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Study of Gasoline Combustion

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Dedication

أهدي نجاحي هذا إلى من وضع المولى –سبحانه وتعالى-الجنة تحت قدميها ووقرها في كتابه العزيز أمي الحبيبة، وإلى ذلك الرجل العظيم الذي أفخر أن أكون من صلبه الذي جاهد وناضل لأجلنا أبي العزيز والى أحبائي ومهجة قلبي إخوتي الأعزاء، وإلى أصدقائي الذين فارقونا جسداً وبقيت ذكراهم العطرة في قلوبنا، أصدقائي الشهداء: الدكتورعبد الرحمن أبو شمالة، الدكتور عبد الحميد سلامة والمهندس أمجد محارب وإلى كل شهداء فلسطين.

وإلى كل من ساندني لأنجاز هذا العمل من أصدقائي: مهند بحر، يوسف الحايك، حمزة عيسى ونور أبودقة

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List of Abbreviations

$Va = $ Stoichiometric volume of air $\left[\frac{Nm^3}{Nm^3}\right]$

$Va'' = $ actual volume of air $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{CO_2} = $ Volume of carbon dioxide in flue gas $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{SO_2} = $ Volume of sulphur dioxide in flue gas $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{H_2O} = $ Volume of water vapour from combustion hydrogen $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{O_2} = $ Volume de l'oxygène $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{N_2} = $ Volume of nitrogen in flue gas $\left[\frac{Nm^3}{Nm^3}\right]$

$V_W = $ Volume of humidity $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{fg} = $ Total stoichiometric volume of dry flue gas $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{fg\ wet} = $ Total stoichiometric volume of wet flue gas $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{fg}'' = $ Total actual volume of dry flue gas $\left[\frac{Nm^3}{Nm^3}\right]$

$V_{fg\ wet}'' = $ Total actual volume of wet flue gas $\left[\frac{Nm^3}{Nm^3}\right]$

AF =Air Fuel Ratio $\left[\frac{Kg_{air}}{Kg_{fule}}\right]$

$\mathcal{H}_{prod} = $ The enthalpy of products(KJ)

$\mathcal{H}_{react} = $ The enthalpy of reactants(KJ)

$T_{adi} = $ adiabatic temperature(K)

e= excess air (%)

Ψ =The amount of oxygen in the oxidizer (%)

$\gamma CO_2 = $ Carbon dioxide content(%)

$\lambda = $ Air ratio

Abstract

This research explores the properties of gasoline and its combustion process, focusing on how different air-fuel ratios affect performance and emissions.The aim of this research is to understand how gasoline behaves during combustion and how changing the air-to-fuel ratio impacts efficiency and environmental effects.To conduct this study, we examined combustion reactions with varying amounts of added air each time.The results of this study showed that as the air ratio in the combustion process increased, the values of V_{fg}'' and Va" increased while the values of T_{adi} and the carbon dioxide ratio decreased.From the previous results, we conclude that adjusting the amount of air in the combustion process improves efficiency and reduces harmful emissions. Using gasoline with an optimal air-fuel ratio can provide efficient energy while reducing emissions, making it a cleaner option for modern engines.

Keywords: Gasoline, Combustion, Air-Fuel Ratio

Résumé

Cette recherche explore les propriétés de l'essence et son processus de combustion, en se concentrant sur la façon dont différents rapports air-carburant affectent les performances et les émissions.L'objectif de cette recherche est de comprendre comment l'essence se comporte lors de la combustion et comment le changement du rapport air-carburant impacte l'efficacité et les effets environnementaux.Pour mener cette étude, nous avons examiné les réactions de combustion avec des quantités d'air ajoutées différentes à chaque fois.Les résultats de cette étude ont montré qu'à mesure que le rapport d'air dans le processus de combustion augmentait, les valeurs de $\mathbf{V_{fg}}''$ et **Va"** augmentaient tandis que les valeurs de $\mathbf{T_{adi}}$et le taux de dioxyde de carbone diminuaient.Des résultats précédents, nous concluons que l'ajustement de la quantité d'air dans le processus de combustion améliore l'efficacité et réduit les émissions nocives. En utilisant de l'essence avec un rapport air-carburant optimal, il est possible de fournir une énergie efficace tout en réduisant les émissions, ce qui en fait une option plus propre pour les moteurs modernes.

Mots-clés : Essence, Combustion, Rapport Air-Carburant

ملخص

يستكشف هذا البحث خصائص البنزين وعملية احتراقه، مع التركيز على كيفية تأثير نسب الهواء والوقود المختلفة على الأداء والانبعاثات.يهدف هذا البحث الى فهم كيفية تصرف البنزين أثناء الاحتراق وكيف يؤثر تغيير نسبة الهواء إلى الوقود على الكفاءة والأثر البيئي ولإجراء هذه الدراسة قمنا بدراسة تفاعلات الاحتراق مع تغير نسبة الهواء المضاف في كل مرة. أظهرت نتائج هذه الدراسة انه كلما زادت نسبة الهواء في عملية الاحتراق، زادت قيم"$\mathbf{Va}$ و"$\mathbf{V_{fg}}$ و تناقصت قيم $\mathbf{T_{adi}}$و نسبة تاني أكسد الكربون.ونستنتج من النتائج السابقة أن تعديل كمية الهواء في عملية الاحتراق يحسن الكفاءة ويقلل الانبعاثات الضارة ،وعند استخدام البنزين مع نسبة هواء-وقود مثالية، يمكن توفير طاقة فعّالة مع تقليل الانبعاثات، مما يجعله خيارًا أنظف للمحركات الحديثة.

الكلمات المفتاحية :البنزين، الاحتراق، نسبة الهواء-الوقود

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General Introduction

Across the globe, hundreds of millions of people today use gasoline, also known as petrol, and rely on it for numerous purposes: in transportation, industry, agriculture, power generation, and more. However, few are aware of how gasoline is produced, where it comes from, and which countries consume it the most. Gasoline, or petrol, is a liquid fuel primarily derived from the refining of crude oil. It is a mixture of hydrocarbons, including octane (C_8H_{18}), and constitutes about 19% of the crude oil processed. Gasoline is crucial for the functioning of internal combustion engines in cars, motorcycles, and various other vehicles.

Compared to other fuels, gasoline has several advantages. Its use can result in:

-A significant reduction in the emissions of nitrogen oxides,

-Lower emissions of carbon monoxide,

-Reduction in hydrocarbons and particulate matter, especially when modern emission control technologies are employed.

Combustion, from the Latin *combustion* (burning), is an exothermic chemical reaction, specifically the oxidation of a fuel, that releases energy which can be harnessed for various purposes. This rapid reaction involves radicals and is a widely used technology. It is employed in power generation, land, sea, and air transportation, propulsion, heating, material processing, and other technologies. Combustion occurs in industry through test boilers, foundries, furnaces, incinerators, engines, and domestic stoves, in both mobile and stationary applications.

In this study, we aim in this research is to understand how gasoline behaves during combustion and how changing the air-to-fuel ratio impacts efficiency and environmental effects. To achieve this goal, our work is divided into three chapters:

1 .The first chapter presents a bibliographical review on gasoline.

2 .The second chapter provides a summary of combustion principles.

3 .The third chapter focuses primarily on the influence of excess air on various combustion parameters, followed by a general conclusion summarizing the key results.

