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Fabrication of a Constant Volume Bomb Calorimeter.

a Thesis

Submitted to the College of Engineering, University of Babylon in Partial Fulfillment of the Requirements for the Degree of a Higher Diploma in Engineering/ Mechanical Engineering / Fuel and Energy

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بسم الله الرحمن الرحيم

اقرأ باسم ربك الذي خلق

صدق الله العظيم

سورة العلق ايه(١)

Certification

I certify that this thesis entitled **" Fabrication of a Constant Volume Bomb Calorimeter "** has been prepared by “***Hassan Hamid Ali***” under my supervision at the department of Mechanical Engineering, College of Engineering, University of Babylon as a partial fulfillment of the requirements for the Degree of higher Diploma in Mechanical Engineering / Fuel and Energy.

I recommend that this research be forwarded for examination in accordance with the regulation of the University of Babylon.

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Dedication

To everyone who studied science for the sake of humanity and peace and to all my teachers since the first letter I learned and even if I wrote this thesis, I dedicate this work with gratitude and the soul of my mother who rests with her lord in peace.

Hassan 2021

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Hassan 2021

Abstract

This work included the manufacture of a constant volume bomb calorimeter, its bomb, from aluminum metal, to measure the calorific value of solid and liquid materials. It was tested on samples of solid and liquid fuels .It also include measuring devices to measure temperature and pressure changes. This calorimeter worked well in comparison with the standard tables with acceptable deviations. The bomb calorimeter is used to measure the heat released during combustion processes at a constant volume.

The bomb calorimeter consists of the following parts: a metal bucket made of aluminum alloy 7175, that is filled with water , combustion chamber is immersed in the water, a thermocouple to measure the change in water temperature , mixer to mix the water inside this bucket. Experimentally the use of a constant-volume bomb calorimeter is the most common and easiest way to measure the high calorific value of solid and liquid fuels. The amount of heat released from a chemical reaction or the combustion of a fuel inside a calorimeter bomb under constant volume conditions raises the temperature inside the calorimeter bomb to become higher than the temperature of the surrounding water.

The difference in temperature causes heat transfer from the system to the surrounding water, and the amount of heat exchange depends on the high calorific value of the fuel used and its quantity. Thermal energy is exchanged between the combust product inside the calorimeter, the metal mass of the calorimeter, and the surrounding water. The process is assumed to be adiabatic(no heat exchange with surrounding).

Nomenclatures

Symbols	Definition	Units
C	specific heat	$\frac{kJ}{kg.℃}$
C_{calori}	specific heat of the calorimeter	$\frac{kJ}{℃}$
dv	change in volume	m^3
HHV	high calorific value	MJ/kg
H	enthalpy	KJ/kg
I	current	ampere
LCV	low calorific value	MJ/kg
m	mass	Kg
p	pressure	bar
q	heat	J
t	time	second
T_{final}	final bucket water temperature	℃
T_{intial}	initial bucket water temperature	℃
T	temperature	℃
V	voltage.	Volt
w	work	J

Greek Symbols

Symbol	Description
$\emptyset$	the thermal inertia factor
α	the number of moles of carbon in hydrocarbon fuel
γ	the number of moles of Hydrogen in hydrocarbon fuel
β	the number of moles of Oxygen in hydrocarbon fuel

Abbreviation

Symbol	Description
C	carbon
H	hydrogen
O	oxygen
N	
S	sulfur
F	flour
Cl	chlorine
Br	brome
I	iodine
B	boron metal
Al	aluminum metal
CEA	chemical equilibrium with applications code
P/PE/B	paraffin/polyethylene/boron
P/PE/Al	paraffin/polyethylene/ Aluminum
wt %	moisture content
O/F	oxygen to fuel ratio
PVC	polyvinyl chloride
MSW	municipal solid waste
ASTM	American Society for Testing and Materials
XRF	is a non-destructive analytical technique used to determine the elemental composition of materials
R1234yf	is a hydrofluoroolefin (HFO) refrigerant
DAM	double aluminized Mylar
MWCNTs	multiwall carbon nanotubes
TBHP	thermal hazard of tert-butyl hydroperoxide
ARC	accelerating rate calorimeter
COD	chemical oxygen demand
TBHP	tert-butyl hydroperoxide
ARC	accelerating rate calorimeter
nAl2O3	nanoporous aluminum oxide

n-Al	nanoparticles of aluminum
cc	cubic centimeter
MPD520	is universal process indicator
SMT	Surface-mount technology(is a method in which the electrical components are mounted directly onto the surface of a printed circuit board)
atm	atmospheric pressure 1 bar

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Chapter One

Introduction

Chapter One: Introduction

1.1 General

The calorific value of any substance such as fuel and food is defined as the amount of energy released in the form of heat when a certain amount of that substance is completely burned with oxygen under standard conditions. This value is considered a distinctive feature of each substance. In a hydrocarbon chemical reaction, organic molecules react with oxygen to form carbon dioxide and water, producing heat, which can be expressed in various formulas for liquid and solid fuels such as the energy unit per mole of fuel, kilograms of fuel, and per unit volume in gas fuels.**[1]**

The heat of reaction can be expressed as the difference between the heat of formation (or the enthalpy of the reaction products) and the reactants. Certainly, water is a component of the combustion of hydrocarbon fuels hence if the water is in a liquid state, that is completely condensed, the liberated heat of combustion is the highest heating value (or high calorific value). Whereas, if the water is vapor the latent heat of evaporation is not lost or not recovered , the calculated amount of heat is the lower heating value(LHV)[2]. There is a difference between the higher and lower heating values in hydrocarbons fuels. The calculation of the heat or internal energy of any material using a calorimeter is the most experimental method. Normally the calorimeter is an instrument that can be used to measure the unknown calorific value of a substance such as wood, coal, and any liquid or solid fuel. The calorimeter method is one of the oldest known scientific methods used to measure the calorific value of fuel in the form of heat during an experimental chemical reaction or physical process. It is based on the law of conservation of energy in a closed and isolated system in which no heat from the outside enters the system and no heat is lost to the surrounding environment (Energy cannot be created or destroyed, but it can be converted from one form to another) .**[2]**

The first ice calorimeters were created in 1761, based on Joseph Black's latent heat hypothesis. (Joseph Black, British chemist, had many discoveries in the field of chemistry regarding heat and carbon dioxide). Lavoisier The world's first ice-calorimeter was used in the winter of 1782–83 by Antoine Lavoisier and Pierre-Simon Laplace. These investigations laid the groundwork for thermochemistry. Figure (1.1) depicts a Lavoisier calorimeter.[3]

Hugo Junkers (1859-1935) was a German aero engineer and designer who pioneered the design of all-metal aircraft and flying wings and has multiple thermal and metallic patents.

Made a calorimeter in 1892 and registered it under his name to retain the rights to his invention.

Figure (1- 1) La Place and Lavoisier Calorimeter, 1801[3]

1.2 Constant Volume Bomb Calorimeter:

This calorimeter is experimentally used to find the heat generated by the combustion reaction of a specific substance while maintaining a constant volume and characterized by its resistance to the large amounts of pressure. It is also known as bomb calorimetry, or the device that is used to detect the enthalpy of any substance. The principle of operation of the bomb calorimeter is based on the law of the conservation of energy(the total heat lost by the hot body is equal to the total heat gained by the cold body).

$$q_{lost\ from\ hot\ body} = q_{gain\ \ by\ cold\ body} \qquad (1\text{-}1)$$

Where, the liberated heat is equal to the difference between the internal energy of the reactants and products of the combustion reaction **[3]** .

$$dq = du + pdv \qquad (1\text{-}2)$$

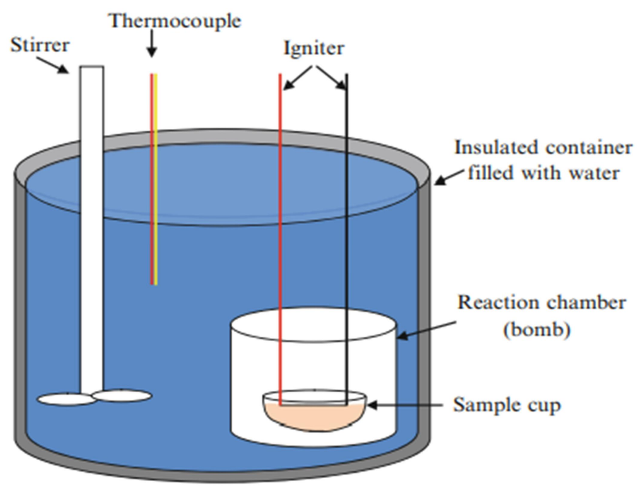


Figure (1- 2) Bomb calorimeter[2]

The use of constant volume data analysis to estimate the heating value of a certain fuel is the foundation of bomb calorimeter technology. In a closed system, a known mass of fuel is burnt with a suitable amount of oxidizer. After that, the closed system is cooled down so that the heat flows to the fluid around the calorimeter bomb (the water that immerses the calorimeter bomb). Due to the end water temperature in this device is near room temperature, the water in the combustion products is generally in the liquid phase, hence the measured calorific value is the high calorific value (HHV) in a constant volume combustion process.

When the ultimate temperature of the bucket and calorimeter water is a few degrees Celsius higher than the temperature before combustion, the inaccuracy in the bomb calorimeter is quite tiny. The high calorific value of the substance under test is calculated from the temperature difference before the reaction combustion occurred in the calorimeter bomb and the maximum temperature of the calorimeter bucket water. Since the bomb calorimeter is made of metals, the volume of the bomb calorimeter is constant, and the combustion reaction occurs inside the bomb calorimeter in conditions of constant volume. Therefor there is no work done from burning the fuel and all the energy in it is converted into heat.

To start the ignition of the fuel sample under test using a direct current electrical circuit with a voltage not exceeding 24 volts is used. The circuit is connected to the electrodes of the calorimeter bomb and is closed using a fuse wire of very small diameter so that it is cut off as soon as the ignition begins. It is placed in contact with the test sample and does not touch the walls of the metal fuel crucible.

The whole bomb is filled with compressed pure oxygen and a known mass of the material whose calorific value is to be assessed, as well as a very little quantity of water (no more than 1 ml) (is used to saturate the inner atmosphere, thus ensuring that all water produced is liquid, eliminating the need to include the enthalpy of vaporization in the calculations). Before closing the electrical ignition circuit, the bomb calorimeter is immersed in a known volume of water. When the fuel burns, the surrounding water in the bomb calorimeter heats up owing to the heat transfer produced by the fuel combustion process.

The calorimeter bomb is a closed system. The reaction of the combustion of the fuel sample with the oxygen occurs inside where no gases escape during this process .So the higher calorific value can be correctly measured.

The combustion of the fuel is a hydrocarbon chemical reaction between the organic molecules of the fuel and the oxygen. The reaction produces heat , carbon dioxide ,and water in the case of ideal combustion (stoichiometric combustion). The calorific value of a fuel is defined as the amount of total energy produced or released as heat when a complete or ideal combustion of fuel with air occurs under standard conditions (usually the combustion reactions are exothermic (give off heat). Each type of fuel has a high calorific value or high heating value (HHV)when the water resulting from the combustion reaction has completely condensed with the products of combustion and comes out in a liquid phase, while if the water produced with the combustion products is in the vapor phase, the calorific value produced by the fuel is the low calorific value of the fuel (LHV). The difference between the two calorific values depends on the chemical composition of the fuel.

The difference in hydrocarbons is determined by the amount of hydrogen present in the fuel. The higher calorific value of diesel, gasoline and natural gas is higher than the lower calorific value by 7%, 10% and 11%, respectively. The difference between the high and low calorific values (HHV and LHV) is equal to the latent heat of evaporation of water. The amount of heat measured in a constant volume bomb calorimeter test is high heating value (HHV) since the water in the combustion products is generally in the liquid phase because its end temperature is near to room temperature.

1.3 Types of calorimeter

1.3.1 Flame Calorimeter:

This type of calorimetric system is a flow system in which the reaction combustion takes place with sufficient oxygen or air in a room controlled with the highest level of insulation possible to prevent heat from escaping from the system as shown in Figure (1.3).

The combustion process begins when the fuel source lights up and the generated heat transferred to the can and the water in it, that leads to an increase in their temperature. The heat capacity of the calorimeter must be included in the calculation because it may absorb a large amount of heat resulting from combustion and the water temperature is measured using high precision thermometer.[4]

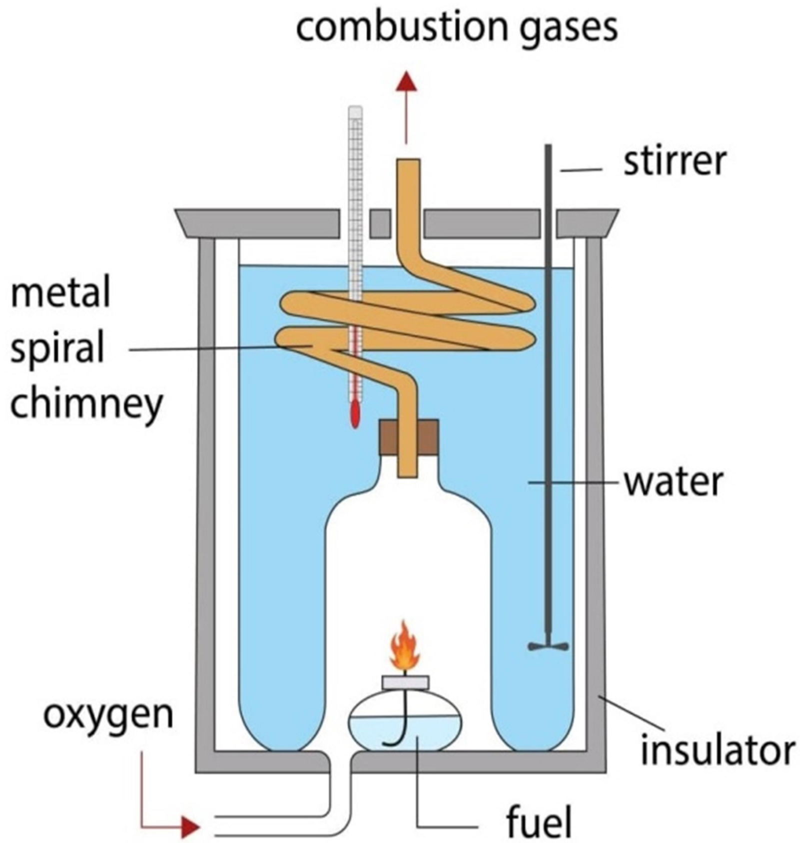


Figure (1- 3) scheme of flame calorimeter[4]

1.3.2 Reaction calorimeter:

A reaction calorimeter is a device that measures the quantity of heat liberated (exothermic reactions) or absorbed (endothermic reactions) in a chemical reaction in order to offer an accurate picture of the events.

Total heat is calculated by integrating heat flow versus time at reaction temperatures. This standard is used in industry to determine temperatures in industrial operations where steady temperatures are required. The reaction calorimeter is also used to find the maximum rate of heat release for engineering chemical processes and to track the movement of reactions. Figure (1.4) shows the reaction of calorimeter.

Figure (1- 4) reaction calorimeter

The heat of combustion or reaction in this type of calorimeter is measured in the following ways **[5]**: -

1.3.2.1 Heat flow calorimeter:

The heating or cooling jacket is regulated by either the process temperature or the jacket temperature in this sort of measuring system. The heat of the sample is assessed by the difference in temperature between the heat transfer fluid and the process fluid. In addition the filling volumes, specific heat transfer, and heat transfer coefficient must be established to arrive at the right result**[6]**.

1.3.2.2 Heat balance calorimeter:

The heat entering the system or liberating from it through the heating or cooling jacket of the heat transfer fluid (where its specifications are known) is measured in a calorimeter. This is the best method for measuring heat because it solves most of the calibration problems that faced by heat flow measurement and energy compensation. However, this method is not well optimized in conventional batch vessels because the process heat signal is obscured by large thermal shifts in the heating or cooling jacket**[6]**.

