International Current Journal of Engineering and Science (ICJES)
Volume 4, Issue 7, pp 1-17, July-2025
ISSN (Online): 2583-7257
Article DOI: https://doi.org/10.47001/ICJES/2025.407001

Spark Timing Influence on the Emissions and Performance of Spark Ignition Engines (Review)

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***Abstract* - This study reviews different (latest) technologies for controlling emissions and enhancing performance in spark-ignition (SI) engines. The primary pollutants—carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and carbon dioxide (CO_2)—are examined, with a focus on fuel system contributions to emissions. Key strategies such as lean combustion, optimized compression ratio, fuel modifications, exhaust gas recirculation (EGR), total emissions control packages, and pre-combustion control are discussed.**

Additionally, the study reviews the impact of ignition timing on engine performance and emissions. By changing ignition timing at different speeds and designing it for wide-open throttle, key performance parameters such as brake mean effective pressure (BMEP), torque, and power are analyzed alongside emissions levels. The findings emphasize the relationship between optimal ignition timing and reduced emissions while maximizing performance. This review provides insight into effective approaches for improving SI engine efficiency and reducing environmental impact.

Keywords: Emissions, Ignition timing, Performance, Spark-Ignition, Thermal efficiency.

I. Introduction

Generally, the internal combustion engine is a heat engine which converts the chemical energy that stored in a fuel into mechanical energy, which made available on a rotating shaft as an output power. The chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the combustion chamber, this thermal energy raises the temperature and pressure of the gases within the engine and the high-pressure gas then expands against the mechanical mechanisms of the engine. This expansion is converted by the mechanical linkages of the engine to a rotating crankshaft, which is the output of the engine to the desired final use [1].

Most internal combustion engines are reciprocating engines having pistons that reciprocate back. Usually, reciprocating engines can have one cylinder or more, may be up to 20 or more. The cylinders can be arranged in many different geometric configurations, different sizes with different power obtained. [2]

Figure (1): Piston and connecting rod [2]

The most important event in the last century was the invention of internal combustion engines in 1860s. It is considered as one of the most significant inventions of the last century, and has had a significant impact on society, especially human mobility. The internal combustion engine has been the foundation for the successful development of many commercial technologies. For example, consider how the internal combustion engine has transformed the transportation industry, allowing the invention and improvement of automobiles, trucks, airplanes, and trains. The adoption and continued use of the internal combustion engines in different application areas has resulted from its relatively low cost, favorable power to weight ratio, high efficiency, and relatively simple and robust operating characteristics. The reciprocating piston--cylinder geometry is the primary geometry that has been used in internal combustion engines. This configuration of a reciprocating internal combustion engine, with an engine block, pistons, valves, crankshaft, and connecting rod, has remained basically unchanged since the late 1860s. The main differences between a modern-day engine and one built 100 years ago can be seen by comparison of their reliability, thermal efficiency, and emissions level. For many years, internal combustion engine research was aimed at improving

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thermal efficiency and reducing noise and vibration. As a consequence, the thermal efficiency has increased from about 10—20% at the beginning of the 20th century to values as high as 50% today [2].

There are different engine technologies in use with differing applications. The two main engine technologies are spark ignition (SI) engines which typically use gasoline fuel and compression ignition (CI) engines which typically use diesel fuel as shown in the figures bellow for two different engines [3].

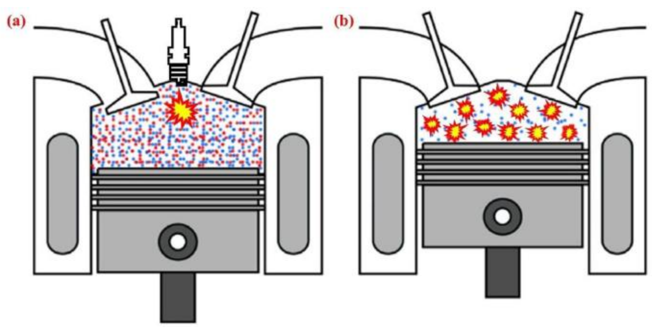

Figure (2a): (SIE), Figure (2b): (CIE)[4]

