Assessment of the homologous series for the hydroxyl functional group in combustion systems

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***Abstract* - Enthalpies of combustion of alcohols are used by manufacturers in the petroleum industry to compare the efficiency and heating value of fuels as well as the stabilities of chemical compounds. The tribology investigation seeks to explore the effect of the position of alcohol in the homologous series on its standard enthalpy of combustion. Under laboratory conditions, four alcohols – methanol, ethanol, propanol, butanol – were viable to be experimented with. An insulated calorimeter and spirit lamp along with other supplementary apparatus served as the heating tools. The temperature rise was measured for 5 trials per alcohol and with the help of the raw data, the standard enthalpy of combustion for each alcohol was mathematically deduced. A clear positive relationship between the number of carbon atoms in the alcohol molecule and its standard enthalpy of combustion existed thus, the data was reliable with respect to its scope and methodology; however, a percentage error accompanied the calculations.**

***keywords* - homologous series, functional group, standard enthalpy, combustion, specific heat capacity**

I. INTRODUCTION

Alcohols are organic compounds containing Carbon, Hydrogen and Oxygen. They are a family of hydrocarbons containing the *OH functional group*, where the functional group determines the characteristic reactions of a compound molecule. The general formula for alcohols is $C_nH_{2n+1}OH$, where n is the alcohol number. As we go down the homologous series of alcohols, the number of Carbon atoms increase. Each alcohol molecule differs by CH_2 (a Carbon atom and two Hydrogen atoms). Moreover, it can be seen that these carbon atoms are added onto the hydrocarbon chains causing the chains to become longer and much more complex. As we move down the group, the alcohols' boiling points, enthalpy change of combustion, and other characteristics show changes as well.

The *standard enthalpy of combustion* is the enthalpy change when one mole of a reactant burns completely in oxygen under thermodynamic conditions. Therefore, *enthalpy of combustion of an alcohol* means the enthalpy change when one mole of an alcohol is burnt in the presence of oxygen under standard conditions. For this experiment, four alcohols including methanol (CH_3OH), ethanol (C_2H_5OH), propanol (C_3H_7OH) and butanol (C_4H_9OH) are heated in presence of oxygen. Hence, the aim of the experiment is to determine the relationship between the number of carbon atoms in alcohol molecules and their enthalpy change of combustion to investigate their fuel efficiency.

This experiment is designed in order to investigate how the standard enthalpy change of combustion differs based on the type of alcohol molecule and to determine a relationship between its fuel efficiency as we move down the homologous series from methanol to butanol. The experiment will be performed, keeping in mind the minimization of random and systematic errors in an attempt to produce accurate and precise results. The standard enthalpy of combustion of alcohols will be calculated using raw data of the change in mass of alcohol and temperature rise as heat is supplied to the water contained in the calorimeter. Further, uncertainties would be propagated, and a graph will be generated to evaluate my findings.

II. HYPOTHESIS AND VARIABLES

As we move down the homologous series of alcohols, the number of carbon atoms in the molecules increase and thus, the molecules become larger. As a result, more bonds are added to the substance and it becomes more difficult to separate the molecule from its bonds. Thus, more energy is required to combust the substance. This led me to a hypothesis stating that the more the number of carbon atoms in an alcohol molecule, the higher the standard enthalpy of combustion and greater the fuel efficiency.

The independent variable in this investigation is the number of carbon atoms in the alcohol molecule. depends on the particular alcohol, hence, has a different magnitude relative to different alcohols. It affects the mass of alcohol burnt as, to raise the temperature of the water by 10 degrees Celsius, different masses will be lost due to the different enthalpies of combustion of alcohols. On the other hand, the mass of alcohol burnt is the dependent variable. The hypothesis being tested is that the mass of alcohol burnt depends on the number of carbon atoms in the alcohol molecule. In order to measure the dependent variable, the final and initial mass of the spirit burner containing the alcohol will be measured using an electronic mass balance and their difference will determine the mass of alcohol burnt.

The controlled variables are listed as follows:

(1) The rise in temperature at which the heat supply is cut-off is represented as the difference between the final and initial temperature until which the water is being heated. The heat supply is not being provided after a 10 degrees Celsius rise in temperature for each alcohol. It should be kept constant because different alcohols have a different enthalpy of

combustion hence, to raise water's temperature by a fixed amount, different masses of alcohol will be lost. Thus, this variable has to be kept constant as it will directly affect the dependent variable.