1.3.2.3 Power compensation

Power or energy compensation is a one form of heat flow. In this method a constant temperature and flow cooling jacket are used. The process temperature is controlled by electric heater that is to be placed inside the vessel to keep the temperature constant. The electrical energy supplied to this heater varies according to the reaction requirements, and the calorimeter signal is derived using this energy**[7]**.

1.3.2.4 The constant flux calorimeter

This method not only gives better temperature control but ,for the first time ,it provides plant operators with a simple all-purpose tool for monitoring the rate or progress of virtually any chemical, physical or biological process. The continuously stirred tank reactor is the most common type of process equipment to be found in a modern pharmaceutical manufacturing plant . Batch vessels built or adapted to operate on the principles of constant flux control can be transformed into precision calorimeter with addition of flow meter and temperature elements .The constant flux calorimeter incorporate a new concept of reduced volume jackets .Heat transfer fluid is delivered in very small pipes and heat transmission plates. These new jackets are simple to fabricate and do not require in situ welding. They offer exceptionally good heat transfer coefficients, as well as very good fluid distribution without sacrificing heat transfer area **[8].**

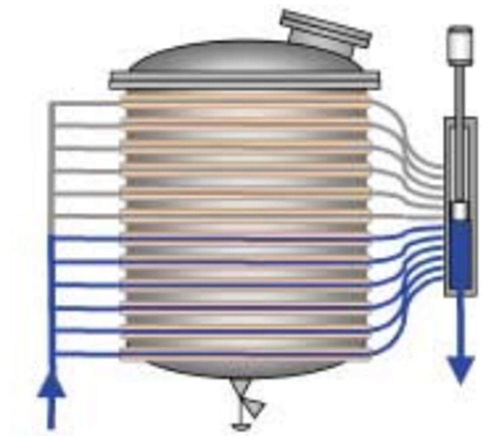


Figure (1- 5) Diagram of constant flux calorimeter.[8]

1.3.3 Calvet-type calorimeters:

This type of calorimeter is of limited use, see figure (1-6). It is utilized during sublimation process to measure the changes in enthalpy and to monitor the behavior of a substance. These calorimeters sensors are used to detect the latent heat of the phase shifts or the heat capacity of the system **[9]**.

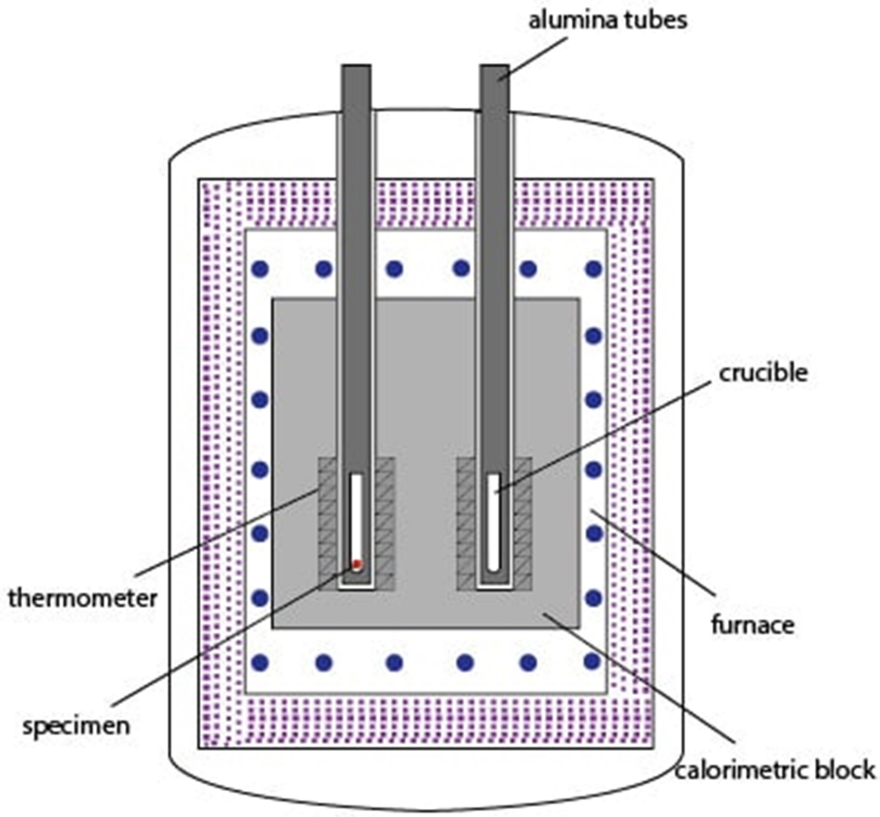


Figure (1- 6) Calvet-type calorimeters

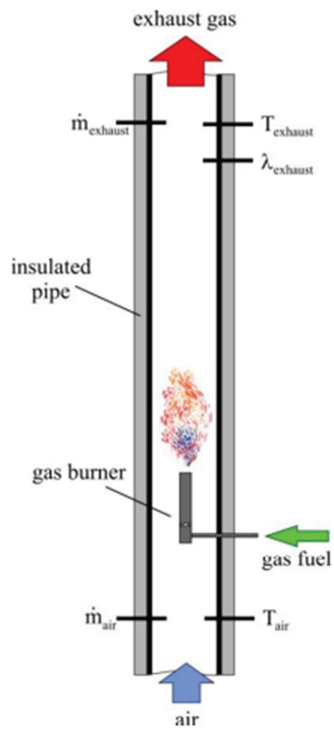
1.3.4 Constant-Pressure Calorimeters:

Constant pressure calorimeters assess the change in enthalpy of a solution-based reaction while keeping the pressure constant. It is one of the most basic kinds of calorimeters. A coffee cup calorimeter is the most basic type of constant pressure calorimeter as can be seen in figure (1-7). It is made of two overlapping styrofoam cups and a top with two holes for inserting a thermometer and stir bar.

Because the gaseous pressure above the solution remains constant, the pressure calorimeter is referred to as a constant. The heat transported to or from the solution for the reaction to occur is equal to the change in enthalpy ($\Delta H = q_p$), and this heat of reaction is measured using the constant pressure calorimeter. A specified amount of liquid, generally water, is put in the inner cup to absorb the heat from the reaction. The outer cup is supposed to be entirely adiabatic, which means it absorbs no heat at all. As a result, the outer cup is thought to be an excellent insulator **[10]**.

Figure (1- 7) Constant pressure calorimeter[10]

1.3.5 **Junkers calorimeter:** which is a vertical cylindrical chamber coated with chromium metal from outside which prevent heat loss is used to measure the calorific value of a gaseous fuel as can be seen in figure (1-8). It bases on water flow principle in which known volume of gas is burnet at constant known rate in enclosed combustion chamber under constant pressure equal to atmospheric pressure. Water is injected from the top of the external coil at a constant rate moving down the chamber. A draw thermometer showing the initial and final temperatures is inserted and, if steam is formed during the experiment, it is collected**[11]**.



*Figure(1-8) Diagram of the gas calorimeter concept**[11]**.*

1.3.6 Objectives and application:

The main objective of this study is a fabrication of a constant volume bomb calorimeter to experimentally measured higher calorific value of solid and liquid fuel.

The high calorific value is a distinctive feature of each type of fuel, and by using this calorimeter it can be identified and approved to classify and distinguish between types of fuels. The calorimeter can also be used to determine the energy content of solid and liquid materials such as foodstuffs. For incombustible martials ,their energy content can be measured using a combustible catalyst by means of this calorimeter.

Chapter Two

Literatures Review

Chapter Two :Literatures Review

2.1 Introduction

In this chapter, the search on the previous literatures and studies have been carried out to view all efforts that led to the design of a constant volume bomb calorimeter and to estimate the calorific value of the liquid and the solid fuels.

A bomb calorimeter test is a procedure performed to determine the heat of combustion of materials. It can also be used as a basic examination of great importance to anyone involved in the production and/or use of solid and liquid fuels, the energy content of waste, excrement, foods, thermal powders, rocket fuel and related fuels. In this chapter, a historical review is presented.

Linglong Wang et al [12] proposed and applies an on-site coal calorific value measuring system to power plants where rapid monitoring is beneficial for combustion management during coal-fired power plant operation. They evaluated the impact of a variety of model parameters with altering temperature and flow meter accuracy on measurement time and uncertainty. The measuring properties of the bomb calorimeter and this modified calorimeter were compared in a variety of conditions. Increases in gas volume flow rate and water mass flow rate have a beneficial effect on measurement time, however increases in coal mass and water mass ratio in two cylinders show a negative effect. All of these factors contribute to a reduction in relative standard uncertainty. It is proved that the proposed calorimeter is capable of monitoring the calorific value of fuel for the purpose of optimizing power plant performance.

Shivam Gupta et al [13] Investigated thermo-catalytic conversion of the Polyalthia Longifolia leaves solid waste at temperatures ranging from 450 °C to 600 °C. Commercial biofuel products such as bio-oils and bio-chars have developed from the catalytic conversion of biomass with zeolite Y and hydrogen. The PL leaves biomass has a significant energy potential, with 20.23 MJ/kg of HHV. The energy density of bio-oils produced by thermo-catalytic energy conversion of biomass is greater than that of the original biomass. The liquid is separated into two phases: aqueous and organic. Only the organic fraction is employed to evaluate and describe the bio-oil, while the aqueous phase is discarded. For pyrolysis temperatures of 450°C, 500°C, 550°C, and 600°C, bio-oils (organic fraction) exhibited HHV values of 22.30, 22.68, 26.43, and 27.08 MJ/kg, respectively whereas bio-chars had HHV values of 22.59, 22.89, 23.68, and 24.26 MJ/kg, respectively. The yield of the liquid product increases as the reaction temperature rises from 450 °C to 600 °C. The maximum liquid product yield is reached at 600 °C with 29.833 wt percent while maximum bio-char yield is obtained with 46.667 wt percent. The yield of non-condensable gases decreases with increasing temperature from 37.942 wt% to 23.500 wt%.

Luísa M.P.F. Amaral et al [14] Carried out an experiment in which they acquired dimethoxyacetophenone samples, purified the solid compounds by sequential sublimation under low pressure, and the liquid sample using partial vacuum. The standard molar enthalpy of combustion was determined using an isoperibol calorimeter fitted with a stainless steel two-valve bomb. Dimethoxyacetophenone liquid samples were burnt in sealed polyester bags, while solid samples were burned in pellet form. Before charging the bomb with oxygen, 1.00 cm^3 of water was put into it in all combustion trials. At the end of each experiment, carbon dioxide was collected using absorption tubes. The amount of substance was calculated based on the total mass of carbon dioxide created after accounting for those made by the auxiliary materials utilized. The compounds' molecular masses were estimated using the standard method.

Theoretical standard enthalpies of formation were estimated utilizing the Gaussian composite approach using an atomization reaction and various practical reactions. A comparison of experimental and theoretical pairwise interactions reveal that they are in good agreement, implying that both data sets are reliable.

Yash Pal [15] Investigated the energy properties and theoretical performance of hybrid rocket fuels. To increase the energy density of paraffin-based solid fuels, metal additives such as aluminum (Al) and boron (B) were used. The heat of combustion of these solid fuels was measured using an adiabatic bomb calorimeter. The inclusion of Al and B enhanced the heat of combustion of paraffin-based fuels. When compared to B-loaded fuels, solid fuels containing Al produced a higher heat of combustion. It is believed that this is due to poor combustion of B particles at low temperatures and pressures. The introduction of Al, according to the CEA data, does not increase the specific impulse for the P/PE/Al formulation. However, with a 25% B loading, the P/PE/B combination yielded a specific impulse of about 372 s. In terms of specific impulse, boron-containing fuel formulations surpass alumina-containing fuel formulations. Furthermore, when the metal additive was added to the fuel, the ideal O/F dropped to lower values. This might be helpful in certain applications, such as space missions, where less oxidizer tank volume is required (more payloads). This article's theoretical performance does not account for actual multiphase losses, nozzle erosion, or paraffin droplet trapping, all of which can have a substantial influence on performance. As a result, a detailed experimental assessment is required to anticipate the real performance of these paraffin-based fuels.

Aurel Lunguleasa et al [16]: evaluated and classified many exotic wood species from tropical Africa based on calorific characteristics in order to estimate the ability of their biomass to be a solid, natural, and renewable fuel. The calorific values of wood waste from eight tropical species were determined using an oxygen bomb calorimeter. The specimens were conditioned at three distinct degrees of moisture: 10%, 20%, and 50%. Moisture content has an effect on calorific value , density, heat release rate, and calorific efficiency. The maximum high calorific value and lowest low calorific value (21200-20700 kJ/kg) are found in Guaiac and Rose species. Acajou has the lowest calorific value in both the high and low ranges (18929 and 18456 kJ/kg, respectively). The higher the calorific density (Guaiac), the greater the density of wood. The moisture content of the specimens reduced calorific efficiency and energy release rate. The ash content was less than 4%, with Guaiac having the highest value (3.6 % ash) and Acajou having the lowest (0,5 %). They findings found that the tropical wood species had a forest calorific capacity that was 23-47 % more than that of European beech, indicating that they had significant potential as renewable energy sources.

Ida Farida et al [17] studied the design of a waste-based calorimeter as an alternative device or way for measuring heat . The research products developed through the steps of design-based research comprising the steps of analysis, design, and development. The results of calorimeter optimization from various simple materials ,like (styrofoam, paper, plastic) in determining the calorimeter heat capacity and the change in neutralization enthalpy obtained the calorimeter accuracy value between 78-97%. The highest accuracy is obtained by bamboo calorimeter and the lowest accuracy is obtained by Styrofoam calorimeter. The validation test results of 0.78 and the feasibility test results of 94.49% indicate that calorimeters from various simple materials are feasible and ready to be used as a learning media.

Obid Tursunov et al [18] examined the qualities and composition of urban solid trash. According to their findings, wood waste had the highest amount of contamination among the other MSW components. As a consequence, the MSW samples were divided into two groups: (a)the mixed municipal solid waste (MSW) and (b)the wood waste The samples' proximal and ultimate analyses were carried out in compliance with the international standards ASTM and European Pn-En. An energy recovery research was carried out using a bomb calorimeter and the ASTM standards. Mixed MSW had an energy content or calorific value of 2479.34 kcal/kg, whereas wood waste had a calorific value of 2190.02 kcal/kg. The elements in the samples were examined using the CHNS/O elemental analyzer (a scientific instrument used to measure the concentrations of carbon, hydrogen and nitrogen in a given sample with precision and accuracy).

Mudassir Hussain Tahir et al [19] studied the effect of the functional groups such as (-C=C-) and (C-OH) on the variation of the higher heating values (HHV) of organic compounds. Using a bomb calorimeter, it was discovered that the functional groups such as (-C=C-) and (C-OH) contribute significantly to the variance of HHV. The existence of (-C=C-) decreases the carbon content of the reduced sate, enhances the endothermicity of the reactant by increasing the s-character(is a contribution of s orbital in hybridization) of the hybridization state, and decreases the degree of oxidation of fuels. By creating hydrogen bonds, (C-OH) also decreases carbon and raises the reactant's endothermicity. Because (C-OH) causes carbon to be oxidized rather than reduced, it has less effect on HHV. The FTIR spectra and HHV of green tea polyphenols were compared at three different temperatures RT, 250 °C, and 350 °C. It was discovered that the HHV increased at 250 °C and 350 °C, which is consistent with a more carbon reduced state, lower endothermicity of reactants due to a lower degree of hydrogen bonding, and confirmed by FTIR spectra. This result demonstrates the validity of the current study, which may be beneficial for future research directions.

Quan Zhong et al [20] developed an adiabatic calorimeter to determine the isochoric specific heat capacity of compressed liquid. To confine the measured liquid, a spherical bomb with an embedded platinum resistance thermometer was used, along with two adiabatic shields to minimize thermal radiation heat loss. The isochoric specific heat capacity of liquid propane was evaluated at temperatures between 236 and 340 K and pressures up to 14 MPa. This shows the satisfactory agreement with the existing data on heat capacity, and the experimental setup's trustworthiness is established. Additionally, the isochoric specific heat capacity of liquid R1234yf was determined experimentally at temperatures ranging from (240 to 341) K and pressures up to 13 MPa. Temperature standard errors were determined to be 10 mK, the uncertainties in pressure and isochoric specific heat capacity standards were to be 5 kpa and 1.0 percent, respectively.