In Spark - Ignition (SI) engines the fuel and air are usually premixed prior to admission to the engine cylinder. This is done either in a carburetor, or more commonly now by a port or manifold fuel injection system. [Some of the two- and four-stroke engines being investigated for use in cars do have direct injection into the engine cylinder using an air-blast injector]. All these systems prepare the charge prior to it entering the cylinder, although it is probable that the fuel enters the cylinder with a large proportion in the liquid phase. Under fully warmed-up conditions this fuel will have evaporated by the time of ignition. An SI engine starts the combustion process in each cycle by use of a spark plug. The spark plug gives a high-voltage electrical discharge between two electrodes which ignites the air-fuel mixture in the combustion chamber surrounding the plug. In early engine development, before the invention of the electric spark plug, many forms of torch holes were used to initiate combustion from an external flame [4].

In Compression -Ignition (CI) engines the combustion process are usually starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression [4].

In a spark ignition engine, which is one of the types of internal combustion engines the process of setting the time that an ignition will occur in the combustion chamber relative to piston position and crankshaft angular velocity (during the compression stroke) is called (ignition timing). The setting of the correct ignition timing is a major factor which acting on engine performance and exhaust emissions. Accordingly, many studies concentrated on evaluate whether variable ignition timing can be effect on exhaust emission and engine performance of an SI engines.

Gas turbines, jet engines and most rocket engines, which are a second class of internal combustion engines which use continuous internal combustion [6].

Gasoline engine, any of a class of internal-combustion engines that generate power by burning a volatile liquid fuel (gasoline or a gasoline mixture such as ethanol) with ignition initiated by an electric spark. Gasoline engine can be built to meet the requirements of practically any conceivable power-plant application, the most important being passenger automobiles, small trucks and buses, general aviation aircraft, outboard and small inboard marine units, moderate-sized stationary pumping, lighting plants, machine tools, and power tools. Four-stroke gasoline engines power the vast majority of automobiles, light trucks, medium-to-large motorcycles, and lawn mowers. Two-stroke gasoline engines are less common, but they are used for small outboard marine engines and in many handheld landscaping tools such as chain saws, hedge trimmers, and leaf blowers [5].

Gasoline, mixture of volatile, flammable liquid hydrocarbons derived from petroleum and used as fuel for internal-combustion engines. It is also used as a solvent for oils and fats. Originally a by-product of the petroleum industry (kerosene being the principal product), gasoline became the preferred automobile fuel because of its high energy of combustion and capacity to mix readily with air in a carburetor [2].

The aim of the current work is to present a general overview of ignition timing and its effect on the performance and emissions of gasoline-fueled spark ignition engine. Different aspects were considered acting on the performance and emissions of SI engine.

II. Technologies for improving the performance, efficiency and emissions of the engine

In this research, various aspects of improving engine parameters like efficiency and emissions were discussed in spark ignition engines in general, for many research groups. Different methods were used for this purpose and the most popular of them are given below.

2.1 Tolga Topgu¨l, Hüseyin Serdar Yücesu, Can C- inar, Atilla Koca. (7)

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This research studies the effects of unleaded gasoline (E0) and gasoline–ethanol blends (E10, E20, E40, and E60) on the performance and emissions of a single-cylinder, four-stroke, spark ignition engine. Experiments were conducted at a constant speed of 2000 rpm and wide-open throttle (WOT), varying compression ratios (8:1, 9:1, and 10:1) and ignition timings. Results shows that blending gasoline with ethanol improves brake torque, reduces carbon monoxide (CO) and hydrocarbon (HC) emissions, and increases the engine's tolerance to higher compression ratios without knock. Optimal performance and emissions were achieved with 40–60% ethanol blends, demonstrating significant reductions in CO and HC emissions across varying compression ratios. These findings highlight the potential of ethanol–gasoline blends in reducing harmful emissionsand enhancing engine performance.

2.2 Marek FLEKIEWICZ. (8)

This researchstudies the impact of ignition timing on the combustion process in a 1.6-liter spark-ignition (SI) engine powered by compressed natural gas (CNG). Engine testing included measurements of in-cylinder pressure, crank angle, fuel mass consumption, and exhaust gas temperatures under various operating conditions. The effects of ignition timing advance (0 to 15° crank angle) on combustion chamber temperature and heat release ratio were analyzed. A mathematical model estimated NO, CO, and CO_2 emissions, providing insights into the environmental benefits of natural gas as a fuel. The results highlight the necessity of a dedicated ignition timing map to optimize the combustion process in bi-fuel engines. Additionally, proper exhaust gas recirculation (EGR) strategies were identified as crucial for reducing in-cylinder temperature and ensuring efficient operation.