CHAPTER ONE: LITERATURE REVIEW

1.1 Introduction

Petroleum is a naturally occurring, thick liquid that is mostly made up of hydrocarbons with trace amounts of other substances. [1] Although there are many and varied uses for petroleum, crude oil cannot be utilized directly as fuel. The bulk of this petroleum is refined into other petroleum fractions, including diesel and naphtha, which are used to make vehicle gasoline. Chemicals known as fuels are compounds that, when burned in the presence of air, allow continuous combustion engines (such gas turbines and aircraft reactors) or thermal engines with pistons to work. It is important to differentiate between the term’s "fuel" and "combustible," as the latter is reserved for goods used to provide heat energy in furnaces, boilers, and power plants. [2]

Gasoline is a compound made to a specific configuration that has no environmentally organic analogue, on the contrary, the gaseous as well as liquid counterparts of in gasoline are the ones which are mostly encountered in the various physical states (gaseous, liquid, others) within human settlements. The making of gasoline is dating back to oil refining.[3]

1.2 State of the Art

Lei Feng, Xingyu Sun, Xiaoyan Pan, Wentao Yi, Yanqing Cui, Yu Wang, Mingsheng Wen, Zhenyang Ming, Haifeng Liu and Mingfa Yao in (30 /May /2021): The study used laser-induced exciplex fluorescence (LIEF) to compare liquid and vapor phases of gasoline and diesel sprays in a constant volume vessel. It explored the effects of injection and ambient pressure on gasoline sprays during evaporation. Findings indicated stable liquid penetration but increasing vapor penetration with fuel injection. Spray volume and entrained gas mass increased proportionally with injected fuel mass. Gasoline sprays had shorter liquid penetration than diesel sprays, but similar vapor penetration. High equivalence ratios suggested efficient combustion potential. Increasing ambient pressure reduced penetration and spray volume while increasing entrained gas mass. Higher injection pressure stabilized liquid penetration but reduced vapor penetration, spray volume, and entrained gas mass, while increasing equivalence ratio. [4]

Zhanming Chen, Tiancong Zhang, Xiaochen Wang, Hao Chen, Limin Geng and Teng Zhang in (21/July/2021): A study compared the performance of a dual-fuel engine using natural gas/methanol and natural gas/gasoline blends. Tests were conducted at 1600 rpm and 0.387 MPa brake mean effective pressure, varying the Energy Substitution Ratio (ESR) at four levels. Results showed that adding methanol or gasoline accelerated natural gas combustion, increasing peak cylinder pressure and maximum heat release rate. The crank angle of peak cylinder pressure and maximum heat release rate advanced after enrichment with either fuel. With a spark timing of 25° Crank Angle Before Top Dead Center, increasing (ESR) from 0% to 44% improved brake thermal efficiency to 28.1% for the natural gas/methanol blend but decreased to 25.5% for the natural gas/gasoline blend. Methanol reduced total hydrocarbon and carbon monoxide emissions, while gasoline increased them. [5]

Van Thanh Ngo and Truong Giang Nguyen in (12 /January /2022):In this study, conventional gasoline with a Research Octane Number of 95 and a gasoline–ethanol blend (20% ethanol by volume [E20]) were experimentally compared in terms of combustion characteristics and performance. First, the Start of the 2nd Injection was investigated to study combustion characteristics while maintaining the dilution level at 25%. In this part, two fuels with high octane numbers were used to investigate the influence of ethanol on combustion characteristics under Gasoline Compression Ignition mode. The in-cylinder pressure and Heat Release Rate (HRR) indicated that fueling the engine with E20 leads to the maximum peak pressure and an easier position of maximum HRR in comparison with pure gasoline in all cases of the second injection. The main HRR curve of E20 moves closer to the Top Dead Center compared with that of gasoline. This HRR behavior indicates that the overall HRR of E20 is more compact than that of gasoline. Second, the Start of the 2nd Injection was fixed at two cases of -6 and -3 Crank Angle Degrees After Top Dead Center. Charge dilution and boosted pressure were investigated to study the sensitivity of dilution on combustion characteristics with the gasoline–ethanol blend fuel. The in-cylinder pressure and HRR indicated a two-stage combustion phenomenon for a low dilution. [6]

Melih YıldızandBilge Albayrak Çeper in (9/May/2022): Low temperature combustion concepts in internal combustion engines, like reactivity-controlled compression ignition (RCCI), and exhaust gas recirculation (EGR) in diesel-compression ignition (CI) engines, are effective ways to reduce nitrogen oxides and particulate emissions without increasing fuel consumption. This study compared high-EGR CI fuelled with diesel and gasoline/diesel fuelled RCCI modes in terms of combustion, performance, and emissions. Results showed RCCI's potential for wider operating ranges and better smoke emissions. Nitrogen oxide emissions were significantly lower with RCCI at higher engine speeds, although they increased with higher premixed ratios at lower speeds. Reactivity controlled compression ignition combustion also showed slightly higher brake thermal efficiencies compared to high-EGR CI. [7]

Rıdvan Küçükosman, Hüseyin Değirmenci, AhmetAlper Yontar, Kasim Ocakoglu in (5 /June/ 2023): The study investigates the combustion characteristics of gasoline-based fuel droplets containing boron-based particles, essential for a carbon-neutral energy future. Various particle compositions were tested, showing reduced ignition delay times and enhanced flame temperatures, particularly with amorphous boron particles. Aluminum Diboride AlB12 particles exhibited the shortest extinction time, while Magnesium Diboride MgB12 showed promise in electric field tests. The addition of amorphous boron particles notably increased flame speed by 4.6%. Regression plots demonstrated droplet size reduction following the D2-law. Overall, the findings suggest that low-cost boron derivatives hold significant potential as energy carriers for liquid hydrocarbon fuels.[8]

Patrickc. O'Donnell, Benjamin Lawler, Dario LopezPintor, Aimilios Sofianopoulos in (15/June/2023): The study investigates Low Temperature Gasoline Combustion (LTGC) for reducing emissions in gasoline engines. It utilizes single direct injection (S-DI) to achieve fuel stratification, focusing on injection pressure, start of injection timing, and intake valve closing temperature effects. Through three-dimensional computational fluid dynamics (3D-CFD), experiments on a medium-duty engine at low loads reveal performance and emissions tradeoffs. Increasing injection pressure and delaying start of injection timing influence combustion efficiency and emissions. The research emphasizes the importance of optimizing injection parameters for LTGC and suggests avenues for further improvement.[9]

Hao Zhou, Shuo Meng and Zhiyu Han in (20/June/2023): The study analysed combustion and misfire in a turbocharged direct-injection gasoline engine with a pre-chamber using multi-dimensional modelling. Key findings: pre-chamber jets post-spark ignition led to multiple ignition spots, enhancing combustion efficiency. Momentum of these jets influenced combustion timing; increasing momentum improved combustion efficiency. Flame quenching occurred under low-load conditions due to factors like lower pressure and temperature, leaner fuel mixture, weaker turbulence, and wall heat losses. Mitigation strategies included heat-insulated pre-chamber, improved air-fuel mixing, and advanced spark timing. Understanding and implementing these strategies can enhance engine performance and thermal efficiency. [10]

Sam Joe Chintagunti, Avinash Kumar Agarwal in (27/December/2023):The study examines the effects of fuel injection pressure and quantity on low-octane gasoline sprays in a simulated high-pressure environment relevant to Gasoline Compression Ignition (GCI) engines. Using diesel-gasoline blends, it analyses spray characteristics such as penetration length, cone angles, and droplet velocity. Results show that gasoline-diesel blends exhibit shorter penetration lengths but higher cone angles and entrained air mass compared to baseline diesel. Additionally, they demonstrate superior mixture formation, with smaller droplet sizes and higher velocities, indicating potential for reduced emissions and enhanced combustion efficiency in GCI engines. [11]

1.3 Overview of Gasoline

1.3.1 Definition of Gasoline

Gasoline is a flammable liquid which is brought about as the result of distillation of petroleum and is the form of fuel that us used in internal combustion (ICS) engines. It is not just that; more than that, it serves as fuel for spark-ignition engines blended molten hydrocarbons that can also be containing fuel additives.[12] The average empirical formula for gasoline can be approximated based on its typical composition of hydrocarbons. While gasoline is a complex mixture, an often-used empirical formula to represent its composition isC_8H_{18}, which corresponds to octane, a major component. [13]

1.3.2 Characteristics of Gasoline

Octane Rating:

The octane rating stands as a critical parameter determining the quality of gasoline. Its optimal utilization conditions are intricately tied to the thermodynamic efficiency of the engine, an efficiency that ascends with an increasing compression ratio. Nevertheless, this efficiency encounters a threshold, beyond which an undesirable knocking phenomenon, commonly referred to as "knock" emerges.

