
-
- V_s = $Pm\,Vm\,Ts/\ Ps\,Tm\ =$ 0.24644 ft^3
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- Ce = hc At ΔT = (5/60) * 2.1 * 5*(71-62) = 7.875 Btu
-
- C_t (Btu/lbmole)= [(1×C_P CO2 +1xC_PO2 +11.285xC_PN2)* (T_{exh}-60)+2x C $_P$H2 O (T_{cond}-60)] -[1xCpCH4 (T_{gas}-60) + (3* CP O2, + 11.285C_PN2 \(T_{air}-60)] = 878.349 Btu/lbmole = 2.31 Btu/ft3
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- HHV = [(w *ΔT H2O*Cp H2O) + C_e / Vs] -C_t = 1506 Btu/ft3
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- %HHV = HHV/ HHV $_{standard}$ *100 = 1506/1089 * 100 = 38.38%
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- LHV = HHV - ($W_{consendate}$ * hfg $_{water}$)/ Vs = 1478 Btu/ft3
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- %LHV = LHV/ LHV $_{standard}$ *100 = 1478/983 *100 = 50.41%

Discussion and Analysis of Results

a) The yielded results and the calculated HHV of three runs are overall pretty reasonable when compared to the standard values. However the error percentage is still prominent.which is ranging from 6.45% to 38.45%.
b) The first two runs yielded the most error results. And in the third run, the students were familiar with the experiment processes, therefore the lab was operated in a smoother flow. It can be observable through the less percentage errors in the HHV AND LHV values.
c) First of all, the majority of data were observed by requiring the students reading the graduated cylinders and the pressure gauges. The data error for the temperature was recorded through a digital display, therefore the human errors can be limited. The collected heated water volume would have the least accuracy. First, the graduate cylinders to collect the water themself would have very low accuracy. Secondly, during the process of changing the cylinder, water could potentially be dropped. Moreover, the data were observed by reading the liquid surface by eye level.
d) The first factor contributing to the collected data is the unwanted heat loss during the experiment. Secondly, the graduate cylinder used to collect the heated water has very low accuracy. Furthermore, the majority of the data were collected by human eyes, therefore human errors would be a huge contributing factor. Also, the time was recorded by a timer, therefore the alignment between the time recorded and duration might not be aligned.

Conclusion and Recommendations

In conclusion, the experiment went as planned and the obtained data as well as the calculated data reflect the standard values. However, the experiment can still be improved. First of all, humans can be minimized by implementing the right techniques and utilizing digital display data. Also, the better lab instruments would increase the accuracy of the data.

References

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

Member’s Contribution

Hung Ngo: Abstract, Objective, Sample Calculation, Discussion and Analysis of Results.

Paul Yousefian: List of apparatus, Introduction

Ricardo Jimenez: Calculations, Procedure

Appendix