(2) The volume of distilled water is fixed at 40 cm^3, which will be measured out using a measuring cylinder for all the alcohols being tested. This variable is kept constant because more energy is required to heat a higher volume of distilled water hence, in order to have uniformity in the results, the same volume has to be used to determine the mass of alcohol burnt effectively.

(3) The distance between the wick of the spirit burner and the base of the calorimeter is arbitrarily measured by keeping an eye on the distance that separated the wick and the calorimeter and ensuring that it was similar throughout the conduction of the experiment. The distance had to be similar throughout because as the distance increases, more heat is lost to the surroundings and less heat reaches the bottom of the calorimeter. This will lead to a low rise in temperature of water and hence, an incorrect change in enthalpy of combustion.

(4) As the experiment would be performed on different days due to the paucity of time, it needs to be ensured that the same apparatus was being used which had the same least count. This is essential in order to produce accurate and precise results at the end of the investigation and so that the propagation of uncertainties along with the percentage error of the calculations could be measured effectively.

(5) The calorimeter being used on subsequent days of the experiment would be washed before it is filled with water. The calorimeter had to be cleaned so that there were negligible impurities present in it and would not affect the volume and the temperature rise of water.

(6) The experiment is conducted at the same lab all throughout where the room temperature and pressure are kept constant. The room temperature and pressure have to be kept constant so that they do not affect the heating process of the water using the fuel and result in uniformity across the results.

III. Methodology

The methodology to be followed has been documented here, alongside the materials and apparatus:

(1) Take an empty spirit lamp and weigh it using an electronic mass balance. Record this mass reading.
(2) Add 40 cm^3 of the particular alcohol being tested into the spirit lamp.
(3) Weight this spirit lamp using an electronic mass balance. Record this reading.
(4) Measure out 40 cm^3 of distilled water using a measuring cylinder.
(5) Add this water into the calorimeter.
(6) Record the initial temperature of the water using a thermometer.
(7) Cover the calorimeter with the help of a lid and place the thermometer inside it.
(8) Place a wire gauze over a tripod stand and then, place the calorimeter over it.
(9) Place the spirit lamp under the tripod stand such that it comfortably fits in.
(10) Light the wick of the spirit lamp using a matchstick.
(11) Observe the temperature rise in the thermometer. When it has increased by 10 degrees Celsius, cut heat supply.
(12) Take the spirit lamp containing the alcohol and weigh it using the electronic mass balance. Record this reading.
(13) Record the reading on the thermometer when the temperature had become stable.
(14) Wash the necessary apparatus and repeat the above steps in order to obtain 4 readings for the particular alcohol.
(15) Repeat the above steps for the 4 alcohols- methanol, ethanol, propanol and butanol.

IV. Data processing

Table 1: Experimental Data

Alcohol	Homologous Position	Standard Enthalpy of Combustion *($kJmol^{-1}$)*	Uncertainty in Standard Enthalpy
Methanol	1	29.97	2
Ethanol	2	46.23	2
Propanol	3	72.25	6
Butanol	4	98.01	32

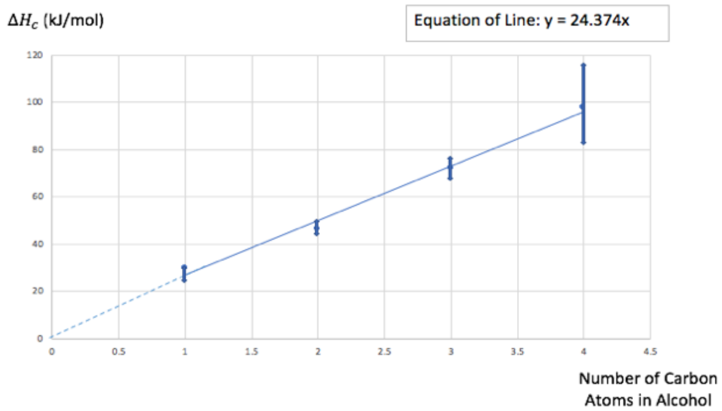

Figure 1: Data Presentation

The above graph depicts a **linear relationship** between the number of carbon atoms in an alcohol, or the position of the alcohol in the homologous series, and its standard enthalpy of combustion. As the number of carbon atoms increases, the standard enthalpy of combustion also increases leading to greater fuel efficiency thus, the hypothesis is verified.