This rating serves to characterize the anti-knock properties inherent in gasoline. The determination of the octane rating is carried out utilizing a single-cylinder test engine (CFR), where the benchmark fuel consists of a blend of isooctane and n-heptane.

- Isooctane (2,2,4-trimethylpentane): Exhibits non-detonating characteristics with an assigned NO value of 100.
- N-heptane: Displays highly detonating properties with an assigned NO value of 0.

The perfect gasoline should undergo combustion smoothly without any detonation, and it should contain iso-paraffins and olefins in the lighter portion, along with aromatics in the heavier part. To enhance the octane rating, anti-knock agents, like tetraethyl lead, were traditionally employed. However, the use of tetraethyl lead in automotive fuels is now prohibited worldwide, although it is still utilized in specific aviation fuels.

Density: Density is the ratio of the weight of a certain volume of a sample at a temperature of T°C to the weight of the same volume of water at a standard temperature.

It characterizes, to some extent, the power of the engine and fuel consumption. If density decreases, the specific consumption increases inversely. For premium gasoline, a density of 770 kg/m³ is considered, and for regular gasoline, it is 730 kg/m³. Beyond these limits, the power decreases.

Vapor Pressure:

Vapor pressure is an indicator of gasoline volatility and, consequently, the presence of light components. While these elements facilitate winter starting, there is a risk of vapor lock formation in summer, leading to engine shutdown.

- In summer, Vapor Pressure (TVR) =0.650 kg/cm²
- in winter, Vapor Pressure (TVR) =0.800 kg/cm²

Vapor pressure directly affects the occurrence of leaks and losses during storage.

ASTM distillation:

The ASTM distillation is a laboratory process to obtain the ASTM distillation curve of gasoline, indicating distillation points at different temperatures. This curve provides insights into the gasoline composition, influencing engine performance, including cold starts, oil dilution, and cylinder wear, Various distillation points, such as

- Point 10% distilled (50-70°C): Critical for cold starts, ensuring effective vaporization.
- Point 50% distilled (100-140°C): Crucial for achieving optimal combustion.
- Point 95% distilled (<195°C) with specific criteria: Essential to prevent problems like vapor lock or incomplete combustion.

ASTM distillation assesses gasoline quality, ensuring optimal engine performance while avoiding complications related to vaporization and combustion. [14]

1.3.3 Origin of gasoline

1. Simple Distillation: “Straight-run" gasoline was initially produced by simple distillation of crude oil without the use of chemical conversion processes.

2. Natural Gas Utilization: Around 1912, hydrocarbons for gasoline were extracted from "wet" natural gas to meet the growing demand.

3. Refining Operations: Oil refineries have evolved to develop multiple operations contributing to gasoline production. These include direct crude oil distillation, catalytic and thermal cracking, hydrocracking, catalytic reforming, alkylation, and polymerization.

4. Modern Refining: Modern refining starts with the simple distillation of crude oil to obtain various fractions. This involves refining light and heavy naphtha, kerosene, light and heavy gas oil, and reduced crude.

5. Cracking Operations: The use of cracking operations to produce gasoline began in 1913.Catalytic and thermal cracking break down high-boiling hydrocarbons into lower-boiling ones.

6. Hydrocracking: Hydrocracking operations allow for flexible production to meet seasonal demand changes and effectively process challenging feedstocks.

2 CHAPTER TWO: GENERAL INFORMATION ON COMBUSTION

2.1 Introduction

Combustion is a chemical process where fuel reacts with an oxidizer to produce heat, light, and often carbon dioxide and water. It relies on the presence of oxygen to react with combustible materials and is utilized in various contexts such as power generation, vehicle propulsion, heating, and industrial processes. Combustion involves stages of heating the fuel, ignition, and formation of final products like carbon dioxide, water, and ash. Requirements and conditions vary depending on fuel types, oxidizers, and operating conditions like temperature and pressure. It's a fundamental process in energy generation and industry, but careful management is necessary for environmental and safety reasons.

This chapter begins by discussing the concept of combustion, its components such as combustibles, hydrocarbons, and oxidizers. Then it addresses types of combustion, the principle of conservation of mass in this process. Then, the focus is on theoretical combustion, theoretical air, volume of dry flue gas, and volume of wet flue gas and the chapter reviews combustion with excess air, incomplete combustion, and adiabatic flame temperature at the end.

2.2 Definition of Combustion

A combustion reaction is a chemical reaction that releases heat, energy, and light (in the form of a flame) between substances, typically involving oxygen gas.

The resulting products of a combustion reaction vary depending on the substance being combusted. For instance, when metals and nonmetals burn in the presence of oxygen, they produce their respective oxides. Conversely, hydrocarbons produce carbon dioxide and water when they undergo combustion.

- Hydrocarbon + Oxygen ⇢ (CO_2) + (H_2O) + Thermal energy. [15]

2.3 Definition of Combustibles

Combustible substances, also known as flammable materials they predominantly consist of hydrocarbons, combinations of carbon and hydrogen, and undergo combustion burn in the presence of air producing heat and light energy. These substances have the ability to burn, ignite, making it crucial to handle them with care to prevent accidents. Examples include petrol, kerosene, wood, charcoal, diesel, and various others. [16]

2.4 Definition of Hydrocarbon

A hydrocarbon is a compound consisting exclusively of carbon and hydrogen atoms. Hydrocarbons serve as the main component of fossil fuels, such as natural gas, petroleum, and coal. These substances are utilized as fuel due to their ability to release vast amounts of energy upon combustion. Given that various hydrocarbons possess distinct hydrogen-to-carbon ratios, they yield differing proportions of water to carbon dioxide when burned. [15]

2.5 Definition of Oxidizers

An oxidation-reduction (redox) reaction is a chemical reaction where there's an exchange of electrons between two substances. It occurs when the oxidation number of a molecule, atom, or ion change as it gains or loses electrons. Redox reactions are widespread and essential for fundamental life processes, like photosynthesis, respiration, combustion, and corrosion (rusting). [17]

2.6 Types of Combustion

A combustion reaction is classified primarily into three types based on the process and products formed. These types are:

- Rapid Combustion: This type of combustion involves the swift burning of a gas, generating heat and light. An example is phosphorus, which burns in air at room temperature.
- Spontaneous Combustion: Spontaneous combustion occurs when a substance unexpectedly bursts into flames without an apparent external cause.
- Explosion: An explosion is a rapid reaction that releases heat, light, and sound, often accompanied by the production of a significant volume of gas. This phenomenon can be observed, for instance, in the detonation of firecrackers. [16]

2.7 Conservation of Mass

In combustion reactions, the total mass of the products must be equal to the total mass of the reactants, and also, the total mass of each chemical element is preserved during the process. Dry air composition can be approximated as 21% of O_2 and 79% of N_2. Thus, for each kilomole of O_2 introduced into the furnace, there corresponds 3.76 kilomoles of N_2.