S S Edie et al [21]:studied, the effect of employing a bomb calorimeter on physics students' science process skills was investigated.

The efficacy of utilizing the equipment, as well as recognizing the progress of students' science process abilities before and after using tools, are influenced. The sample was drawn using simple random sampling and a pretest-posttest study method with one group. The tool employed is a written test that assesses science process abilities. The efficacy of the bomb calorimeter was determined to be 87.88 percent beneficial, while the examination of scientific skill improvement revealed an n-gain value of 0.64, which falls into the medium range.

Gisela Montero et al [22] studied the energy content of wheat straw and the possibility of converting it into biofuel to generate electric power . In this research, the following tests were carried out, creating different .First the chemical composition analysis: 57.09% cellulose, 16.81% hemicellulose, 19.10% lactic acid. Second, the approximate composition is as follows: 64.42 % volatile matter, 19.49 % fixed carbon, and 16.09 % ash, 37.20 % C, 5.57 % H, 1.14 % N, 0.20 % S, and 37.30 % O were found in the final analysis. The experimental higher heating of wheat straw was 14.86 MJ/kg. Higher heating value estimations by proximate and ultimate analysis were 15.71 MJ/kg and 14.59 MJ/kg, respectively.

Kishan B S et al [23] explored the conversion of biomass waste(such as sawdust, coconut tar, coffee husk, etc) into useable biomass. This work focuses on the design and manufacture of portable briquetting equipment that can be done at a minimal cost. It also concentrates on the manufacture of biomass briquettes using raw materials such as sawdust and dry leaves, as well as binding ingredients like coffee husk and wheat flour. A bomb calorimeter is also used to evaluate the calorific properties of the briquettes. Briquettes made from sawdust, dry leaves, and a very small amount of wheat flour (binding agent) are compact, dry, and have a higher calorific value than briquettes made from sawdust, dry leaves, and coffee husk (binding agent), which are not strongly bonded and have a slightly lower calorific value.

Kyle R. et al [24] design and constructed a unique non-adiabatic bomb calorimeter to measure the heat generated by intermetallic production processes and subsequent partial combustion of nanocomposite metallic foils. To investigate reaction and burning qualities in a variety of environments. Reactions are begun using a low-energy electrical spark and can be carried out in a vacuum of 1 atm of air, oxygen, nitrogen, or argon. To decrease heat loss and enhance the surface area available for oxidation and nitridation, the bomb was designed to have little thermal contact with the foil samples. Samples are limited to milligrams and contain far less energy than an equivalent mass of organic material such as benzoic acid. To increase instrument sensitivity, the heat capacity of the bomb was minimized by designing it as small as possible and bathing it in low-viscosity silicone oil rather than water. The calorimeter's energy equivalent is C_{calori}= 279 J/K, which enables us to quantify heat generation in the tens of Joules range. Calibrations in argon were conducted using Al:Ni Nano composite foils with known reaction temperatures measured using differential scanning calorimetry.

Richard E. Lyon et al [25] mention that there are three different ways to model the thermal dynamics in bomb calorimeters: a lumped-heat-transfer approach where the pressure vessel/bomb is immersed in the stirred water bath and the static air space that surrounds it is protected from heat loss by an isoperibol, a constant/controlled temperature jacket, or a changing temperature jacket (adiabatic). Calorimeter reaction to a heat pulse (combustion) is well described by a two-term solution for the water bath temperature history, which allows for parametric determinations of the bomb's heat transfer coefficients and thermal capacities to be determined. The verified heat transfer model gives a formula for calculating the heat released in any process within a bomb calorimeter directly using the temperature history of the water bath for each of the boundary conditions (methods). This discovery enables direct computation of a sample's heat of combustion in an isoperibol calorimeter using only the temperature history recorded, without the requirement for semi-empirical temperature corrections to account for non-adiabatic behavior. Additionally, the maximum temperature rise of the water bath in the static jacket technique is proportionate to the total heat generated, and the empirical proportionality constant, which is calculated during calibration, compensates for all of the calorimeter's heat losses and thermal delays.

Jonathan Melville [26] evaluate the heat of combustion of a sample of sugar using a bomb calorimeter. By precisely regulating the pressure, heat flow, and composition of our bomb, as well as by calibrating with a sample of benzoic acid with known calorific values.

YIN Jiawang et al [27] evaluate the combustion heat of ten different types of conventional pyrotechnics by utilizing an oxygen bomb calorimeter. The purpose of this study is to demonstrate the practicality of this approach by calculating the combustion heat value of pyrotechnics using Hess Law theory, comparing the theoretical value to the actual value and analyzing the causes of the inaccuracy. It may provide some thoughts and serve as a reference for later study. Simultaneously, it establishes the optimal dose of pyrotechnics for the test. If there are fewer than a certain number of data, the device will be unable to access the temperature rise. The ten different types of reagents are usually in the 100-200 mg range, while the exceptional reagent with a high calorific value is somewhat less than 100mg. Dosage cannot be excessive, as the combustion heat value of pyrotechnics is high if we use too much, components will be unable to participate fully in the reaction, affecting the accuracy of the results; it will also result in the destruction of the crucible used in the experiment, with the most serious consequence being burning the crucible to wear and damage the instrument. As a result, they have been recommended conducting this experiment using a quartz crucible.

Xin Yu et al [28] calculated the combustion enthalpy of glyphosate using an oxygen-bomb calorimeter at a constant volume. The standard mole combustion and formation enthalpies, respectively, have been determined to be -1702.19 and -1478.36 kJ/mol. To evaluate the instrument's reliability, glycerin and naphthalene were used as reference materials. When measured values were compared to published values, the absolute and relative errors for glycine were 2.58 kJ/mol and 0.26 percent, respectively, and for naphthalene were 4.08 kJ/mol and 0.08 percent, respectively. Additionally, the constant-pressure heat capacities of glyphosate were determined using differential scanning calorimetry throughout a temperature range of 303.15–365.15 K, and a link between cp and temperature was established. This research may offer a thermodynamic foundation for their future use.

Luísa M.P.F. Amaral et al [29] calculated the values of the condensed phase standard molar enthalpy of formation for 20 – methylacetophenones (CH3C6H4COCH3) and 40 – methylacetophenones (C9H10O) by using static bomb combustion calorimetry. Calvet microcalorimetry has been used to determine the standard molar enthalpy of vaporization at T = 25℃ .After combining these two results, the following enthalpies of formation in the gas phase at T = 25℃ were calculated: 20 -methylacetophenone, –(115.7) kJ/mol; and 40 -methylacetophenone, –(122.6 -2.4) kJ/mol. Alternative impacts on stability have been studied and compared to those of other comparable substances. Additionally, isomerization techniques have been used to determine the standard molar enthalpy of production for 30 -methylacetophenone.

Jianfeng Shen et al [30] determined the rice husk's higher calorific value utilizing an oxygen bomb calorimeter in conjunction with benzoic acid as a combustion aid. The impacts of sample mass, oximeter pressure, and rice husk/benzoic acid mass ratio are examined. The optimal sample mass and oximeter pressure are calculated in the first stage. The oxygen pressure must be adequate to completely burn the rice husk and benzoic acid, as partial combustion has an effect on the sample's determined heating value. The greater heating value of rice husk increases significantly at first and subsequently diminishes as the oximeter pressure is increased. Indeed, when the oximeter pressure is low, the oxygen concentration is insufficient to ignite the rice husk completely. As a result, the greater heating value recorded is less.

Matthew Jones et al [31] investigated the impact of burning on nanoparticles of aluminum (n-Al) and nanoporous aluminum oxide (nAl2O3) suspended stably in biofuel (ethanol) as a secondary energy carrier experimentally utilizing a modified static bomb calorimeter system. N-Al and n-Al2O3 particles having diameters of -50 and 36 nanometers. There are combustion processes, with volume fractions of 1, 3, 5, 7, and 10% for n-Al and 0.5, 1, 3, and 5% for n-Al2O3. The results suggested that the quantity of heat realesed during ethanol burning increased roughly linearly with n-Al concentration. While volume fractions of N-Al of 1%

and 3% did not result in an increase in the average volumetric HoC, volume fractions of 5, 7, and 10% resulted in increases of 5.82, 8.65, and 15.31 %, respectively. N-Al2O3 and strongly passivated nAl additives did not engage in reactive combustion, and Al2O3 had no effect on the HoC in the experiments.

Ioannis Gravalos et al. [32] conducted an experimental investigation on the calorific properties of biomass residual pellets for use in heating. The biomass remnants of agricultural and forest wastes were utilized as fuel samples. A bomb calorimeter was used to determine the calorific values by the standard ASTM method. The experimental results obtained are encouraging and show that these materials can be used as alternative fuels.

John Nail et al [33] summarized the damage that may occur to the calorimeter bomb as a result of incorrect usage and lack of sufficient maintenance following the tests: (1) failing to add water when loading the bomb; water acts as an absorbent for the acids produced during the reaction; (2) venting the gases too quickly, allowing acidic gases to enter the valve assembly; and (3) failing to keep the compression nut on the valve needle properly tightened, allowing gases to burn through the head. Typically, the results of combustion are carbon dioxide and water; however, if the sample contains nitrogen, sulfur, or phosphorous, respectively, nitric acid, sulfuric acid, and phosphoric acid will be generated. After the combustion reaction is complete, the valve is used to expel the gaseous products and unreacted oxygen. It looks as though the acidic components of this combination gradually eroded the valve, eventually culminating in its collapse.

Manuel A.V [34] stated that the mini-bomb combustion calorimeter is ideal for performing high-precision combustion calorimetry on samples weighing between (10 and 40) mg. It is a calorimetric system of the aneroid isoperibol type based on a copper cylinder. The thermostat bath's thermal insulation is provided by a polystyrene layer that entirely encloses a system of distilled water that flows throughout the calorimeter. The mini-bomb and its support are inserted into the block's concentric cylindrical hole. The mini-body bomb's is constructed entirely of stainless steel. The bomb's interior components (electrodes, crucible, sheet, and support) are entirely composed of platinum. At the top of the head, there is a single gas valve and an insulated electrode that is connected to the calorimetric system to complete the discharge from the condenser. The mini-bomb is kept horizontal throughout the experiment.

Ioannis Shizas et al. [35] used the bomb calorimeter to determine the high calorific value of raw municipal wastewater. The approach was initially verified using standard substances such as arginine, glucose, and propionic acid, and then applied to municipal sludge samples, with the findings compared to previously reported values. By drying a big enough sample to give around 0.5 g of solid residue and utilizing benzoic acid in a 1:1 ratio as a combustion aid, the energy content of raw municipal wastewater may be determined accurately and precisely.

An Xu et al [36] used a calorimeter for the combustion of a mini-bomb. This calorimeter is ideal for performing high-precision combustion calorimetry on samples weighing between (10 and 40) mg. The energy equivalent of the calorimeter (calorimeter constant) was determined using benzoic acid in 15 separate calibration trials. As test substances, anthracite, succinic acid, acetanilide, and 1,2,4-triazole were utilized, with excellent agreement with published values.

Henry J. Albert [37] explained that the bomb head is sealed inside the cylinder using a modified breech block closure with a 1/16 turn. The bomb is inserted inverted with the head at the bottom of the cylinder, where it is rotated by a controlled pneumatic system to form the seal.

Stainless steel is the standard building material for these explosives. This alloy has double the nickel of 300 series austenite stainless steel and is stabilized with molybdenum and columbium to give exceptional resistance to hot mixed nitric and sulfuric acids generated during the combustion of sulfur-containing materials. For testing halogenated solvents, wastes, and other relevant compounds, alternate bombs of the same design but manufactured of a specific alloy with increased resistance to chlorides are available.

Table (2- 1) summary of literatures in chapter two.

Ref. No.	Authors	Publish year	Main conclusions and results
[18]	Linglong Wang et al	2021	In this study, a worksite calorimeter design was proposed to regulate combustion during operation of coal-fired power plants. It turned out that the proposed calorimeter has the ability to monitor the calorific value of fuel and improve the operation of the power plant.
[19]	Shivam Gupta et al	2021	In this study, the thermal stimulation of leaf solid waste was carried out. Catalytic conversion of biomass using zeolite Y, hydrogen has resulted in the production of profitable biofuel products in the form of bio-oils and bio char. PL leaf biomass has good energy potential stored inside with 20.23 MJ/kg HHV measured with a calorimeter.
[20]	Luísa M.P.F. Amaral et al	2021	In this study, samples of dimethoxyacetophenone were obtained. Use an isoperibol calorimeter to measure its enthalpy of combustion. Calculate the enthalpy of formation theoretically by the method of decomposition reaction and using the method of the Gaussian compound. The results showed that there is a convergence between the theoretical and practical results.
[21]	Yash Pal.ea al	2020	Using a adiabatic bomb calorimeter, the effect of adding aluminum and boron to the paraffin-based solid rocket fuel was studied, and the results showed an increase in the combustion energy due to these additions.
[22]	Aurel Lunguleasa et al	2020	This study was conducted to evaluate and classify types of African wood according to its combustion energy using an oxygen bomb calorimeter and the possibility of using it as a renewable

Ref. No.	Authors	Publish year	Main conclusions and results
			fuel.
[23]	Ida Farida et al	2020	This research aims to manufacture a calorimeter from waste materials, which are Styrofoam, paper, plastic, melamine and PVC and bamboo. The results have proven that this calorimeter is valid and practical and its accuracy is not less than (78%).
[25]	Obid Tursunov et al	2019	This study was conducted using a bomb calorimeter and ASTM standards for energy recovery of municipal solid waste. The results were that the combustion reaction of those wastes from coal, but this can be improved by treatment processes to separate non-combustible materials and make use of their thermal energy.
[26]	Mudassir Hussain Tahir et al	2019	This research aims to know the effect of functional groups such as (-C = C-) and (C-OH) on the change of the higher heating values (HHV) of organic compounds by using the bomb calorimeter. The results showed that functional groups such as (-C = C-) and (C-OH) play an important role in HHV variation.
[27]	Quan Zhong et	2018	The purpose of this work was to build an adiabatic calorimeter for the purpose of determining the specific heat capacity of a pressured liquid. The specific heat capacity of liquid propane was determined and compared to previously published data, as well as the experimental setup's dependability.
[28]	S S Edie et al	2017	The purpose of this study is to ascertain the influence of bomb calorimeter use on the development

Ref. No.	Authors	Publish year	Main conclusions and results
			of students' scientific practical skills. The efficacy of the bomb calorimeter was determined to be 87.88 percent.
[31]	Gisela Montero et al	2016	This study was conducted to evaluate the energy content of wheat straw and the possibility of converting it into biofuel and generating electrical energy from it. Using a bomb calorimeter it was found that the high calorific value of wheat straw is 14.86 MJ/kg.
[32]	Kishan B S et al	2016	The purpose of this project is to develop and build a portable briquetting machine for the purpose of preparing samples of tree leaves, sawdust, and other materials. The high calorific values of the manufactured briquettes were determined using a bomb calorimeter, and the results indicated that briquettes composed of sawdust and dry leaves with a trace amount of wheat flour (binding agent) pressed dry leaves have a higher calorific value than briquettes composed of sawdust, dry leaves, and coffee husks (binding agent), which are not strongly bound and have a slightly lower calorific value.
[33]	Kyle R. et al	2015	This study aims to design and build an adiabatic thermal bomb calorimeter to measure the heat generated by formation reactions between metals and subsequent molecular the combustion of metallic nanocomposite flakes. The calorimeter has been tested and used to measure the heat generated by the reactive multilayer foil.
[34]	Richard E. Lyon et al	2015	The heat of the combustion reaction is measured using a bomb calorimeter. There are three common