2.3 SRINATH PAI[1], SATHEESH KUMAR N[2], SRINIVAS RAO B.R[3],(9)

This study examines the effect of ignition timing on the performance and emissions of a 4-stroke twin-plug spark ignition engine fueled with pure gasoline. Experiments were conducted under varying load conditions, using three combinations of spark timings: ‘A’-260 - ‘B’-210 (BTDC), ‘A’-260 - ‘B’-260 (BTDC), and ‘A’-260 - ‘B’-310 (BTDC). The performance was evaluated in terms of brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and exhaust emissions, including unburnt hydrocarbons (UBHC), carbon monoxide (CO), and nitrogen oxides (NO). The results shows that the spark timing combination ‘A’-260 - ‘B’-260 (BTDC) achieved the highest BTE, lowest BSFC, and minimal UBHC and CO emissions, though it led to a rise in NO emissions. These findings indicate that optimal spark timing significantly enhances engine performance while minimizing specific emissions, with ‘A’-260 - ‘B’-260 (BTDC) emerging as the best configuration

2.4 Ahmad Gairsain, Mahdi Shahbakhti[1], Charles Robert Koch[2*],(10)

This study deals with five crank-angles-based methods for determining the start of combustion across various conditions, including CA50 and CA10 from total heat release,start of combustion from the third derivative of the pressure trace (with and without limits), and a novel CA10 method based on the peak of the main combustion stage. The proposed CA10 method demonstrates superior accuracy, particularly in high cyclic variation regions. Analyzing 115 operating points at a fixed engine speed confirms that the new CA10 method is the most reliable for combustion timing characterization across varying conditions.

2.5 Wojciech Tutak[1], Arkadiusz Jamrozik, Arkadiusz Kociszewski, (11)

This research presents the results of computational fluid dynamics (CFD) modeling of the thermal cycle in an internal combustion engine with exhaust gas recirculation (EGR). Both hot and cooled EGR systems were analyzed to determine their effects on nitrogen oxide (NOx) emissions and thermal cycle parameters. The results revealed that cooled EGR is more effective in reducing NOx emissions. However, the cooling degree must be controlled to avoid water vapor condensation in the exhaust gases. The findings show the importance of optimizing EGR temperature to enhance its efficiency, with cooled EGR being the preferred method for significant NOx reduction.

2.6 A. H. Kakaee, M. H. Shojaeefard, and J. Zareei, (12)

This study focuses on analyzing theperformance of a spark ignition (SI) engine under varying ignition timing using a two-zone burnt/unburned combustion model with a Wiebe function for fuel burning rate. Experimental validation was conducted to compare calculated and measured results. Key engine characteristics, including power, torque, thermal efficiency, pressure, and heat release, were evaluated. Optimal performance, with maximum power and torque, was achieved at 31° crank angle (CA) before top dead center (BTDC).Maximum thermal efficiency occurred when peak pressure was observed between 5–15°CA after top dead center. Results indicated that insufficient ignition advance delays combustion, decreasing power and efficiency, while excessive advance increases heat loss and reduces network output.

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2.7 Rafeq Ahmad Khalefa,(13)

Thisresearchinvestigates the effect of spark timing on the performance of spark ignition (SI) engines through computer simulations and experimental tests at engine speeds of 1500 to 3500 rpm with spark advances ranging from 20° to 60° before top dead center (TDC). Theresults show that increasing engine speed without modifying spark timing leads to reduced cylinder pressure and temperature, lower indicated mean effective pressure, and higher exhaust temperature. Advancing spark timing improves the efficiency of combustion but excessive advancement causes premature combustion and decreasing in efficiency.