The balanced chemical equation for the reaction of carbon with dry air to form carbon dioxide and nitrogen is:

$$C + O_2 + 3.76N_2 \rightarrow CO_2 + 3.76N_2 \qquad (1)$$

on a molar basis, as follows:

$$\mathbf{1Kmol\ C + 1Kmol\ O_2 + 3.76Kmol\ N_2 \rightarrow 1Kmol\ CO_2 + 3.76Kmol\ N_2} \quad (2)$$

the volume occupied by one kilomole of ideal gas is 22.41$\left[\frac{Nm^3}{Kmol}\right]$.. Since the mass of each element is given by its molecular mass, and all ideal gases occupy equal volumes per kilomole at the same pressure and temperature, Equation (2) can also be expressed as:

$$\mathbf{12kg\ C + 22.41\ O_2 + 3.76 * 22.41N_2 \rightarrow 22.41\ CO_2 + 3.76 * 22.41N_2}$$

$$\mathbf{1kg\ C + \frac{22.41}{12}O_2 + 3.76 * \frac{22.41}{12}N_2 \rightarrow \frac{22.41}{12}CO_2 + 3.76 * \frac{22.41}{12}N_2}$$

Here, C and O_2 are the reactants as they exist before combustion, and CO_2 is the product since it exists after combustion. However, N_2 appears both as a reactant and as a product, but it does not chemically react in the combustion chamber; it acts as an inert gas. Chemical equations are balanced based on the conservation of mass principle: The total mass of each element is conserved during a chemical reaction, but the total number of moles is not conserved during a chemical reaction.

Hydrogen combustion: $\mathbf{H_2 + \frac{1}{2}O_2 + \frac{3.76}{2}N_2 \rightarrow H_2O + \frac{3.76}{2}N_2}$

$$\mathbf{1Kmol\ H_2 + \frac{1}{2}Kmol\ O_2 + \frac{3.76}{2}Kmol\ N_2 \rightarrow 1Kmol\ H_2O + \frac{3.76}{2}Kmol\ N_2}$$

$$\mathbf{2kg\ H_2 + \frac{22.41}{2}O_2 + \frac{22.41}{2} * 3.76N_2 \rightarrow 22.41\ H_2O + \frac{22.41}{2} * 3.76\ N_2}$$

$$\mathbf{1kg\ H_2 + \frac{22.41}{4}O_2 + \frac{22.41}{4} * 3.76N_2 \rightarrow \frac{22.41}{2}\ H_2O + \frac{22.41}{4} * 3.76\ N_2}$$

Sulphur Combustion: $\mathbf{S + O_2 + 3.76N_2 \rightarrow SO_2 + 3.76N_2}$

$$\mathbf{1Kmol\ S + 1Kmol\ O_2 + 3.76Kmol\ N_2 \rightarrow 1Kmol\ SO_2 + 3.76Kmol\ N_2}$$

$$\mathbf{12kg\ S + 22.41\ O_2 + 3.76 * 22.41N_2 \rightarrow 22.41\ SO_2 + 3.76 * 22.41N_2}$$

$$\mathbf{1kg\ S + \frac{22.41}{32}O_2 + 3.76 * \frac{22.41}{32}N_2 \rightarrow \frac{22.41}{32}SO_2 + 3.76 * \frac{22.41}{32}N_2} \quad [18]$$

2.8 Definition of Theoretical Combustion (Stoichiometric Combustion)

Stoichiometric or theoretical combustion: This describes the ideal combustion process in which a fuel is completely burned with the minimum quantity of air (i.e., theoretical air). In theoretical combustion, there is no excess air or fuel, and all the reactants combine in the precise ratio dictated by the stoichiometry of the chemical reaction. [18]

2.8.1 Definition of Stoichiometric or Theoretical Air

Theoretical or stoichiometric air is the minimum amount of air required for complete fuel combustion, resulting in no uncombine oxygen or combustible elements like soot or carbon particles, especially for solid fuel. Excess combustion happens when too much air is supplied the quantity of air can be expressed in weight or in volume.

$$V_{O_2} = \frac{22.4}{100}\left(\frac{C}{12} + \frac{H}{4} + \frac{S}{32} - \frac{O}{32}\right)$$

$$Va = \frac{V_{O_2}}{0.21}$$

$$Va = \frac{1}{\Psi}\left(V_{CO_2} + V_{SO_2} + \frac{V_{H_2O}}{2} - V_{O_2}\right)$$

Ψ: represents the concentration of oxygen in the air (for example, 0.21 for air and 1 for oxygen).

There are two methods for calculating V_{CO_2}, V_{SO_2} , V_{H_2O} , V_{O_2}, V_{N_2} and V_W volumes:

1. **For solid and liquid fuels:**

$$V_{CO_2} = c \times \frac{22.4}{12}$$

$$V_{SO_2} = s \times \frac{22.4}{32}$$

$$V_{H_2O} = h \times \frac{22.4}{2}$$

$$V_{O_2} = o \times \frac{22.4}{32}$$

$$V_{N_2} = n \times \frac{22.4}{28}$$

$$V_W = w \times \frac{22.4}{18}$$

2. **For gaseous Fuels, the volume is Calculated as Follows**

V_{CO_2}= the sum of (number of Carbon molecules multiplied by the percentage of the gas that contains carbon out of a hundred) $\left[\frac{Nm^3}{Nm^3}\right]$.

V_{SO_2}= the sum of (number of sulphur molecules multiplied by the percentage of sulphur gas in a hundred) $\left[\frac{Nm^3}{Nm^3}\right]$.

V_{H_2O}= the sum of (number of hydrogen molecules out of two multiplied by the percentage of the gas that contains hydrogen in a hundred)$\left[\frac{Nm^3}{Nm^3}\right]$.

V_{O_2}= the sum of (number of oxygen molecules out of two multiplied by the percentage of the gas that contains oxygen out of a hundred) $\left[\frac{Nm^3}{Nm^3}\right]$.

V_{N_2}= the sum of (number of nitrogen molecules out of two multiplied by the percentage of the gas containing nitrogen out of a hundred)$\left[\frac{Nm^3}{Nm^3}\right]$. [18]

2.8.2 Total Stoichiometric Volume of Dry Flue Gas

We sum up the volume of the different gases present in the smoke, excluding water vapor**.**

$$V_{fg} = V_{CO_2} + V_{SO_2} + V_{N_2} + (1 - \Psi)Va$$

The presence of nitrogen in combustion air impacts efficiency, reducing flame temperature and increasing heat loss. Nitrogen, introduced into the combustion chamber in large quantities and low temperatures, exits at higher temperatures. It accounts for 79% of flue gas nitrogen originating from both fuel and combustion air.[19]

2.8.3 Total Stoichiometric Volume of Wet Flue Gas

Water vapor originates from combustion: $V_{H_2O}$and from fuel moisture: V_W, which represents the volume of water vapor produced by the moisture content in the fuel. [19]

$$V_{fg\,wet} = V_{fg} + V_{H_2O} + V_W$$

2.9 Real Combustion

2.9.1 Definition of Combustion with Excess Air

The practice of using more air than the stoichiometric quantity in combustion processes to enhance the chances of complete combustion or to control the temperature of the combustion chamber.

$$\lambda = \frac{Va''}{Va}$$

$$Va'' = \lambda * Va = (1+e)\,Va$$

$$V_{fg}'' = V_{fg} + e * Va$$

$$V_{fg\,wet}'' = V_{fg\,wet} + e * Va$$

λ= Air ratio **e=** Excess air

λ> 1, indicates excess air combustion and the products may contain CO_2, SO_2, H_2O, N_2 and O_2.[18]

2.9.2 Definition of Incomplete Combustion

When the combustion process fails to consume all available fuel or when oxygen is insufficient, it is termed incomplete combustion. It can occur due to inadequate oxygen supply, poor mixing of fuel and air, or inefficient combustion conditions. There are two types:

- Mechanically Incomplete Combustion: Characterized by the presence of unburned elements like carbon (C) in combustion gases.
- Chemically Incomplete Combustion: Marked by the presence of combustible gases like carbon monoxide (CO) in flue gases.