Ref. No.	Authors	Publish year	Main conclusions and results
			systems: adiabatic, isoperibol, and static jacket. For adiabatic and constant casing calorimeters, the heat emitted by combustion is proportional to the difference between the initial and final temperature. The isoperibol calorimeter calculates the heat of combustion from the recorded temperature difference without the need for correction and calculation of the calorimeter constant.
[36]	Jonathan Melville	2014	In order to understand why bomb calorimetry is the preferred approach for determining reaction energy levels ranging from the breakdown of food to the explosion of an explosive, it is necessary to understand how bomb calorimetry differs from normal constant-pressure calorimetry methods. It's also useful for elemental analysis, therefore the usage of a high-pressure oxygen bomb is not limited to calorimetry.
[37]	YIN Jiawang et al	2014	An oxygen bomb calorimeter was used to measure the heat of combustion of specific types of fireworks, and the combustion reaction of pyrotechnics was calculated using Hess's law. The results of this study can be used to investigate the reasons for discrepancies between theoretical and empirical values.
[40]	Xin Yu et al	2013	In this study, the enthalpy of combustion of glyphosate was determined by an oxygen bomb calorimeter at a constant volume. e. The standard mole combustion enthalpy and the standard mole formation enthalpy have been calculated to be -1702.19 and -1478.36 kJ mol-1 , respectively
[41]	Luísa M.P.F. Amaral	2012	In this study Values of the condensed phase standard molar enthalpy of formation for 20 –

Ref. No.	Authors	Publish year	Main conclusions and results
	et al		methylacetophenones (CH3C6H4COCH3) and 40 – methylacetophenones(C9H10O)were derived from the standard molar energies of combustion measured by static bomb combustion calorimetry.
[42]	Jianfeng Shen et al	2012	The increased caloric value of rice husk was determined in this study utilizing an oxygen bomb calorimeter and benzoic acid as a combustion aid.
[45]	Matthew Jones et al	2011	The purpose of this experimental study was to determine the effect of combustion on nanoparticles of aluminum (n-Al) and nanoporous aluminum oxide (nAl2O3) suspended stably in biofuel (ethanol) as a secondary energy carrier. The heat of combustion (HoC) was determined using a modified static bomb calorimeter system. The results suggested that the quantity of heat emitted during ethanol burning increased roughly linearly with n-Al concentration.
[46]	Ioannis Gravalos et al.	2010	This paper includes an experimental investigation of the calorific properties of biomass residual pellets used for heating. The experimental results are positive, indicating that these materials have the potential to be employed as alternative fuels.
[47]	By John Nail et al	2010	Damage to the calorimeter bomb may occur as a result of improper use and lack of proper maintenance during its use in combustion reactions, so the user must be aware of the method of use.
[48]	Manuel A.V	2007	At the University of Porto, a new mini-bomb combustion calorimeter built at the University of Lund was upgraded, installed, and calibrated. This calorimeter is ideal for performing high-precision combustion calorimetry on samples weighing between (10 and 40) mg. The mini-bomb is controlled

Ref. No.	Authors	Publish year	Main conclusions and results
			horizontally throughout the experiment.
[49]	Ioannis Shizas et al	2004	This study explained the method of using a bomb calorimeter to measure the amount of energy in wastewater by drying a sample of it and mixing it with benzoic acid as an aid to combustion because its calorific value is known and from which the wastewater energy is measured
[50]	An Xu et al	2000	This study presented the design of oxygen bomb calorimeters that test small samples, which saves their consumption because they may be expensive and unavailable, and the test results were highly accurate and in a short time.
[51]	Henry J. Albert	1997	In this study, the oxygen bomb calorimeter was designed with a high degree of automation and reduced operator interference in its work, thus reducing measurement errors at high combustion temperatures.

Chapter Three

Procedures of Fabrication

Chapter Three: Experimental set up of Fabrication

3.1 Introduction

Many techniques are followed to produce a constant volume bomb calorimeter which is used to measure the calorific value of any liquid and solid fuel. In this work all parts are selected and purchased from local Iraqi market and the validity of each part is tested experimentally. The procedure of designing in this study is happened depends on the required of manufacturing. In this chapter, all details are described to explain the design, selecting, manufacturing, assuming, and testing experimentally.

3.2 Description of constant volume bomb calorimeter

In general, the calorimeter can be described as a vessel made from tough material, close tightly with a cap with an O-ring. The measuring instrumentalists include a thermocouple and a Burdon pressure gauge . In this work the components of bomb calorimeter are:

3.2.1 The bomb of calorimeter

The bomb, is a cylindrical vessel with an inner volume of 1140 cc, in which the samples that are to be extracted for their calorific value are burned. It is made of aluminum alloy 7175, which has a high hardness and a good resistance to stress corrosion, stress cracking , fatigue and fracture, using a lathe machine. A groove has been made to place an O-ring in it on the upper circumference of the cylinder section in the place where the bomb cap sits. The O-ring is used to prevent the leakage of oxygen when it is filled under high pressure, as well as to prevent the exit of combustion gases inside it during the tests as shown in Figure (3.1). The bomb cap can be opened and lifted completely to easily place the sample in the sample crusible and fix it in place, as well as to clean the bomb after each burning of the examined sample and re-close it by using a toothed ring .

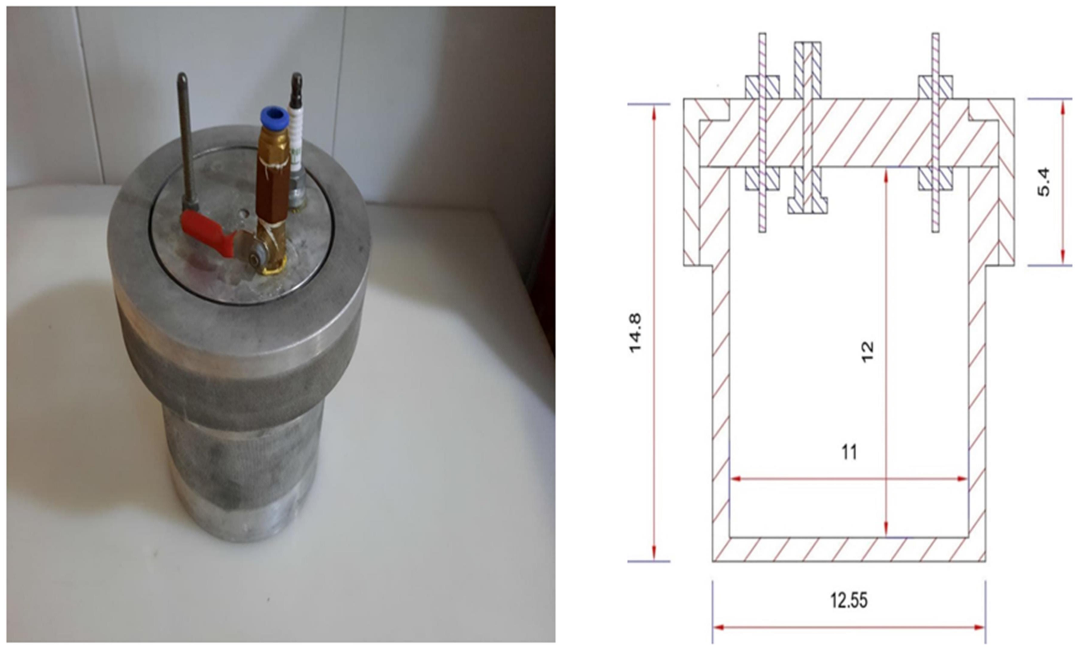


Figure (3- 1) calorimeter picture and diagram

3.2.2 Bomb cap

The bomb cap is made of two parts: a circular disc with same diameter of the outer diameter of the cylinder and a flange with inner threading. The charging and discharging valve and the electrode are fixed in the disc and passing through it , as shown in figure(3.1).

The flange seals the bomb completely when screwed tightly on the bomb, that no oxygen leakage from the bomb and no combust product leaks to the outside. The dismantled bomb is shown in figure (3.2)

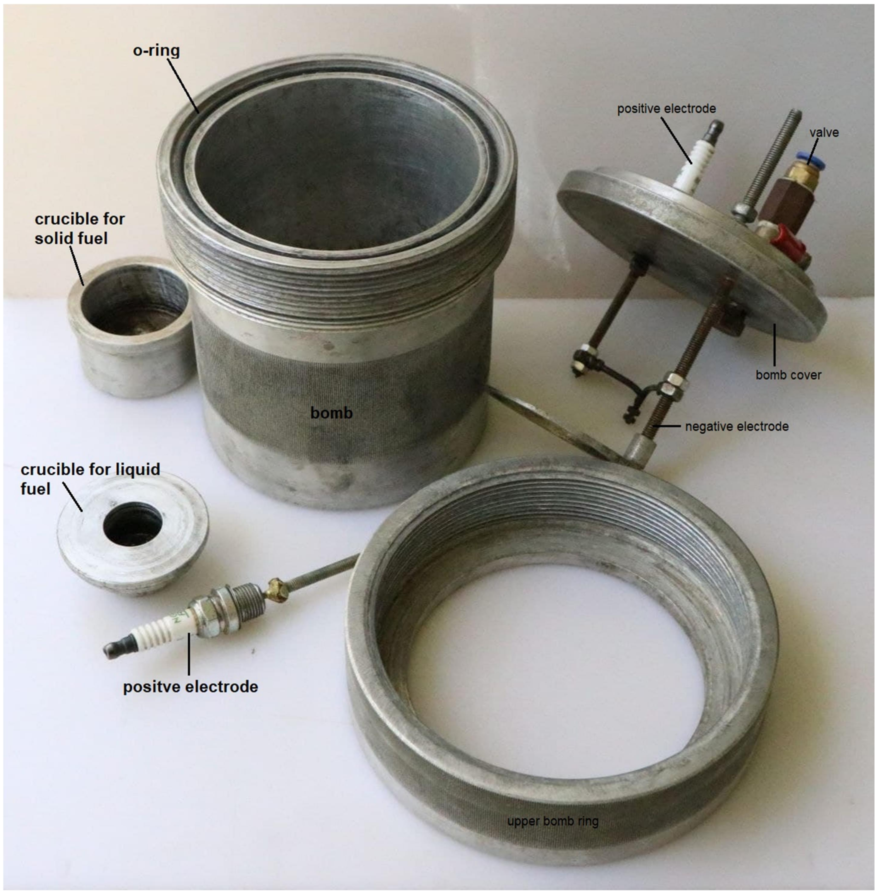


Figure (3- 2) Photograph of bomb parts

3.2.3 Crucibles

Two crucibles were manufactured for this device as shown in figure (3.2). The first with an inner diameter of 4.7 cm and a depth of 2.7 is used for testing samples of solid fuel. The second crucible, with an inner diameter of 2.3 cm and a depth of 1.8 cm, used when the testing liquid fuel .The reason for choosing a smaller diameter is so that the height of the liquid fuel under test is sufficient for the passage of the fuse wires.

These crucibles were also manufactured using a metalworking method of 7175 series aluminum alloy and a lathe machine.

3.2.4 Electrodes

The electrode are used to pass the electric current through the resistance wire to ignite the fuel sample. A positive electrode is made from a spark plug by cutting the small inclined part at its end, which is the gap of the events of the electric discharge and the occurrence of a spark. While keeping the part through which the positive part of the electric circuit passes and connecting it to a screw. It has a diameter of 0.6 cm and 6 cm a length that reaches the middle of the bomb cylinder . This electrode passes through a slotted hole in the cap of the calorimeter bomb from the outer face of the cap. The spark plug is protruding upwards, through which is connected to the electrical circuit.

The negative electrode is a 6 mm diameter screw attached to the bomb cap from the inside and extending to the sample crucible where the fuse wire is connected between the electrodes .The fuse wire is in contact with the test sample in order to heat it to the ignition temperature and start a combustion reaction to release fuel energy. In the negative electrode screw the holder of the sample crucible is attached as shown in Figure 3.2 . Figure 3.3 shows the positive electrode.

Figure (3- 3) Photograph of the positive electrode

3.2.5 The aluminum bucket

it is a container made of aluminum alloy sheets 7175,that is filled with water to make a water bucket. The water bath absorb the heat liberated by sample combustion . The cross section of this bucket has an oval shape with diameters of (22×18 cm) and a height of (18 cm) .This shape provides a place to immerse the mixer to move the water when the reaction occurs, as well as provides a place to immerse a thermometer on the other side as shown in figure (3.4). During the making of the calorimeter bucket, it was taken into account that its volume can be accommodated from the inside of the a quantity of water that submerges the bomb and covers it completely to prevent heat from escaping into the external environment and reaching the water without dispersal.

Figure (3- 4) bucket picture

3.2.6 The mixer

The mixer is a six stainless steel blades mounted on a 5 mm diameter stainless steel shaft connected to a 24V DC (2A) electric motor .The motor is installed in the calorimeter housing which is a 6 mm thick glass-plastic plate that covers the water of the bucket and the calorimeter bomb to prevent the leakage of heat and isolate it from the outside environment. Through this cover, the electrodes and thermometer connections are passed. The mixer is used to mix the bucket water uniformly distribute the combustion heat of the reaction homogeneously. So that the water temperature is uniform allways. Figure 3.5 shows the mixer and the bucket lid.

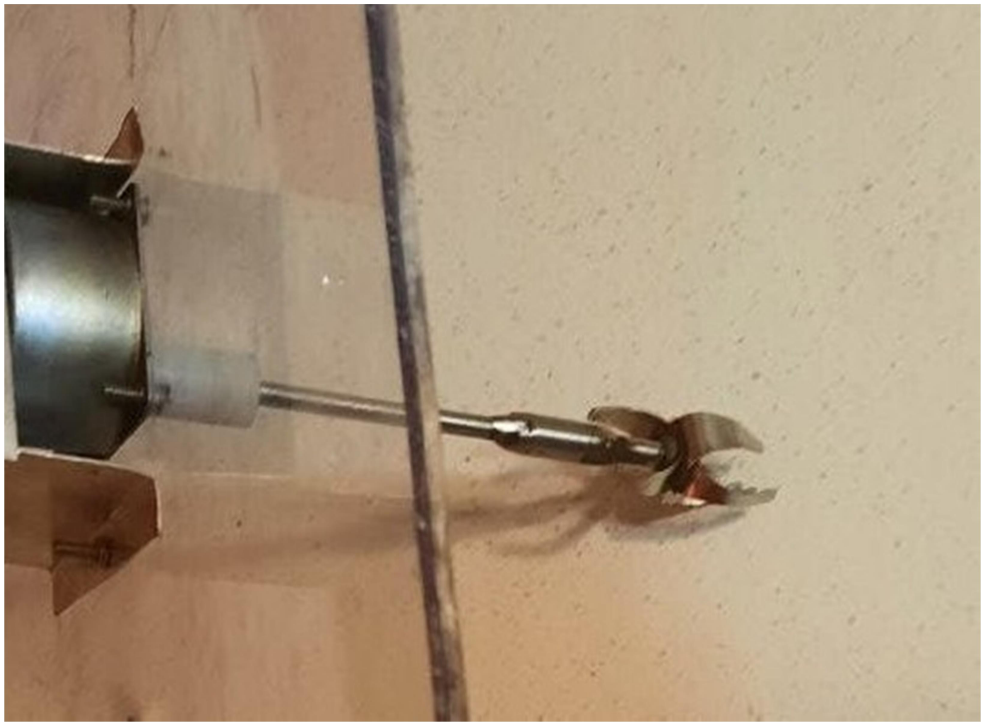


Figure (3- 5) water mixer picture

3.2.7 Insulating jacket

It is an oval section cylinder encasing the calorimeter. It is manufactured from white plastic insulators with a section thickness of 0.2 cm .Its large and small diameters are sufficient to create an air gap of more than 1 cm around the bucket. Insulating foam sheets are used to improve the insulation of the jacket. This insulation is increased by assembling sheets one above the other to make an oval-section cave with dimensions that allow the insulating jacket to enter in it. The external dimensions of the oval hole are equal to the dimensions of the box that forms the outer shell of the calorimeter. The insulator to include it inside with the bucket and all the contents are placed inside a plastic container whose walls, base and cover (with two insulating layers) to form a cover outside the calorimeter and provide good thermal insulation as shown in the figure (3.6).