2.8 Mehrnoosh Dashti, Ali Asghar Hamidi, Ali Asghar Mozafar,(14)

This study presents a thermodynamic cycle simulation for a four-Stroke SI engine to analyze the performance and emission characteristics of integration of compressed naturalCNGas an additive to gasoline to improves fuel characteristics blends. The model, based on the first law of thermodynamics and solved numerically using the Newton-Raphson method, eliminates the need for analytical solutions. A quasi-dimensional combustion model is employed, dividing the combustion chamber into two zones separated by a propagating flame front. The simulation predicts variations in indicated power, indicated specific fuel consumption (ISFC), and emissions across different engine speeds. The closed-cycle model incorporates compression, ignition delay, combustion, and expansion processes to accurately describe the thermodynamic behavior and chemical states of the working fluid. Experimental validation demonstrates good agreement between simulated and observed data, confirming the model's reliability in predicting engine performance and emissions of CNG/gasoline-fueled engine.

2.9 LIN Man-qun[1, 2, a], ZHOU Peng[1, 2, b], QIN Jing[1, 2, c], PEI Yi-qiang[2, d], PAN Suo-zhu[2, e],(15)

A simulation and experimental study have been done on a Gasoline Direct Injection (GDI) engine to analyze the effects of ignition timing on fuel mixture distribution and soot emissions. The results indicate that ignition retard reduces soot emissions by influencing local temperature, oxygen concentration, and oxidation duration. In a single-injection model, delayed ignition lowers soot formation. However, in a two-stage injection strategy used for catalyst heating during cold start, show that increasing in soot emissions occur due to a denser fuel mixture and lower ambient temperatures. This issue can be mitigated by ignition retard, which improves fuel atomization and moderates temperature spikes. The findings suggest that an optimized combination of spray and ignition timing can improve air-fuel distribution, combustion efficiency, and overall engine performance while minimizing soot emissions.

2.10 J. Zareei & A. H. Kakaee, (16)

This study examines the effect of variable ignition timing on the performance and exhaust emissions of a spark ignition (SI) engine. Experiments were conducted at 3400 RPM, adjusting ignition timing from 41° before top dead center (BTDC) to 10° after top dead center (ATDC). Results show optimal torque and power were achieved at 31° BTDC, with increasing in volumetric efficiency and brake mean effective pressure (BMEP) as ignition timing advanced. While O_2, CO_2, and CO levels remained stable, hydrocarbons (HC) increased, and the lowest nitrogen oxides (NOx) emissions occurred at 10° BTDC. The findings suggest ignition timing as a viable approach for optimizing engine performance.

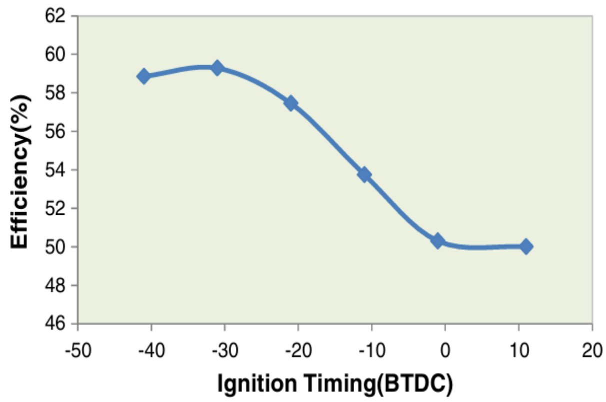

Figure 3: The relationship between efficiency versus ignition timing

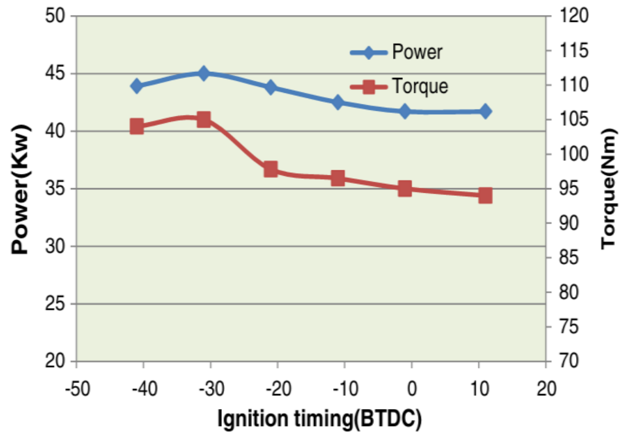

Figure 4: The relationship between power and torque versus ignition timing

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2.11 M. İ. Karamangil [*1], N. Türköz [2], B. Erkuş [2] and A. Sürmen[1],(17)