Incomplete combustion can lead to lower efficiency, increased emissions, and the formation of pollutants like CO and soot. Proper air-fuel ratio control and combustion optimization are crucial to minimize incomplete combustion and ensure cleaner and more efficient combustion processes.

$\boldsymbol{\lambda} < 1$, indicates incomplete combustion and the products may contain CO, CO_2, SO_2, H_2O and N_2.[18]

2.10 Definition of Adiabatic Flame Temperature

The maximum temperature reached by combustion products when the combustion chamber is insulated, preventing heat loss. It's crucial for designing combustion chambers, gas turbines, and nozzles, as it determines material limits. The maximum temperature can be regulated by adjusting the quantity of excess air, which acts as a coolant. The adiabatic flame temperature of a steady-flow combustion process is determined by conducting an energy balance, specifically when there is no heat exchange (Q = 0).

$$\boldsymbol{\mathcal{H}_{prod} = \mathcal{H}_{react}}$$

$$\sum \boldsymbol{N_P(\overline{h_f^o} + \overline{h} - \overline{h^o})_p} = \sum \boldsymbol{N_r(\overline{h_f^o} + \overline{h} - \overline{h^o})_r}$$

The determination of the adiabatic flame temperature requires the use of an iterative technique such as the one described below:

(T_{adi}) adiabatic temperature.

(T_{ref})is a reference temperature, typically chosen to be a specific temperature such as 25 degrees Celsius (298.15 Kelvin) or any other value considered appropriate for the specific application. T_{ref} is used as a reference point for measuring temperature differences and for calculating changes in temperature during chemical reactions.

Step 1: Calculate the H_{react} based on known values of T_{react} and T_{ref}.

Step 2: Calculate the H_{prod}based on the guessed value of $T_{adi}$and T_{ref}.

Step 3: Repeat Step 2, until $H_{react} = H_{prod}$.

The adiabatic flame temperature of a fuel is not unique; its value depends on:

1) The state of the reactants

2) The degree of completion of the reaction

3) The amount of air used.

Note that the adiabatic flame temperature attains its maximum value when complete Combustion occurs with the theoretical amount of air (0% excess air). [20]

2.11 Air Fuel Ratio

It is expressed on a mass basis and defined as:

$$\boldsymbol{AF = \frac{m_{air}}{m_{fuel}} = \frac{N_{air}*(M_{air})}{N_{fuel}*(M_{fuel})}} \qquad \boldsymbol{M_{air} = 28.97 \approx 29\ \frac{Kg}{Kmol}}$$

Where N is the number of moles and M is the molar mass. [20]

3 CHAPTER THREE: RESULTS AND DISCUSSIONS

3.1 Introduction

Understanding and analysing stoichiometric combustion processes is crucial in various applications of chemical and mechanical engineering. These processes rely on the chemical reaction between fuel and an oxidizer (typically oxygen in air) to achieve complete combustion, producing the heat and energy required to power engines and various thermal systems.

In this chapiter, we outline the fundamental calculations for stoichiometric combustion using as a model. The calculations include estimating the air-fuel ratio necessary for complete combustion, the stoichiometric volume of air, and the volume of dry exhaust gas. We also examine the impact of excess air on the volume of the resulting gases and the carbon dioxide content in the exhaust gases. Finally, we analyse the relationship between the excess air ratio and the adiabatic flame temperature produced by combustion, which is a critical indicator of thermal system efficiency.

These calculations aim to provide a scientific basis for improving the efficiency of combustion systems and reducing environmental impact by precisely adjusting the fuel-to-air ratio. This analysis plays a crucial role in the design and operation of combustion systems in various industries, including automobiles, boilers, and generators, where achieving complete combustion is essential for minimizing harmful emissions and enhancing energy utilization.

3.2 Stoichiometric Combustion Calculations

3.2.1 Calculation of Air Fuel Ratio :

e=0%

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{N_{air} * (M_{air})}{N_{fuel} * (M_{fuel})}$$

$$AF = \frac{12.5(1 + 3.76) * 28.97}{114.231} = 15.08 \frac{Kg_{air}}{Kg_{fule}}$$

3.2.2 Calculation of Stoichiometric Volume of Air:

$$Va = \frac{AF}{\rho_{air}} \qquad \rho_{air} = 1.2 \frac{Kg}{m^3_{air}}$$

$$Va = Va" = \frac{15.08}{1.2} = 12.57 \frac{m^3_{air}}{Kg_{fule}}$$

3.2.3 Calculation of Total Stoichiometric Volume of Dry Flue Gas:

$$V_{fg} = V_{CO_2} + V_{SO_2} + V_{N_2} + (1 - \Psi)Va$$

$$V_{CO_2} = c \times \frac{22.4}{12} = \frac{8 * 12}{114.231} \times \frac{22.4}{12} = 1.56$$

$$V_{fg} = 1.56 + 0 + 0 + (1 - 0.21)12.57 = 11.5 \frac{m^3_{air}}{Kg_{fule}}$$

3.2.4 Calculation of the Percentage of Carbon Dioxide:

$$\boldsymbol{\gamma} CO_2 = \frac{V_{CO_2}}{V_{fg}} = \frac{1.56}{11.5} = 13.63\%$$

3.3 Combustion Processes with Excess Air Calculations

e=10%

$$AF = \frac{m_{air} + (\mathrm{m}_{air} * e)}{m_{fuel}}$$

$$AF = \frac{1723.71 + 1723.71 * 0.1}{114.231} = 16.59 \frac{Kg_{air}}{Kg_{fule}}$$