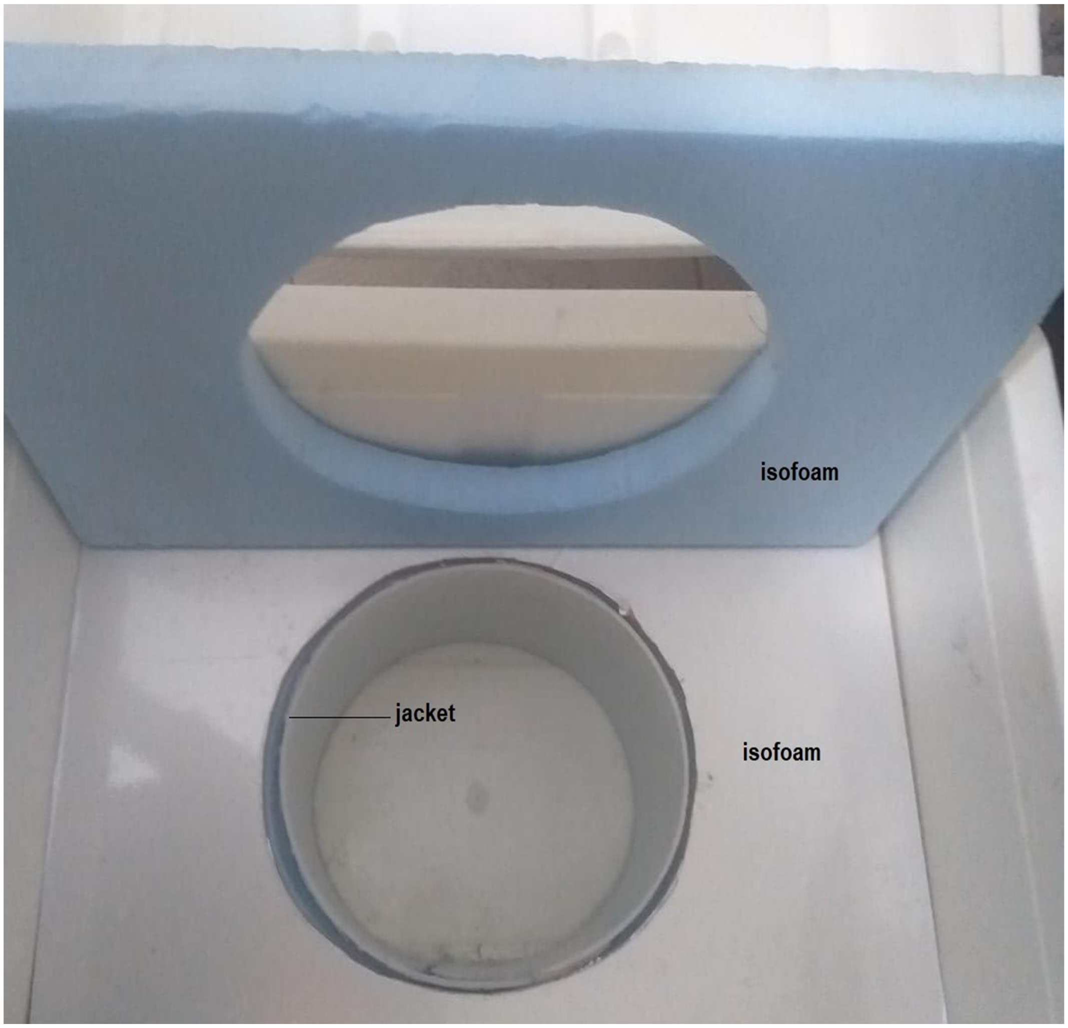


Figure (3- 6) Photograph of the jacket and isofoam.

3.2.8 Measuring Instruments

The following instruments are used :

a. Thermocouple: In this work, a k-type thermocouple with a diameter of 5 mm and a length of 20 cm has a wire connected to the display device of with a length of 1.5 m (see figure 3.7) to monitor the change in the temperature of the water in the bucket. By measuring this change, the higher calorific value of the fuel under test is calculated. Type K thermocouples are used as a temperature sensor. It consists of two different types of metals, joined together at one end. When the junction of the two metals is heated or cooled, a voltage is generated which can again be related to the temperature.

b. Digital multi-channel process indicator MPD520 series: A k-type thermocouple is connected to the MPD520 Series multi-channel digital process indicator as shown in figure (3.7). This temperature indicator is connected to a computer via USB 2.0 to the DB9 adapter cable. The temperature can be read from the device directly or from the computer screen .These degrees are stored over time in the form of tables using an Excel program with high accuracy to enable an accurate calculation of the highest calorific value. In addition, the change in the temperature during the combustion reaction is monitored in the form of a graph (temperature versus time) on the computer screen which can be directly printed as shown in figure (3.8).

Overview MPD520: is a universal process indicator with two channels, built using cutting-edge SMT technology and modular construction. It is aimed at consuming less power, measuring processes such as temperature, humidity, pressure, flow, and vibration with high accuracy, and being easy to operate in a wide range of industrial settings.

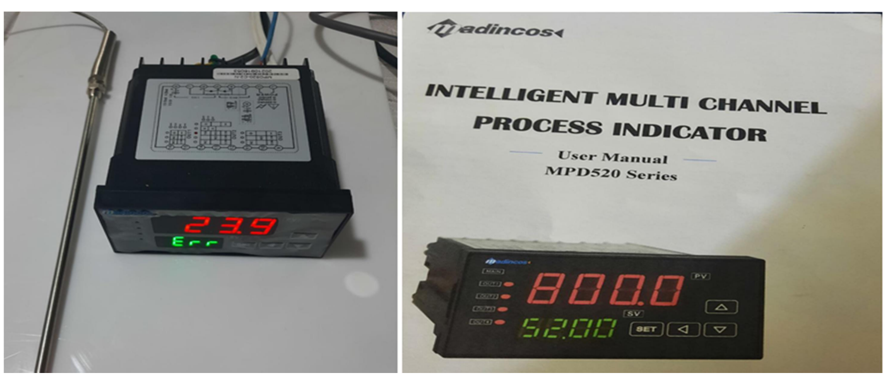


Figure (3- 7) Photograph of MDP 520 and thermocouple k-type

Features

- Dual 4 digit 7 segment LED display, 0.2%FS accuracy
- Programmable universal input: T.C., RTD, mA, VDC
- Input channels no.: 2 channels
- Built in thermocouple automatic cold junction compensation
- Output: 4-20mA, relay, 24VDC auxiliary power supply
- RS485/RS232, standard MODBUS-RTU protocol
- Multi channels display in turn or fixed channel display
- Wide power supply: 100-240VAC

Specification: Its specification as shown in table (3.1)

Table (3- 1) specification of Intelligent multi-channel process indicator MPD520 series

Accuracy	±(0.2%FS+1)digit	Input Type		Measured Range
Sample time	≤1 second when fliter=0	RTD	Pt100	-200 to 600℃
Display interval time	1-240 seconds		CU50	-50 to 150℃
Channels Input	2 channels , universal input	T.C	B	300 to 1800℃
Input type	Thermocouple, RTD, mA, VDC		E	0 to 800℃
T.C. cold compensation	Built- in auto. Compensation		J	0 to 1000℃
Filter	0-99, programmable		K	-50 to 1300℃
Offset	-99.9 to 9999, programmable		N	0 to 1300℃
Retransmission output	4-20ma output, 2 wire, 1 channel		S	-50 to 1700℃
Relay output	NO, NC, NO+NC, 220VAC/3A		T	-200 to 350℃
Alarm type	HA,LA, -HA,-LA , up to 2 limits alarming	Analog	4-20mA	-999 to 9999
Communication	RS485,RS232, standard Modbus-rtu		0-10mA	-999 to 9999
Baud rate	9600 default		0-5VDC	-999 to 9999
Case material	ABS for case and bezel		1-5VDC	-999 to 9999
Terminal	M5 screw terminal	Power supply		100-240VAC
Mounting	Panel mounting	Power consumption		Max. 5W
Size / Net Weight	96x48x100mm(LxWxD)/0.25kg	Working ambient		T:0 to 50℃, H:10%-85%RH(No dew)

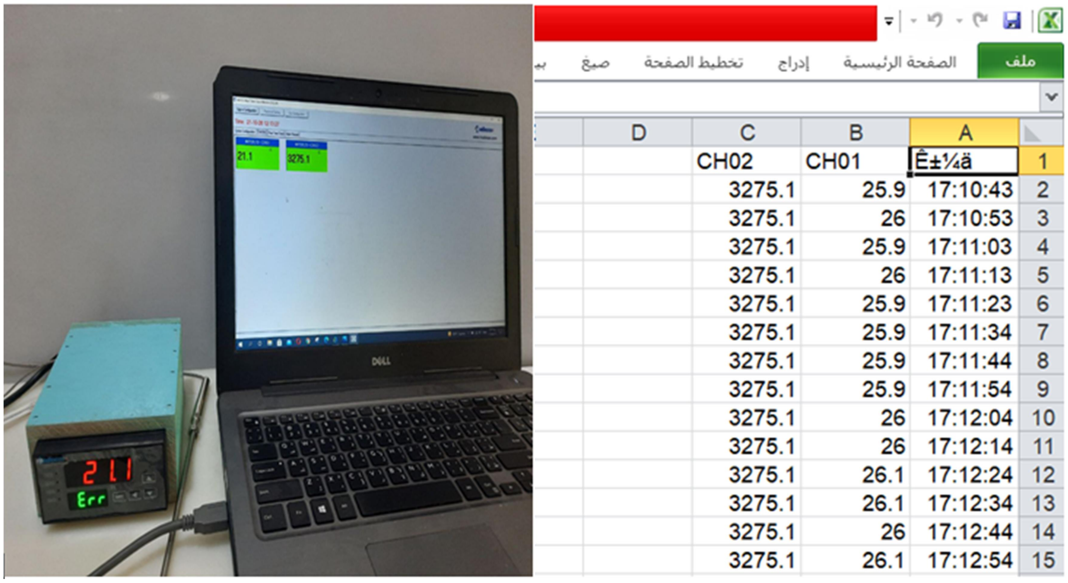


Figure (3- 8) Image showing the temperature display on the computer

c. Oxygen bottle: The oxygen bottle is considered one of the auxiliary parts of the calorimeter in order to fill the bomb with sufficient oxygen for the complete or perfect combustion reaction of fuel to release all the energy in it to calculate its calorific value. The oxygen bottle has a volume of 5.5 liters and a weight of 8.5 kg that can be charged with oxygen up to a pressure of 150 bar. To constantly monitor the oxygen pressure, we connected a regulator that controls the volume of oxygen flowing from the bottle to the calorimeter bomb. This regulator contains two pressure gauges, one of which measures the oxygen pressure inside the bottle and the other measures the pressure that is in the calorimeter bomb, as shown in the figure (3.9)

Figure (3- 9) Photograph of the oxygen bottle with gauge pressure

e. Transformer: A power transformer from AC to DC is equipped to reduce the voltage from 220 volts to a voltage difference ranging from 12 volts to 24 volts and a current of up to 30 amps. It supplied power to the fuse wires to raise the fuel temperature to the ignition temperature to initiate the combustion reaction. The fig (3.10) shown the transformer.

Figure (3- 10) Photograph of the transformer

f. Pressure gauge: It is a Bourdon type pressure device used to measure the pressure inside the calorimeter bomb when it is charged with oxygen because this type of gauge is suitable with the required pressure inside the bomb, as it does not exceed 25 bar as shown in the figure (3.11)

Figure (3- 11) Photograph of the transformer

g. weighing scale: two scale are used, the first with an accuracy of 1 mg to measure the mass of the fuel used, and the other with an accuracy of 1 g to measure the weight of the water used as shown in the figure (3.12).

Figure (3- 12)

h. Beaker: It is a graduated flask with volumetric gradations used to measure the volume of the liquid, and here we need to calculate the volume of water to which heat is transferred from the combustion reaction occurs in the calorimeter bomb as shown in fig(3.13).

Figure (3- 13) Photograph of Beaker

After we mentioned all the previous processes in the manufacture and processing of all the main and auxiliary parts of the constant volume bomb calorimeter, the device becomes ready to conduct tests on samples of liquid and solid fuels. The figure (3.14) and (3.15) shows this device.

Figure (3- 7) calorimeter parts picture

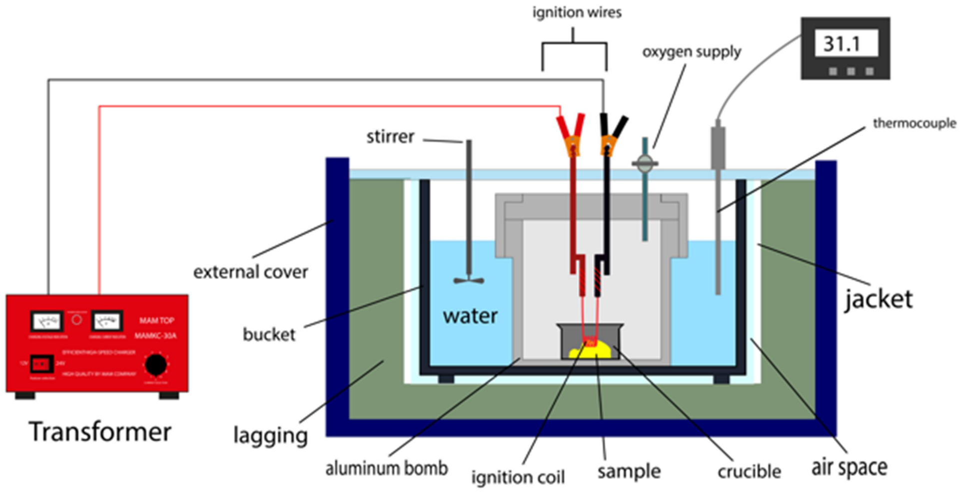


Figure (3- 15) scheme of calorimeter

Caution: conducting a calorimeter bomb test requires precautions to be taken to avoid accidents, including:

- Ensure that there are no sources of open flames close to the place of the experiment, because oxygen is present inside the bottle at high pressure, and any leakage may cause a fire or explosion.
- Failure to close the electrical circuit of the ignition unit before making sure that the calorimeter bomb is closed and immersed in the bucket water and the oxygen supply bottle is closed

Chapter Four

Experimental Test

Chapter Four: Experimental Test

4.1 Introduction

A constant volume bomb calorimeter is used to calculate the thermal changes associated with chemical reactions (the amount of heat absorbed or emitted). The maximum calorific value of the fuel is measured by determining the change in the temperature of the water that immerses the calorimeter bomb. Because the calorimeter metal is isolated from the external environment, all the heat resulting from the reaction is transferred to the bomb metal and the water that immerses them. This is the working principle of the bomb calorimeter with a constant volume.

4.2 Calibration of Calorimeter

When manufacturing any calorimeter and experimentally calculating the higher calorific value of fuel, a calibration of that calorimeter must be performed to calculate the calorimeter constant value (the amount of heat needed to raise the temperature of the calorimeter by one degree Celsius). This is because the calorimeter absorbs part of the heat emitted by the combustion reaction that takes place inside the calorimeter bomb to reach a state of thermal equilibrium with the water that submerges that bomb. In this work the calibration of the calorimeter is done as follow:

4.2.1 Estimation of the calorimeter constant from the specific heat of water:

In this method, the calorimeter constant can be found by calculating the amount of heat transferred from a known mass and temperature of hot distilled water to another known mass of cold distilled water(the water has a high heat capacity of 4.184($\frac{kj}{kg.°C}$)).The metal calorimeter bomb and its bucket are immersed in cold distilled water and their temperature is recorded. Then the known mass of hot distilled water with a known temperature is added to it .The water mixture is mixed using an electric mixer until we reach the equilibrium temperature of the mixture .This temperature is recorded to extract the calorimeter constant.