V. CONCLUSION AND EVALUATION

The experiment conducted was successful in one extent as it yielded valid results through the four trials for each alcohol, which was in conjunction to the hypothesis. It helped me provide a suitable answer to the research question as it enabled me to determine the relationship between the number of carbon atoms in an alcohol and the standard enthalpy change of combustion to bring me to a conclusion that as we move down the homologous series of alcohols, the standard enthalpy change of combustion and the fuel efficiency increases. The graph also supports this conclusion with the line of best fit showing a linear relationship between the variables.

However, in another extent the experimental values for the standard enthalpy change of combustion of alcohol were way off the theoretical values resulting in a large percentage error hence, the results were not accurate, indicating several random and systematic errors in the conduction of this investigation. The high percentage errors led to inaccurate values for the standard enthalpy change of combustion of alcohols and could be justified through the following analysis of the sources of error.

First, a large probability of the heat supplied from the spirit lamp was unable to reach the base of the tripod stand and hence, could not heat the calorimeter in a uniform manner. This heat loss to the surroundings was not accounted for in my calculation and led to a lower than expected rise in temperature of the water. As a result, this value, which was recorded, was used for subsequent calculations to produce the value for the standard enthalpy change of combustion of alcohol and affected it negatively, thus, was a major source of experimental error. Second, the mass of the water might have changed, as I re-used the same calorimeter for 2 subsequent readings, due to evaporation of water. This evaporation was again not taken into account as I assumed the mass of water as 40 cm^3 while processing the data hence, leading to inaccurate results. Third, the calorimeter was not insulated hence, heat may have been lost through the process of conduction. There was a small hole at the top as well so that the thermometer could be held in place, which could be another potential source for heat loss. Fourth, during the calculation of the enthalpy change during combustion, the specific heat capacity of the calorimeter, made of copper, was not incorporated. This might have again led to a large percentage error as the calorimeter also absorbed a considerable amount of heat from the spirit lamp. Also, there might not have been sufficient readings taken to investigate the relationship of alcohol type and standard enthalpy change of combustion of alcohols. Lastly, an incomplete combustion of the alcohols might have also occurred where carbon monoxide is produced instead of carbon dioxide thus, meaning that the reaction was incomplete.

The random and systematic errors mentioned above could have been corrected in order to avoid the inaccuracy and imprecision in my results. The experiment could have also been extended to determine other quantities and relationships. First, the temperature could have been monitored while, performing the experiment to ensure that it was constant throughout and did not affect the readings. Second, there should have been proper insulation around the calorimeter to avoid heat loss to the surroundings. Third, the flame of the spirit lamp should have been blown out readily as even a slight delay may have caused more alcohol to be burnt. Also, during the process of calculations, the actual significant figures for each reading should have been continued to reach the final value as rounding off values in the middle may have affected the accuracy of the final results.

The experiment could be extended by increasing the number of trials for each alcohol and then, calculating the average mass and temperature change. Alternatively, the standard enthalpy change of combustion of alcohol could have been calculated for each trial and then, the mean value could have been produced. Although, this would have been time consuming, it would have led to accurate results. Lastly, the experiment could have also been repeated for a larger variety of alcohols to yield more data related to my investigation.

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VII. REFERENCES

[1] Mohammed, A., Al, A. (2008). Viscosity Index Improvement of Lubricating Oil Fraction (SAE-30). *Iraqi Journal of Chemical and Petroleum Engineering*, 9(3): 51-57.
[2] Nedic, B., Peric, S., Vuruna, M. (2009). Monitoring Physical and Chemical Characteristics of Oil for Lubrication. *Tribology in Industry*, 31(3): 59-66.
[3] M.D. Campbell, "Modelling Clay Models," Journal of Chemical Education, 11th ed, vol. 41, 1964, p.p. 612-626.
[4] Karim, A., Al-Salihi, K., Ahmed, N. (2015). Influence of EPDM viscosity index improvers on Kurdistan manufacturing oils. *International Journal of Scientific and Engineering Research*, 6(8): 638-643.