3.3.1 Calculation of Actual Volume of Air:

$$Va" = \frac{AF}{\rho_{air}} \qquad \rho_{air} = 1.2 \frac{Kg}{m^3_{air}}$$

$$Va" = \frac{16.59}{1.2} = 13.83 \frac{m^3_{air}}{Kg_{fule}}$$

3.3.2 Calculation of Total Actual volume of Dry Flue Gas:

$$V_{fg}" = V_{fg} + e * Va$$

$$V_{fg}" = 11.5 + (0.1 * 12.57) = 12.76 \frac{m^3_{air}}{Kg_{fule}}$$

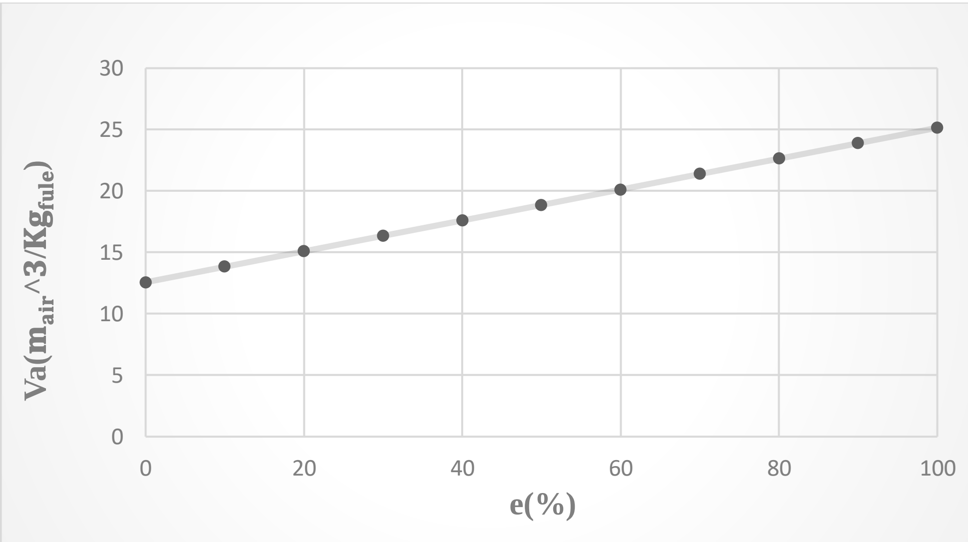
$$\boldsymbol{\gamma} CO_2 = \frac{V_{CO_2}}{V_{\mathrm{fg}}"} = \frac{1.56}{12.76} = 12.29\%$$

Table 1: Percentage Calculations

$e(\%)$	0	10	20	30	40	50	60	70	80	90	100
$Va" \frac{m^3_{air}}{Kg_{fule}}$	12.57	13.83	15.09	16.35	17.6	18.86	20.12	21.38	22.63	23.89	25.15
$V_{fg}" \frac{m^3_{air}}{Kg_{fule}}$	11.5	12.76	14.01	15.27	16.53	17.79	19.04	20.3	21.56	22.81	24.07
$\gamma CO_2(\%)$	13.63	12.29	11.19	10.27	9.487	8.816	8.234	7.725	7.274	6.873	6.514

Table 2: Actual Volume as a Function of Excess Air

$e(\%)$	0	10	20	30	40	50	60	70	80	90	100
$Va" \frac{m^3_{air}}{Kg_{fule}}$	12.57	13.83	15.09	16.35	17.6	18.86	20.12	21.38	22.63	23.89	25.15

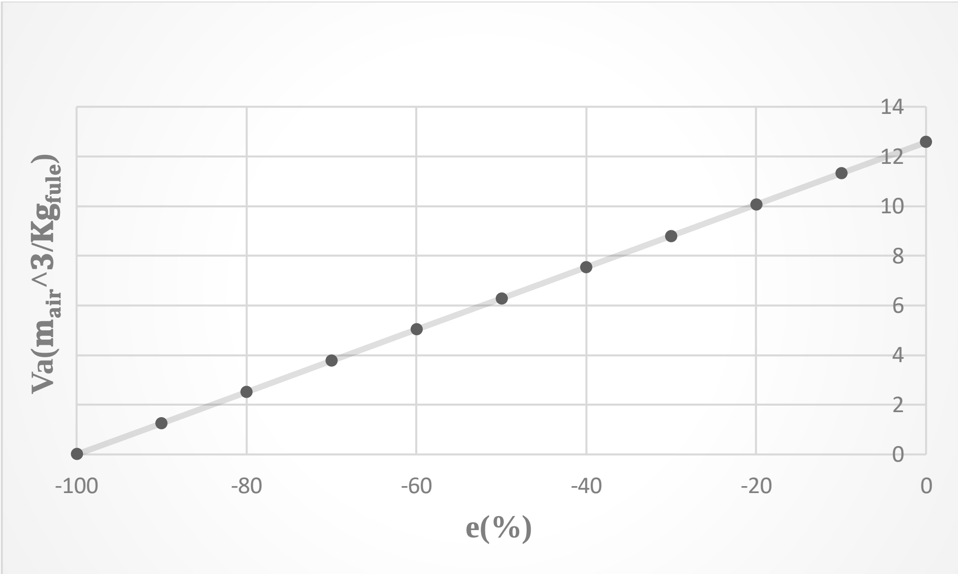


Graph 1: The Influence of Excess Air on Actual Volume

Commentary: The graph shows the relationship between the excess air percentage **(e)** and the actual volume of combustion gases **($Va"$)** for the combustion of octane **(C_8H_{18})**. The graph clearly shows that an increase in the excess air percentage results in an increase in the actual volume of combustion gases. Understanding the relationship helps improve the design of combustion systems, enhance their efficiency, and reduce the environmental impact by carefully controlling the amount of air used in combustion.

Table 3: Actual Volume as a Function of Insufficient Air

$e(\%)$	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
$Va"\frac{m^3_{air}}{Kg_{ful}}$	12.57	11.32	10.06	8.8	7.54	6.28	5.03	3.77	2.51	1.25	0

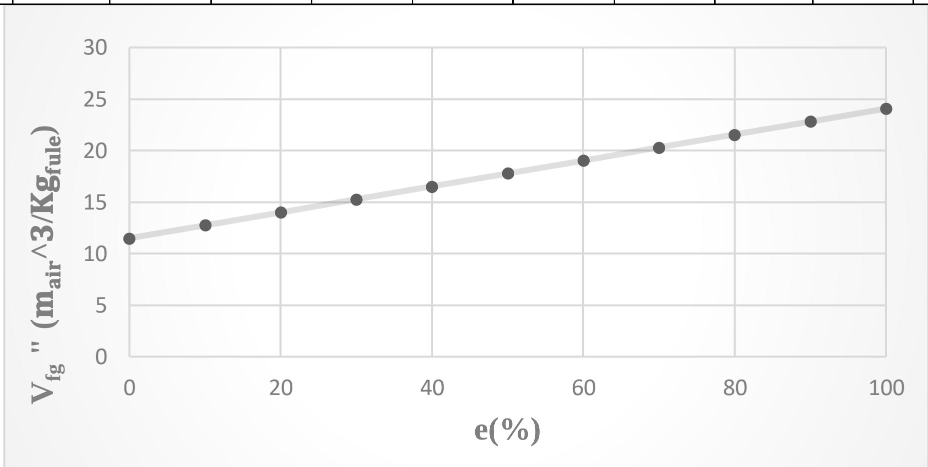


Graph 2: The Influence of Insufficient Air on Actual Volume

Commentary: The graph depicts the effect of insufficient air **(e)**on the actual volume of combustion gases $(Va")$ for octane (C_8H_{18}) combustion. The graph highlights the critical importance of maintaining an appropriate air-to-fuel ratio in combustion processes. Insufficient air leads to reduced volumes of combustion gases, indicating incomplete combustion, which can compromise system efficiency and increase emissions of harmful pollutants. Proper control of air supply in combustion systems is vital for optimizing performance, ensuring safety, and minimizing environmental impact.