The heat is transferred from the hot distilled water to the cold water and the metal calorimeter immersed in it . Their temperatures are raised until the system reaches a state of thermal equilibrium. The final temperature of the mixture is recorded. Because the mass of cold , hot, and the specific heat of distilled water($4.184\frac{kJ}{kg.°C}$) are known, it is possible to extract the specific heat constant of the calorimeter. It is equal to the difference between the amount of heat lost from the hot water and the amount of heat gained in the cold water divided by the difference between the temperature of the final mixture and the initial cold water temperature. The work steps can be summarized as follows**[38]**:

1. A quantity of water was taken at room temperature and with a mass (m_1) of 2 kg where it was measured using an electronic mass scale with an accuracy of 1 g.
2. The temperature of cold water (m_1) is recorded using a thermocouple k-type where it was 33.85 ℃ .This temperature is equal to the ambient and symbolized by it (T_1).
3. The bomb calorimeter and its bucket are immersed in cold water (m_1) in a heat-insulating plastic container and placed inside another container to isolate them from the outside environment to prevent heat from leaking into the surrounding .Their temperature was (T_1) which is 33.85°C ambient temperature.

4. Take a mass (m_2)of distilled water its value 2 kg and heat it using an external heat source to a certain temperature and record that temperature and it was 82.7 ℃ .
5. The temperature of the mixture (T_f) is recorded after reaching the state of thermal equilibrium, that is, the completion of the transfer of heat from hot water to cold water and the mass of the calorimeter.

After completing the recording of the temperature readings and measuring the masses, the calorimeter constant is calculated based on the equations for calculating the amount of heat transferred between the objects from equation (4.1).

$$q = mC(T_f - T_i) \quad (4.1)$$

q-amount of heat transfer in kJ

m-mass of material in kg

C-specific heat in kJ/kg.°C

T_f _final temperature

T_i – initial temperature

In this research we used this equation

$$-q_{ho\ \ wtaer} = q_{cold\ water} + q_{calori} \quad (4\text{-}2)$$

$$-m_2\ c\ (T_f - T_2)_{hot\ water} = m_1 c(T_f - T_1)_{cold\ water} + m_3 c(T_f - T_1)_{calor} \quad (4.3)$$

Let $m_3 c = C_{clori}$

-2×4.184×(54.6-82.7)=2×4.184×(54.6-33.85)+ C_{clori} (54.6-33.85)

C_{clori}=2.96$KJ/$℃

4.2.2 Test of the calorific value for different fuel

The manufactured calorimeter was tested, as this device works on calculating the heat of combustion of solid and liquid fuels. Three types of solid materials were tested, it is charcoal, sawdust ,and table sugar. They are well stacked in the sample crucible and their weight is accurately measured using an electronic scale and placed in its place inside the calorimeter bomb. Two types of liquid fuel were also tested namely gas oil and kerosene. Placing the liquid sample in the calorimeter crucible and passing the fuse wire in it, where it is heated up to the burning temperature and the highest calorific value is extracted from it.

One gram of water added inside the bomb to completely saturate the vapor of water vapor resulting from the combustion reaction and condenses it into a liquid completely. Then the fuse wire is connected between the electrodes of the bomb, making sure it is dipped inside the fuel and not touching the walls of the crucible. Then the bomb cap is placed and closed tightly.

Then the bomb is filled with oxygen up to a pressure of 8 bar and emptied . Filled again in the same way and emptied in order to completely remove the air in it and to reduce nitrogen impurities that were present with the air inside the bomb. Then fill the bomb with oxygen up to a pressure of 10 bar . Make sure that there are no oxygen from the bomb in order to ensure the complete combustion of the fuel samples. As the combustion of hydrocarbon fuel is stoichiometric according to the equation (4.3).**[2]**

$$C_\alpha H_\beta O_\gamma + (\alpha + \frac{\beta}{4} - \frac{\gamma}{2})(O_2 + 3.76N_2) \rightarrow \alpha CO_2 + \frac{\beta}{2} H_2O + 3.76\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right) N_2 \quad (4.4)$$

In this research, the combustion reaction was conducted in an atmosphere of oxygen, so the standard equation for stoichiometric combustion as in equation (4.4)

$$C_\alpha H_\beta O_\gamma + (\alpha + \frac{\beta}{4} - \frac{\gamma}{2})(O_2) \rightarrow \alpha CO_2 + \frac{\beta}{2} H_2O \quad (4.5)$$

A known mass of distilled water is placed in the calorimeter bucket and it is measured either by using a beaker or using an electronic mass scale so that it is sufficient to submerge the calorimeter bomb. Then it is left for up to five minutes and stirred well using an electric mixer. Then the initial temperature of the water is recorded by placing thermometer in it. The calorimeter is closed to prevent heat from leaking out. The electricity source is connected to allow the passage of electric current to the poles of the bomb and the ignition to occur. As well as connecting the current to the electric water mixer to start moving the water and recording the rise in the temperature of the water in the bucket until the maximum temperature is reached . Continuing to record it for a period of no less than five minutes after recording the maximum temperature .

Then the water mixer is stopped, the calorimeter is opened, the bomb is extracted from it, its valve is opened to release the combustion gases and release them from pressure. Then the bomb cap is removed , the inner surfaces of the bomb cylinder, and cap are then thoroughly washed with a distilled water. In the same way, the process of preparing the bomb calorimeter is repeated and the temperature measurements of the other samples are recorded.

Using the data sent from the k-type thermocouple submerged in the calorimeter bucket to the intelligent multi-channel process indicator then to the computer where it is included in the form of temperature-time excel tables, we plot the temperature versus time plot.

All measurements were analyzed and data recorded for each type of fuel to determine its high calorific value by the equation (4.6)

$$HCV = (C_{calori}\Delta T + C_{H_2O} m_{H_2O} \Delta T)/m_{fuel} \qquad (4.6)$$

Where:

HCV-high caloric value in MJ/kg.

C_{calori} –calorimeter constant which equal 2.96 $kJ/$°C.

ΔT=$(T_{maximum} - T_{intial})$ of water in bucket in °C.

C_{H_2O} –specific heat of distilled water where equal 4.184 $\frac{kj}{kg.°C}$.

Each type of fuel mentioned three tests as follows:

4.2.2.1 Charcoal test

A test on a samples of charcoal(C_7H_4O)were conducted that available in the local Iraqi markets with a weight of 2 g as shown in Figure (4.1). Crushing coal and turning it into a powder to facilitate the ignition process and then stacking it in the crucible of the test bomb. The change in temperature of a 3 kg mass of calorimeter bucket water over time were tracked as shown in the table (4.1).

Table (4 -1) the temperature change over time of Charcoal sample

Charcoal Test		
Time In Min	**Temp In °C**	**Notes**
0	26.7	Intimal temperature
2	26.7	
4	27.5	
6	27.8	
8	28.3	
10	28.6	
12	28.9	
14	29.1	
16	29.3	
18	29.5	
20	29.5	
22	29.8	
24	29.9	
26	30.1	
28	30.1	
30	30.1	
32	30.2	
34	30.3	
36	30.4	
38	30.3	
40	30.4	
42	30.5	

44	30.4	
46	30.5	Maximum temperature
48	30.4	
50	30.4	
52	30.4	
54	30.4	

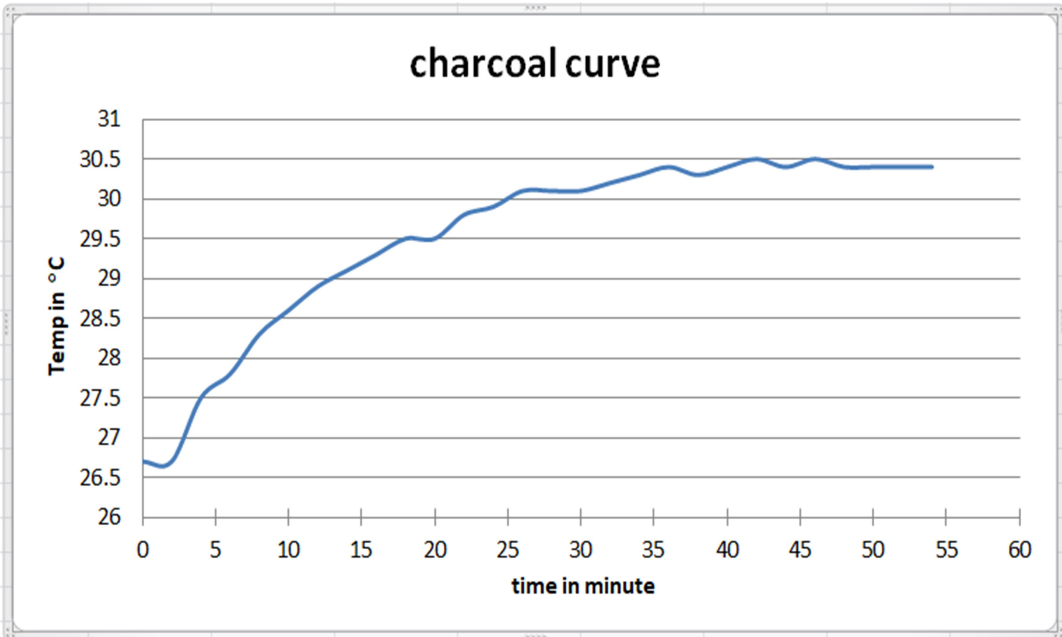


Figure (4- 1) Curve of temperature change with time of charcoal

For all charcoal samples whose image is shown in Figure (4.2), we take the maximum temperatures from the reading's computer or indicator process (MPD520 series) and from them we extract the highest calorific value by applying the equation (4.5) and include their values in the table (4.2)

Figure (4- 2) charcoal sample

4.2.2.2 sawdust test

The same test was conducted on a sample of a mass of 2 g of sawdust($C_6H_{10}O_5$) used in the Iraqi local markets for the manufacture of furniture as shown in Figure (4.3) as a sample for solid fuel and we recorded the temperature change over time as in Table (4.2)

Table (4 -2) the temperature change over time of sawdust sample

Sawdust Data		
Time In Min	**Temp In ◦C**	**Notes**
0	26.6	Intimal temperature
2	26.6	
4	27.6	
6	27.8	
8	28	
10	28.2	
12	28.4	
14	28.5	
16	28.6	
18	28.8	
20	28.9	
22	29	
24	29.4	
26	29.3	

28	29.4	
30	29.4	
32	29.4	
34	29.4	
36	29.5	
38	29.5	
40	29.5	Maximum temperature
42	29.3	
44	29.2	

Figure (4- 3) sawdust sample

The relationship curve showing the change in temperature of a water of mass 2.7 kg of water with time has been drawn as in Figure (4.4).

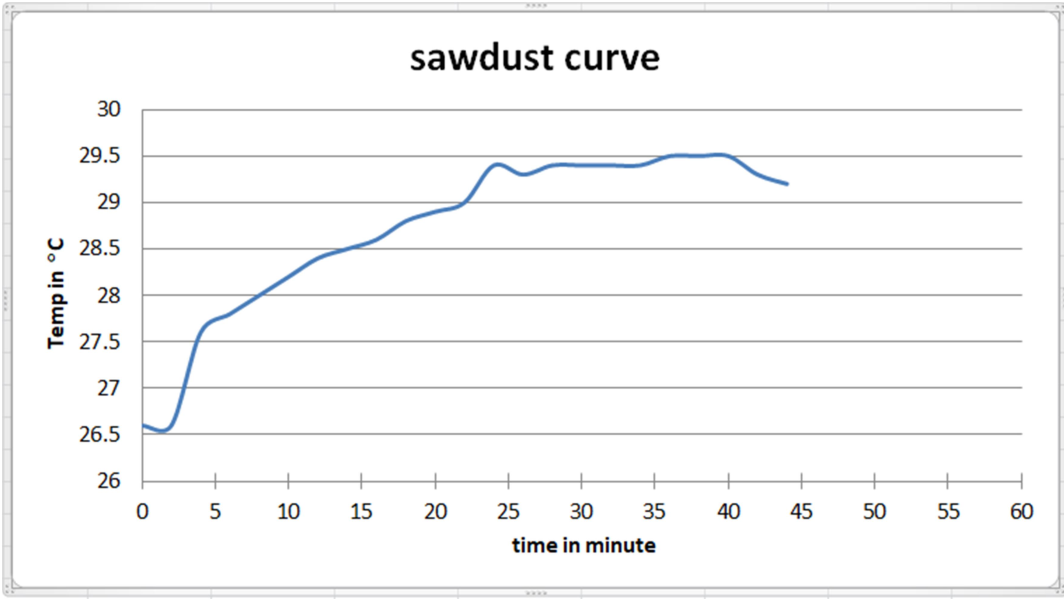


Figure (4- 4) Curve of temperature change with time of sawdust

4.2.2.3 Table Sugar test

The same test on a sample with a mass of 2 g of table sugar available in the local Iraqi markets was conducted as a sample for solids. The 2.6 kg calorimeter bucket water temperature gradually changed over time as shown in Table (4.3) until it reached the maximum temperature . This water remained at this temperature for a long period of time due to the thermal insulation of the calorimeter. The graph in Figure (4.5) shows the temperature change over time.

Table (4 -3) the temperature change over time of sugar sample

Table Sugar data		
Time In Min	Temp In ºC	Notes
0	24.5	Intimal temperature
2	24.5	
4	24.6	
6	24.6	
8	24.8	
10	25.1	
12	25.4	
14	26.4	
16	26.8	

18	26.9	
20	27.1	
22	27.6	
24	27.7	
26	27.8	
28	28	
30	28	
32	28	
34	28.1	
36	28.2	
38	28.1	
40	28.2	
42	28.2	
44	28.2	
46	28.2	
48	28.2	
50	28.2	
52	28.3	
54	28.2	
56	28.3	
58	28.4	Maximum temperature
60	28.3	
62	28.3	

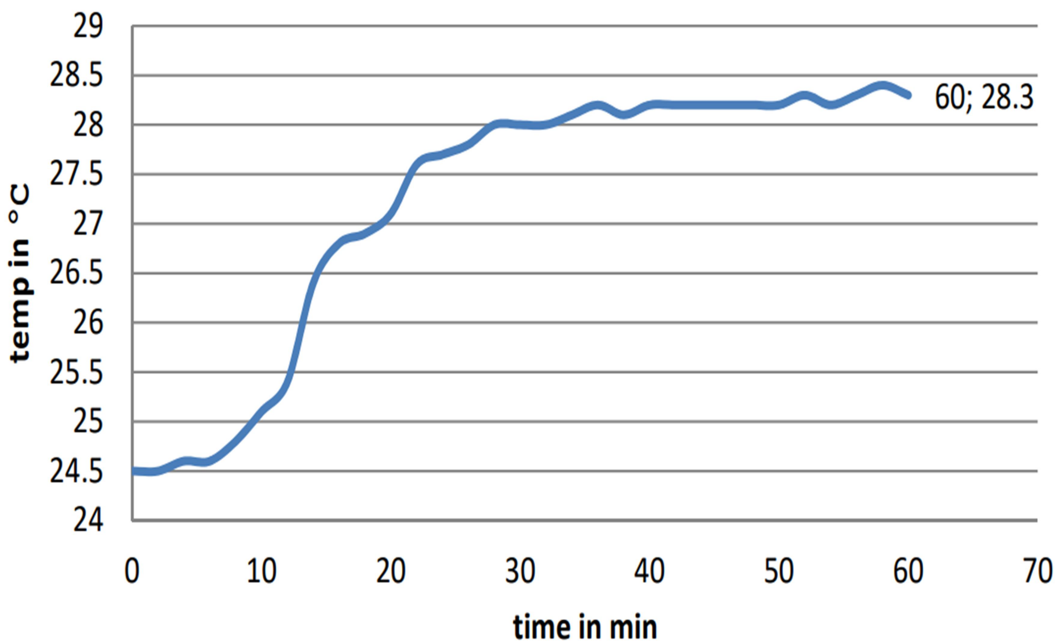


Figure (4- 5) Curve of temperature change with time of sugar sample

4.2.2.4 Gas oil test

A liquid fuel test on a sample of 1 gram of Iraqi gas oil fuel was conducted. Filling the calorimeter with distilled water of mass 2.75 kg, whose calorific value according to the marketing specification guide for Iraqi petroleum products is 10800 kcal/kg which equal 45.21744 MJ/kg. The test was conducted under pressure of 10 bar of oxygen after filling the bottle and emptying it twice in a row to wash it from the air and to be in an atmosphere of pure oxygen to ensure complete combustion of the fuel. After completing the testing of sample, the calorimeter bomb is washed and cleaned and prepared for the next test . The temperatures change over time were as listed in Table (4.4).