Table 4: Total Actual Volume of Dry Flue Gas as a Function of Excess Air

$e(\%)$	0	10	20	30	40	50	60	70	80	90	100
$V_{fg}{}'' \frac{m^3_{air}}{Kg_{fule}}$	11.5	12.76	14.01	15.27	16.53	17.79	19.04	20.3	21.56	22.81	24.07

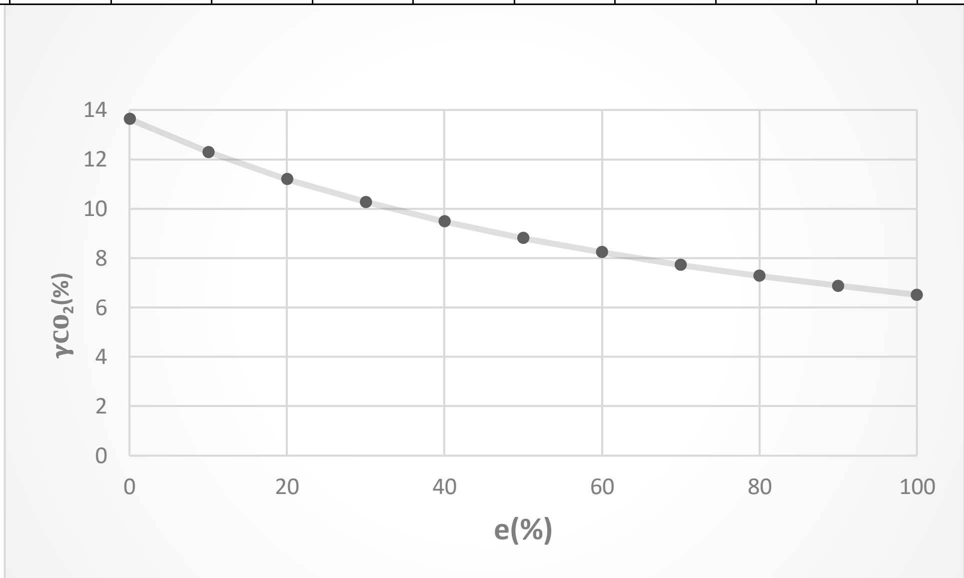


Graph 3: The Influence of Excess Air on Total Actual Volume of Dry Flue Gas

Commentary: The graph shows the relationship between excess air**(e)** and the total actual volume of dry flue gases ($V_{fg}{}''$) for octane (C_8H_{18}) combustion. The graph illustrates that the total actual volume of dry flue gases increases with excess air. While excess air is essential for complete combustion and reducing certain pollutants, excessive amounts can lead to increased flue gas volumes and reduced thermal efficiency. Optimal air management in combustion systems is crucial to achieve efficient combustion, reduce pollutant emissions, and minimize energy losses.

Table 5: The Carbon Dioxide Content as a Function of Excess Air

$e(\%)$	0	10	20	30	40	50	60	70	80	90	100
$\gamma CO_2(\%)$	13.63	12.29	11.19	10.27	9.487	8.816	8.234	7.725	7.274	6.873	6.514



Graph 4: The Influence of Excess Air on Carbon Dioxide Content

Commentary: The graph illustrates the relationship between excess air and the percentage of carbon dioxide in the flue gases for octane (C_8H_{18}) combustion. The graph shows that as the percentage of excess air increases, the carbon dioxide content in the flue gas decreases. This trend reflects the dilution effect of excess air, which lowers the concentration of CO_2 by increasing the total volume of flue gases. While excess air is crucial for ensuring complete combustion and reducing carbon monoxide emissions, it must be carefully controlled to optimize combustion efficiency, minimize heat losses, and balance emissions. Combustion systems should aim to operate at an optimal excess air level to ensure efficient fuel usage and compliance with environmental standards.

3.4 Calculation of the Adiabatic Flame Temperature

The equation of the combustion reaction is

$$C_8H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2$$

In order to determine the adiabatic flame temperature, Q = 0 and W = 0 are set to obtain this energy balance

$$\boldsymbol{\mathcal{H}_{prod} = \mathcal{H}_{react}}$$

$$\sum \boldsymbol{N_P(\overline{h_f^o} + \overline{h} - \overline{h^o})_p} = \sum \boldsymbol{N_r(\overline{h_f^o} + \overline{h} - \overline{h^o})_r}$$

Substance	$\overline{h_f^o}$	$\overline{h^o}_{298K}$
C_8H_{18}	-249950	-
H_2O	-241820	9904
CO_2	-393520	9364
O_2	0	8682
N_2	0	8669

We will calculate the adiabatic flame temperature by changing the value of excess air from e=0% to e=100%

For e=0

$$\boldsymbol{C_8H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2}$$

$$\mathcal{H}_{prod} = \mathcal{H}_{react}$$

$$\sum N_P(\overline{h_f^o} + \overline{h} - \overline{h^o})_p = \sum N_r(\overline{h_f^o} + \overline{h} - \overline{h^o})_r$$

$$8(\overline{h_f^o} + \overline{h} - \overline{h^o})_{CO_2} + 9(\overline{h_f^o} + \overline{h} - \overline{h^o})_{H_2O} + 47(\overline{h_f^o} + \overline{h} - \overline{h^o})_{N_2} = (\overline{h_f^o} + \overline{h} - \overline{h^o})_{C_8H_{18}} + 12.5(\overline{h_f^o} + \overline{h} - \overline{h^o})_{O_2} + 47(\overline{h_f^o} + \overline{h} - \overline{h^o})_{N_2}$$

$$8(-393520 + \overline{h} - 9364)_{CO_2} + 9(-241820 + \overline{h} - 9904)_{H_2O} + 47(0 + \overline{h} - 8669)_{N_2} = (-249950)_{C_8H_{18}} + 12.5(0 + 8682 - 8682)_{O_2} + 47(0 + 8669 - 8669)_{N_2}$$

$$8\overline{h}_{CO_2} + 9\overline{h}_{H_2O} + 47\overline{h}_{N_2} = 5646081 \frac{KJ}{Kmol}$$

Using thermodynamic tables, through iteration, we will determine the adiabatic flame temperature (this temperature is the one for which the above relationship is verified).

$$\frac{5646081}{8+9+47} = 88220\frac{KJ}{Kmol}$$

This enthalpy value corresponds to the following temperatures:

$T_{N_2} \approx 2650\,K$ $T_{CO_2} \approx 1800\,K$ $T_{H_2O} \approx 2100\,K$

the largest number of moles in the combustion products is that of nitrogen, the temperature should be slightly below 2650 K.

We take it for the first try T=2400 K

$$8\overline{h}_{CO_2} + 9\overline{h}_{H_2O} + 47\overline{h}_{N_2} = 5660828\frac{KJ}{Kmol}$$

For T=2350 K

$$8\overline{h}_{CO_2} + 9\overline{h}_{H_2O} + 47\overline{h}_{N_2} = 552655\frac{KJ}{Kmol}$$

$$552655 < 5646081 < 5660828$$

By interpolation:

T=2400 K → 5660828

T_{adi} → 5646081

T=2350 K → 552655

T_{adi}=2395 K

For (e=10%):

$$\boldsymbol{C_8H_{18} + 13.75(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 1.25O_2 + 51.7N_2}$$

$$\mathcal{H}_{prod} = \mathcal{H}_{react}$$

$$\sum N_P(\overline{h_f^o} + \overline{h} - \overline{h^o})_p = \sum N_r(\overline{h_f^o} + \overline{h} - \overline{h^o})_r$$

$$8(\overline{h_f^o} + \overline{h} - \overline{h^o})_{CO_2} + 9(\overline{h_f^o} + \overline{h} - \overline{h^o})_{H_2O} + 51.7(\overline{h_f^o} + \overline{h} - \overline{h^o})_{N_2} + 1.25(\overline{h_f^o} + \overline{h} - \overline{h^o})_{\boldsymbol{O_2}}$$
$$= (\overline{h_f^o} + \overline{h} - \overline{h^o})_{C_8H_{18}} + 13.75(\overline{h_f^o} + \overline{h} - \overline{h^o})_{O_2} + 51.7(\overline{h_f^o} + \overline{h} - \overline{h^o})_{N_2}$$

$$8(-393520 + \overline{h} - 9364)_{CO_2} + 9(-241820 + \overline{h} - 9904)_{H_2O}$$
$$+ 51.7(0 + \overline{h} - 8669)_{N_2} + 1.25(0 + \overline{h} - 8682)_{\boldsymbol{O_2}}$$
$$= (-249950)_{C_8H_{18}} + 13.75(0 + 8682 - 8682)_{O_2}$$
$$+ 51.7(0 + 8669 - 8669)_{N_2}$$

$$8\overline{h}_{CO_2} + 9\overline{h}_{H_2O} + 51.7\overline{h}_{N_2} + 1.25\overline{h}_{\boldsymbol{O_2}} = 5697677.8\,\frac{KJ}{Kmol}$$

Using thermodynamic tables, through iteration, we will determine the adiabatic flame temperature (this temperature is the one for which the above relationship is verified).

$$\frac{5646081}{8 + 9 + 51.7 + 1.25} = 81453.5\,\frac{KJ}{Kmol}$$

This enthalpy value corresponds to the following temperatures:

$T_{N_2} \approx 2450\,K$ $T_{CO_2} \approx 1680\,K$ $T_{H_2O} \approx 1980\,K$ $T_{O_2} \approx 2350\,K$

the largest number of moles in the combustion products is that of nitrogen, the temperature should be slightly below 2450 K.

We take it for the first try T=2250 K

$$8\overline{h}_{CO_2} + 9\overline{h}_{H_2O} + 51.7\overline{h}_{N_2} + 1.25\overline{h}_{\boldsymbol{O_2}} = 5703031.45\,\frac{KJ}{Kmol}$$

For T=2200 K

$$8\overline{h}_{CO_2} + 9\overline{h}_{H_2O} + 51.7\overline{h}_{N_2} + 1.25\overline{h}_{\boldsymbol{O_2}} = 5558795\,\frac{KJ}{Kmol}$$

$$5558795 < 5697677.8 < 5703031.45$$

By interpolation:

T=2250 K → 5703031.45

T_{adi} → 5697677.8

T=2200 K → 5558795

T_{adi}=2248.14K

For (e=20%):

$$C_8H_{18} + 15(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 2.5O_2 + 56.4N_2$$

T_{adi}=2121.64K

For (e=30%):

$$C_8H_{18} + 16.25(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 3.75O_2 + 61.1N_2$$

T_{adi}=2011.14K

For (e=40%):

$$C_8H_{18} + 17.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 5O_2 + 65.8N_2$$

T_{adi}=1913.68K

For (e=50%):

$$C_8H_{18} + 18.75(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 6.25O_2 + 70.5N_2$$

T_{adi}=1827.06K

For (e=60%):

$$C_8H_{18} + 20(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 7.5O_2 + 75.2N_2$$

T_{adi}**=1752.01K**

For (e=70%):

$$C_8H_{18} + 21.25(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 8.75O_2 + 79.9N_2$$

T_{adi}**=1679.76K**

For (e=80%):

$$C_8H_{18} + 22.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 10O_2 + 84.6N_2$$

T_{adi}**=1616.62**

For (e=90%):

$$C_8H_{18} + 23.75(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 11.25O_2 + 89.3N_2$$

T_{adi}**=1559.14**

For (e=100%):

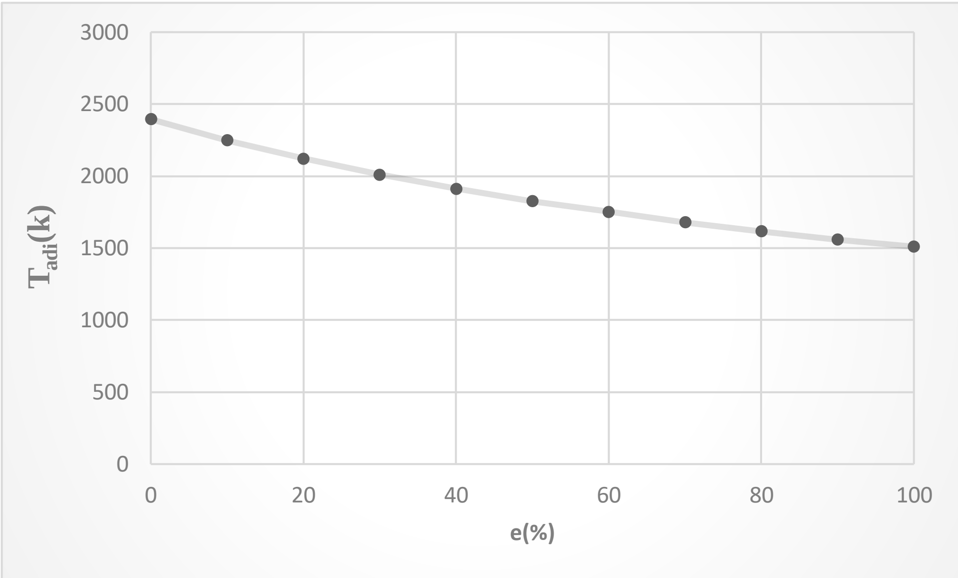
$$C_8H_{18} + 25(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 12.5O_2 + 94N_2$$

T_{adi}**=1509.89**

Table 6: Adiabatic Flame Temperature

T_{adi}(K)	e(%)
2395	0
2248.14	10
2121.64	20
2011.14	30
1913.68	40
1827.06	50
1752.01	60
1679.76	70
1616.62	80

1559.14	90
1509.89	100



Graph 5: The Influence of Excess Air on the Temperature of the Adiabatic Flame

Commentary: The graph illustrates the relationship between excess air and the adiabatic flame temperature in the flue gases for octane $(\mathbf{C_8H_{18}})$ combustion. The graph indicates that increasing the excess air ratio in octane combustion leads to a decrease in adiabatic flame temperature. This effect results from the dilution of thermal energy over a larger quantity of gases, thereby reducing the final temperature. To ensure optimal thermal efficiency, the air-to-fuel ratio must be adjusted to provide enough oxygen for complete combustion without significantly lowering the adiabatic flame temperature.

General Conclusion

This study concludes that gasoline is an efficient fuel and that the air-fuel ratio plays a crucial role in improving combustion efficiency and reducing harmful emissions. The results showed that increasing the air ratio in the combustion process increases the values of V_{fg}" and Va",For example, Va" $= 12.57\frac{m^3_{air}}{Kg_{fule}}$ and V_{fg}" $= 11.5\frac{m^3_{air}}{Kg_{fule}}$ with no excess air, andthese values increased to Va" $= 25.15\frac{m^3_{air}}{Kg_{fule}}$ and V_{fg}" $= 24.07\frac{m^3_{air}}{Kg_{fule}}$ with 100% excess air. At the same time, adiabatic temperatures decreased from 2395 K to 1509.89 K, reflecting more efficient combustion with less heat loss. We also observed that as the air ratio increased, carbon dioxide levels decreased. With no excess air, the CO_2 level was 13.63%, and with 100% excess air, it decreased to 6.514%, ensuring a significant reduction in harmful emissions. Therefore, it is important to develop strategies to precisely adjust the air-fuel ratios to achieve optimal performance and minimize environmental impact. This study represents a significant step toward a better understanding of gasoline combustion processes and their applications in improving engine efficiency and reducing harmful emissions**.**

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