Table (4 -4) the temperature change over time of gas oil fuel

Gas oil fuel		
Time in min	**Temp in ◦c**	**notes**
0	23.3	Intimal temperature
2	23.3	
4	23.5	
6	23.9	
8	24.1	
10	24.4	
12	24.6	
14	24.9	
16	25	
18	25.2	
20	25.3	
22	25.5	
24	25.6	
26	25.7	
28	25.9	
30	26	
32	26	
34	26.1	
36	26.1	
38	26.1	
40	26.3	
42	26.4	
44	26.3	
46	26.4	
48	26.4	

50	26.5	
52	26.5	
54	26.4	
56	26.5	
58	26.4	
60	26.5	
62	26.6	
64	26.6	Maximum temperature
66	26.5	

The change in temperature with time can be represented as in the diagram in fig (4.6)

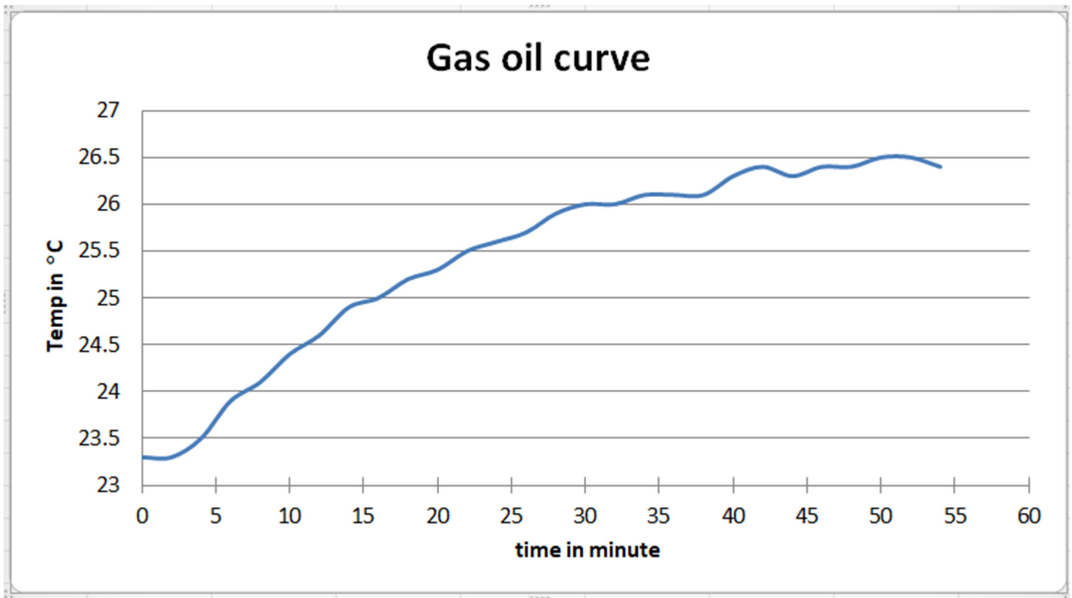


Figure (4- 6) Curve of temperature change with time for gas oil fuel

4.2.2.5 kerosene test

A liquid fuel test also on a sample of 1 gram of Iraqi kerosene was conducted under a pressure of 10 bar of pure oxygen. The calorific value of kerosene according to the marketing specification manual for Iraqi petroleum products is 10900 kcal / kg, which is equivalent to 44.3 Mj / kg, and the results were as shown in Table (4.5).

Table (4 -5) the temperature change over time of kerosene fuel

time in min	temperature in ºC	note
0	23.7	initial temperature
2	23.7	
4	23.8	
6	24.1	
8	24.3	
10	25.2	
12	25.3	
14	25.5	
16	25.5	
18	25.7	
20	25.9	
22	26	
24	26	
26	26.3	
28	26.3	
30	26.4	
32	26.4	
34	26.5	
36	26.5	
38	26.6	
40	26.6	
42	26.7	
44	26.9	
46	26.9	
48	26.9	
50	26.8	
52	26.9	
54	26.9	
56	26.9	
58	26.9	Maximum temperature
60	26.8	
62	26.8	
64	26.8	
66	26.8	

The change in temperature versus time can be represented as in the graph in Figure (4.7).

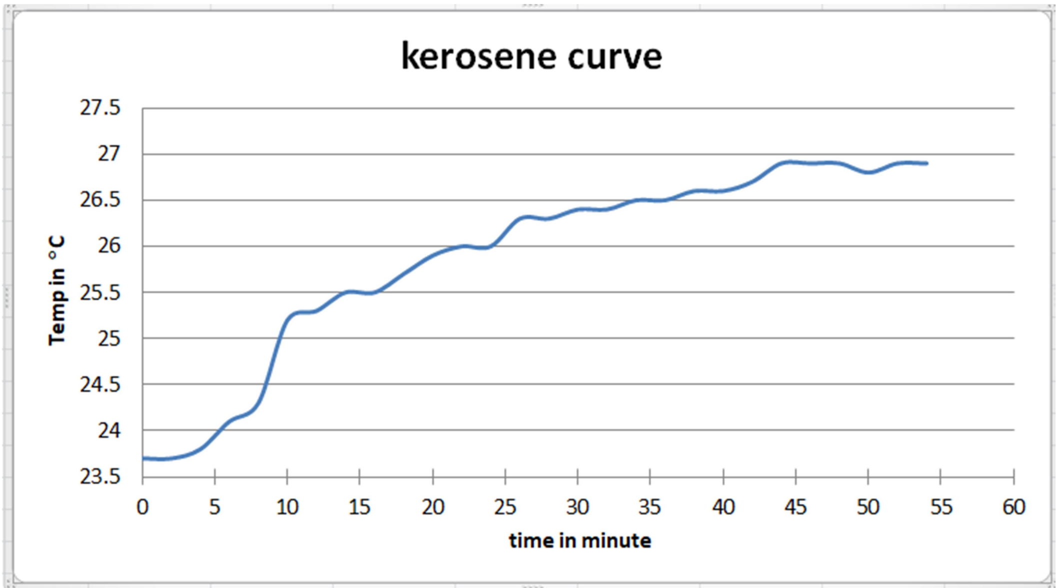


Figure (4- 7) Curve of temperature change with time for kerosene fuel

4.3 Result and Discussion

Five different types of materials, known for their high calorific value, were tested in order to know the accuracy of the manufactured calorimeter. The two types of fuel that was tested in this work are liquid fuel, represented by gas oil fuel, kerosene and solid fuel represented by sawdust, wood charcoal and table sugar.

4.3.1 Analyze of experimental results of the calorimeter

Three tests for each type of solid and liquid fuels were conducted in order to compare the results and to note the accuracy of the work and the deviation rates. The high calorific value in MJ/kg was calculated from equation (4.6) .

The practical results of this experiments were included in the table (4.6) and mentioning the theoretical results from the guide to marketing specifications for Iraqi oil products as shown in fig(5.1) and fig(5.2). The higher calorific value of solid fuel is given in the form of a range in the standard tables, so the comparison is made, provided that the test results are within or outside the range. The error percentage can be calculated from equation 4.6

$$\text{error }\% = \frac{|\text{accepted value} - \text{experimental value}|}{\text{accepted value}} \qquad (4.7)$$

4.3.2 Analysis of the experimental results of solid fuel

Throughout the whole experimental program each test was repeated three times and the average result was taken. The bucket water temperature change data were analyzed along with the weights taken for each type of fuel to determine its higher calorific value. The results were listed in table (4-6). Then a comparison of those results with the theoretical values that obtained from the tables of specifications for those materials with the percentages of deviation from the theoretical values.

Table (4- 6) Solids martial test Results

Solids Test Results								
Result of Charcoal test								
No.	M_{fuel} **in gram**	M_{wate} **in kg**	T_{Intial} **in °C**	T_{Final} **in °C**	**Experimental HCV in MJ/kg**	**Average HCV in MJ/kg**	**theoretical HCV in MJ/kg**	**Error%**
1	2	3	26.4	30.4	31.024	30.13	25-33	In range
2	1.5	3	26.6	31.5	29.9			
3	1	3	27.2	29.1	29.47			
Result of sawdust test								
1	2	3	26.6	29.2	20.16	19.986	17-22	in range
2	1.5	3	28.8	30.7	19.64			
3	1	3	29.1	30.4	20.16			
Table sugar test results								
1	2	3	26.6	28.9	17.83	17.145	16.25	5.5
2	1.5	3	26.3	27.9	16.546			
3	1	3	26.8	27.9	17.06			

4.3.3 Analysis of the experimental results of liquid fuel

Liquid materials require more accuracy in conducting tests, for example, when measuring their mass. This process is more difficult than in solid materials because dealing with milligrams of liquid fuel and placing it in the calorimeter bomb and then filling it with oxygen needs good care to avoid spilling the fuel from its crucible to the bomb.

These experiments were conducted on two types of liquid fuels produced in local refineries. Namely gas oil and kerosene. For each type, test three times were repeated. It is considered arbiter to accept those products. Its high calorific value were calculated and included all relevant details in Table (4.7).

Table (4- 7) Liquid material test results

Liquid material test results								
Result of gas oil fuel								
No.	M_{fuel}	M_{water}	T_{Intial}	T_{Final}	**Experimental HCV in MJ/kg**	**Average HCV in MJ/kg**	**theoretical HCV in MJ/kg**	**Error%**
1	1	2.75	23.3	26.6	47.7	47.6	45.215	5.27
2	1.5	3	31.9	36.5	47.57			
3	1.5	3	33.5	38.1	47.57			
Result of kerosene test								
1	1	2.75	23.7	26.9	46.2912	47.03	45.636	3.06
2	1.5	2.75	35.5	40.4	47.2556			
3	1.5	3	36.1	40.7	47.57			

دليل المواصفات التسويقية للمنتجات النفطية العراقية

2-6. زيت الغاز Gas Oil

Grade	A	B	الدرجة
Density (g/cm3) @ 15 °C	*(0.850)	*(0.850)	الكثافه (غم/سم3) عند 15 م°
Flash point (P.M) °C (min)	60	60	نقطة الوميض(بنسكي مارتن) م° (الادنى)
Viscosity (cst) @ 40 °C (max)	5.6	5.6	اللزوجه عند 40 م° (سنتي ستوك) (اقصى)
Pour point °C (max)	-9	-9	درجة الانسكاب م° (اقصى)
Sulfur Content (wppm) (max)	10000	10	المحتوى الكبريتي (جزء بالمليون وزناً) (أقصى)
Carbon Residue (RAMS) %wt (on 10% Res) (max)	0.2	0.2	الكاربون المتبقي رامسبوتوم % وزناً (على 10 % متبقي) (اقصى)
Color ASTM-D-1500 (max)	2.0	2.0	اللون (اقصى)
Distilled @ 350 °C %V(min)	85	85	المقطر عند 350 م° % حجم (ادنى)
Corrosion (copper strip)	1	1	فحص التاكل (شريط النحاس)
Diesel Index (min)	55	55	معامل الديزل (ادنى)
Cetan Index (min)	50	50	رقم السيتان (ادنى)
Calorific Value(Kcal/kg) (gross) EST	10800	10800	القيمة الحرارية (كيلو سعرة/ كغم) اجمالي (مقدر)
Ash %wt (max)	0.01	0.01	الرماد المتبقي % وزناً (اقصى)
Free water	Nil	Nil	الماء الحر

• **المواصفة الموضوعة بين قوسين تعتبر استرشادية وليست حاكمة.**

الدرجة A:مواصفات الانتاج في المصافي العاملة حالياً.

الدرجة B:مواصفات الانتاج في المصافي الاستثمارية والمصافي الحديثة.

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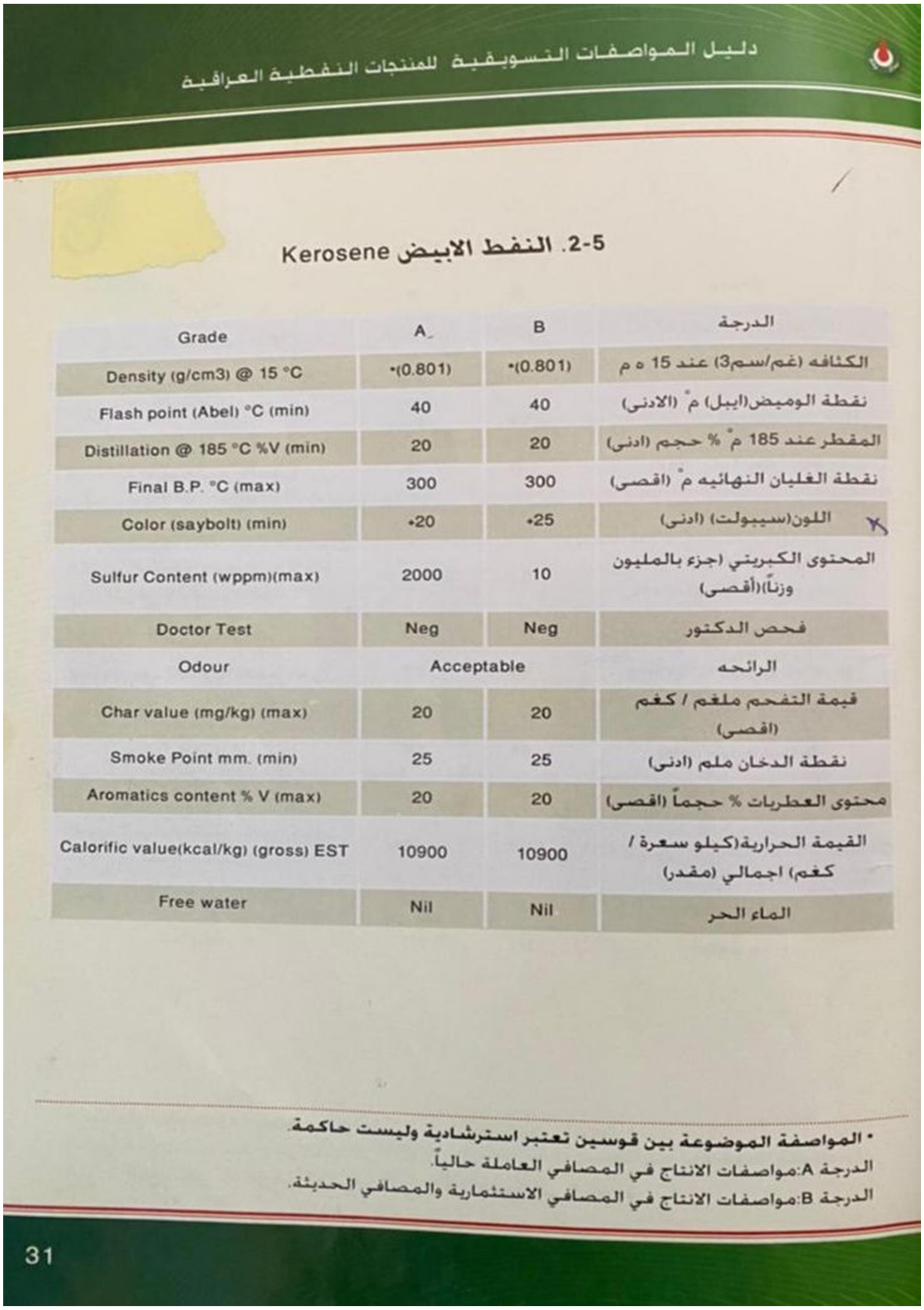
Figure (4- 8) gas oil fuel properties[39]



دليـل الـمواصـفـات الـتـسويـقـيـة للمنتجات الـنـفـطـيـة الـعـراقـيـة

2-5. النـفـط الابيـض Kerosene

Grade	A	B	الدرجة
Density (g/cm3) @ 15 °C	*(0.801)	*(0.801)	الكثافه (غم/سم3) عند 15 ه م
Flash point (Abel) °C (min)	40	40	نقطة الوميض(ابيل) مْ (الادنى)
Distillation @ 185 °C %V (min)	20	20	المقطر عند 185 مْ % حجم (ادنى)
Final B.P. °C (max)	300	300	نقطة الغليان النهائيه مْ (اقصى)
Color (saybolt) (min)	+20	+25	اللون(سيبولت) (ادنى)
Sulfur Content (wppm)(max)	2000	10	المحتوى الكبريتي (جزء بالمليون وزناً)(أقصى)
Doctor Test	Neg	Neg	فحص الدكتور
Odour	Acceptable		الرائحه
Char value (mg/kg) (max)	20	20	قيمة التفحم ملغم / كغم (اقصى)
Smoke Point mm. (min)	25	25	نقطة الدخان ملم (ادنى)
Aromatics content % V (max)	20	20	محتوى العطريات % حجماً (اقصى)
Calorific value(kcal/kg) (gross) EST	10900	10900	القيمة الحرارية(كيلو سعرة / كغم) اجمالي (مقدر)
Free water	Nil	Nil	الماء الحر

* المواصفة الموضوعة بين قوسين تعتبر استرشادية وليست حاكمة.
الدرجة A:مواصفات الانتاج في المصافي العاملة حالياً.
الدرجة B:مواصفات الانتاج في المصافي الاستثمارية والمصافي الحديثة.

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Figure (4- 9) Kerosene fuel[39]

4.4 Discussion

Calculations of high calorific value depend mainly on the difference between the temperature before combustion and the maximum temperature after combustion in the calorimeter bomb. The diagrams shown in chapter four for each type of fuel give us a visual picture of how combustion affects the temperature in the bomb and its transfer to the water in the bucket, during the period of heat transfer to the water, and even reaching the maximum temperature.

The change in the temperature of the calorimeter bucket water can followed directly before it reaches the maximum temperature. Where the timeline for this change during the interaction is drawn via computer as shown in the figure (4.10).

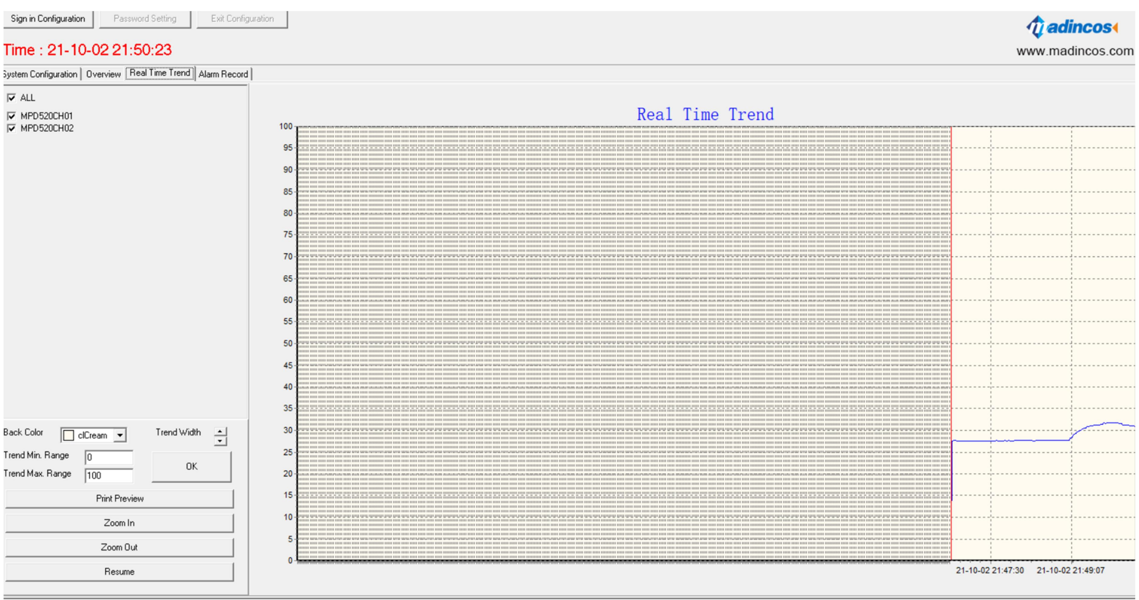

Figure (4- 10) curve of temperature rise

It is noted in the tables of the results of the high calorific value measurements of the tested materials using the constant volume bomb calorimeter show a slight deviation from the theoretical or reference values for various reasons and will be discussed them as follows:

4.4.1 The energy produced by the electric current

A copper was used as fuse wire with a diameter of 0.051 mm ,5 cm length and 0.015 g weight to start the ignition by passing a direct electric current of 30 amps and a voltage difference of 12 volts. This wire was 5 cm long and does not last more than a second, as this wire melts and cuts off the flow of electricity and combustion occurs due to the high pressure of oxygen inside the calorimeter bomb. This means that The heat generated by the electric current is small, according to the equation

$$Q = I \times V \times t \qquad (4.7)$$

q- heat gain in joule.

I-current in ampere

V-voltage.

t-time of current passes in fuse wire (in second unit).

Therefor the time for the electric current to pass is 2 seconds, the heat generated by the electric energy is:

Q=30×12×2

Q=720 joule.

4.4.2 Measurement errors

There are many reasons that lead to errors in measuring the high calorific value of solids and liquids using a bomb calorimeter, including them:

- The measured temperature inside the calorimeter bucket water may not be realistic or accurately represent that temperature due to the location of the thermometer.

- The water used during the tests must be at room temperature and must be distilled and of good purity. Otherwise, it may cause errors in the measurement of the high temperature value.
- Human errors that result from insufficient accuracy in conducting the weighing of the materials under test or inaccurate weighing of the bucket water, as well as the measurement of the length of the fuse wire or its weight may not be accurate enough.
- When placing the bomb in the calorimeter bucket water after it is charged with oxygen and the test sample must wait for several minutes until its temperature balances with the temperature of the water before recording the initial temperature and not applying this procedure also may cause measurement errors.

4.5 Analysis of the faults that occur in the calorimeter bomb

Parts of the calorimeter may be damaged during testing due to improper use or lack of experience, including the following:

- When filling the bomb, the oxygen pressure gauge inside must be monitored so that the oxygen-fuel ratio is suitable to completely burn the samples under test (stoichiometric combustion or rich mixtures) without excessively increasing the pressure, as this may cause damage to the bomb valve or electrodes ports and the occurrence of gas leakage from inside to outside, which affects the accuracy of the measurement.
- Taking into account the mass of the samples on which the test are conducting. Provided that it is not large so that it needs a high pressure of oxygen or may not be enough to burn it completely.
- Failure to vent the bomb and releasing the gases resulting from the reaction combustion of the test sample may cause damage to it,

especially if the sample contains nitrogen, phosphorous or sulfur, because its acids may form and cause damage to the valve and electrodes from the inside, so it must be drained directly and washed with distilled water immediately after any experiment.

- Using a high voltage during the experiment may cause the electrodes to melt, so a voltage difference of 12 volts or 24 volts was used, and it was suitable for solid and liquid fuels.

Chapter Five

Conclusion

Chapter five: Conclusion and recommendations

5.1 Conclusion

From this work the following conclusions were reached.

- The manufactured calorimeter was used in several experiments. The results were close to the standard results; therefore, this calorimeter can be used in subsequent tests to extract the high calorific value.
- In this device, all the water vapor resulting from the test reaction condenses, which represents the difference of the high calorific value from the low calorific value (LCV) and equal to the heat of vaporization.
- The fuel burns inside the calorimeter bomb, as well as the fuse wires used to start the combustion, and their heat is added to the heat resulting from the combustion of the fuel and transferred to the bomb and water mass, and its internal(ΔU) energy increases, causing its temperature to rise. Therefore, the specific heat of the fuse wire must be taken into account in calculating the high calorific value.
- This device is considered one of the applications of the first law of thermodynamics.

5.2 Recommendation

A calorimeter is a very important device to know the heat content or the amount of heat that can be released and converted into useful energy in various materials:

- Manufacture of a special calorimeter to examine the enthalpy of gaseous fuel . Link it in series to know the amount of heat realesed by the gases resulting from the combustion of liquid and solid fuels and to know the possibility of benefiting from the circulation of these gases to liberated the remaining energy in them after reaching the maximum temperature and allowing these gases to be freed from the constant volume bomb calorimeter to the gas calorimeter.

- Manufacture of calorimeters of different sizes according to the need and requirements for use them in evaluating and classifying waste in order to be recycled.

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Appendix 1

Specific (C_s) and Molar (C_m) Heat capacities at constant pressure (1 atm) and 25°C**[53]** .

Substance	**specific heat capacity** $C_{p,s}$ (J/g °C)	**molar heat capacity** $C_{p,m}$ (J/mol °C
air	1.012	29.19
aluminum	0.89	24.2
argon	0.5203	20.786
copper	0.385	24.47
granite	0.790	—
graphite	0.710	8.53
helium	5.1932	20.786
iron	0.450	25.09
lead	0.129	26.4
lithium	3.58	24.8
mercury	0.14	27.98
methanol	2.14	68.62
sodium	1.228	28.23
steel	0.466	—
titanium	0.523	26.06
water (ice, O°C)	2.09	37.66
water	4.184	75.38
water (steam, 100°C)	2.03	36.57

Appendix 2

Table of Heats of Formation **[54]**.

Compound	ΔHf (kJ/mol)
AgBr(s)	-99.5
AgCl(s)	-127.0
AgI(s)	-62.4
Ag2O(s)	-30.6
Ag2S(s)	-31.8
Al2O3(s)	-1669.8
BaCl2(s)	-860.1
BaCO3(s)	-1218.8
BaO(s)	-558.1
BaSO4(s)	-1465.2
CaCl2(s)	-795.0
CaCO3	-1207.0
CaO(s)	-635.5
Ca(OH)2(s)	-986.6
CaSO4(s)	-1432.7
CCl4(l)	-139.5
CH4(g)	-74.8
CHCl3(l)	-131.8
CH3OH(l)	-238.6
CO(g)	-110.5
CO2(g)	-393.5
H2O(l)	-285.8
H2O2(l)	-187.6
H2S(g)	-20.1
H2SO4(l)	-811.3
HgO(s)	-90.7
HgS(s)	-58.2
KBr(s)	-392.2
KCl(s)	-435.9
KClO3(s)	-391.4
KF(s)	-562.6
MgCl2(s)	-641.8
MgCO3(s)	-1113
MgO(s)	-601.8
Mg(OH)2(s)	-924.7
MgSO4(s)	-1278.2
MnO(s)	-384.9
MnO2(s)	-519.7
NaCl(s)	-411.0
NaF(s)	-569.0
NaOH(s)	-426.7
NH3(g)	-46.2

$C_2H_2(g)$	+226.7
$C_2H_4(g)$	+52.3
$C_2H_6(g)$	-84.7
$C_3H_8(g)$	-103.8
n-$C_4H_{10}(g)$	-124.7
n-$C_5H_{12}(l)$	-173.1
$C_2H_5OH(l)$	-277.6
$CoO(s)$	-239.3
$Cr_2O_3(s)$	-1128.4
$CuO(s)$	-155.2
$Cu_2O(s)$	-166.7
$CuS(s)$	-48.5
$CuSO_4(s)$	-769.9
$Fe_2O_3(s)$	-822.2
$Fe_3O_4(s)$	-1120.9
$HBr(g)$	-36.2
$HCl(g)$	-92.3
$HF(g)$	-268.6
$HI(g)$	+25.9
$HNO_3(l)$	-173.2
$H_2O(g)$	-241.8
$NH_4Cl(s)$	-315.4
$NH_4NO_3(s)$	-365.1
$NO(g)$	+90.4
$NO_2(g)$	+33.9
$NiO(s)$	-244.3
$PbBr_2(s)$	-277.0
$PbCl_2(s)$	-359.2
$PbO(s)$	-217.9
$PbO_2(s)$	-276.6
$Pb_3O_4(s)$	-734.7
$PCl_3(g)$	-306.4
$PCl_5(g)$	-398.9
$SiO_2(s)$	-859.4
$SnCl_2(s)$	-349.8
$SnCl_4(l)$	-545.2
$SnO(s)$	-286.2
$SnO_2(s)$	-580.7
$SO_2(g)$	-296.1
$So_3(g)$	-395.2
$ZnO(s)$	-348.0
$ZnS(s)$	-202.9

Appendix 3 :calorific value of materials [55]

Fuel	Gross Calorific value(kj/kg)
Cow dung cake	6000-8000
Wood	17000-22000
Coal	25000-33000
Petrol	45000
Methane	50000
LPG	55000
Biogas	35000-40000
Hydrogen	150000

Appendix 4: calorific value of Iraqi fuel [56]

Fuel	Gross Calorific value(kcal/kg)
Kerosene	10900
Gas oil	10800
Diesel fuel	10500
Fuel oil	10300-10500

الخلاصـــــــة:-

تضمن هذا العمل تصنيع مسعر قنبلة الحجم ثابت ، قنبلته صنّعت من معدن الألمنيوم ، لقياس القيمة الحرارية العليا للمواد الصلبة والسائلة. وقد تم اختباره على عينات من الوقود الصلب والسائل و تبين انه يعمل بشكل جيد مقارنة بالجداول القياسية مع انحرافات مقبولة . يستخدم هذا المسعر لقياس الحرارة المنبعثة من الوقود أثناء عمليات الاحتراق تحت ظروف الحجم الثابت . يتضمن هذا المسعر ايضا أجهزة قياس لقياس تغيرات درجة الحرارة والضغط.

يتكون مسعر القنبلة من الأجزاء التالية: دلو معدني مصنوع من سبائك الألومنيوم ٧١٧٥ يملأ بالماء عند اجراء الاختبارات، غرفة احتراق تغمر بالماء اثناء الفحص، مزدوج حراري لقياس التغير في درجة حرارة الماء، خلاط كهربائي لخلط الماء داخل دلو المسعر.

يعد الاستخدام التجريبي لمسعر قنبلة الحجم الثابت هو الطريقة الأكثر شيوعًا والأسهل لقياس القيمة الحرارية العالية للوقود الصلب والسائل . كمية الحرارة المنبعثة من تفاعل كيميائي أو احتراق الوقود داخل قنبلة المسعر تحت ظروف الحجم الثابت ترفع درجة الحرارة داخل تلك القنبلة لتصبح أعلى من درجة حرارة الماء المحيط.

يتسبب ذلك الفرق في درجات الحرارة في انتقال الحرارة من النظام إلى المياه المحيطة ، وتعتمد كمية التبادل الحراري على القيمة الحرارية العالية للوقود المستخدم وكميته. يتم تبادل الطاقة الحرارية بين نواتج الاحتراق داخل قنبلة المسعر والكتلة المعدنية للمسعر والماء المحيط. يُفترض أن تكون العملية ثابتة الحرارة (لا يوجد تبادل حراري مع المحيط). يتم تبادل الطاقة الحرارية بين منتج الاحتراق داخل المسعر والكتلة المعدنية للمسعر والماء المحيط. يُفترض أن تكون العملية ثابتة الحرارة (لا يوجد تبادل حراري مع المحيط).

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل / كلية الهندسة
قسم الهندسة الميكانيكية

تصنيع مسعر حراري ثابت الحجم

رسالة
مقدمة إلى كلية الهندسة – جامعة بابل كجزء من متطلبات نيل درجة الدبلوم العالي

في الهندسة/الهندسة الميكانيكية/وقود وطاقة

أعدت من قبل

حسن حامد علي كاظم

(بكالوريوس علوم في الهندسة الميكانيكية٢٠٠١)

بأشراف

الدكتور دريد فتحي مكي

٢٠٢١ م ***١٤٤١ هـ***