This study examines the impact of ignition timing variation on the performance and emissions of a spark-ignition (SI) engine operating on an E10 ethanol blend (90%gasolinez10%ethanol). Ignition timing was adjusted by advancing and retarding up to 6° from the baseline gasoline settings under full-load conditions. The results show advancing the ignition timing enhanced efficiency, with the optimal setting observed at a 4° advance, yielding a 6% increase in efficiency at 3000 rpm. While NOx emissions increased with advanced timing, CO and CO_2 emissions remained largely unchanged, and hydrocarbon (HC) emissions also rose. Qn the other hand, retarded ignition timing reduced NOx emissions but led to incomplete combustion, increased fuel consumption, and higher exhaust gas energy. These results indicate that a 4° advance in ignition timing offers the best balance between performance and emissions for E10-fueled SI engines.

2.12 Seyfi Polat, Ahmet Uyuma, Hamit Solma, Emre Yilmaz, Tolga Topgül & H. Serdar Yücesu,(18)

This study employs numerical simulations using KIVA codes to examine the effect of Exhaust Gas Recirculation (EGR) and spark timing on a single-cylinder, four-stroke, gasoline direct injection (GDI) spark ignition engine. The results show that increasing the EGR ratio leads to reductions in in-cylinder pressure, heat release rate, and exhaust gas temperature, while also diminishing NOx emissions. Advancing spark timing results in higher in-cylinder pressure, elevated heat release rates, and increased in-cylinder temperatures, which may elevate the risk of engine knock. The study clarified the necessity of optimizing both EGR ratio and spark timing to enhance engine performance and minimize exhaust emissions.

2.13 N. Homdoung[1], N. Tippayawong[1*] and N. Dussadee[2],(19)

This study contains using of a small, single cylinder, naturally aspirated, compression ignition engine was modified into a spark ignited (SI) engine where producer gas was used solely as fuel. Tests were carried out at various engine speeds (1100-1700) rpm and loads to study the impact of ignition timing adjusted to maximum brake torque (MBT) on overall engine performance. From the tests, the results show that coefficient of variation in a range of 1. 75 - 3. 0 %. As expected, the performance of the engine was dependent on ignition timing advance. The optimum ignition timing of the engine was observed to be between 20° to 25° BTDC at 1100 rpm, and increase with engine speed. Maximum brake mean effective pressure and minimum brake specific fuel consumption rate were 195. 48 kPa, and 0. 93 kg/kWh, respectively, obtained at 1700 rpm on full load. At this condition, brake thermal efficiency achieved of about 19%.

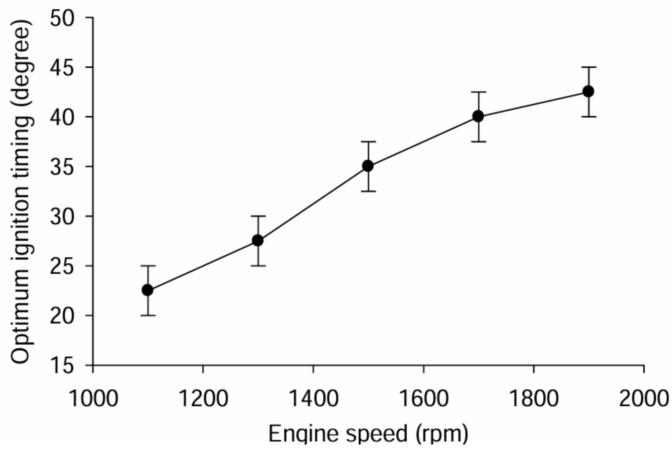

Figure 5: The optimum ignition timing of small producer gas engine with varying engine speed

2.14 Indira Priyadarsini, M. V. S. Murali Krishna, E. Nirmala Devi,(20)

This research investigates the effects of spark timing (ST) and compression ratio (CR) on engine efficiency and emissions. Experiments were conducted on a single-cylinder, four-stroke, spark-ignition engine with variable compression ratio and adjustable spark timing at a constant speed of 3000 RPM. The study examines ST ranging from 20° to 30° BTDC and CR between 3.5:1 and 9:1. Results show that advancing spark timing improves brake thermal efficiency and volumetric efficiency while reducing specific fuel consumption and exhaust gas temperature. Higher compression ratios further enhance peak pressure and thermal efficiency but pose a risk of knocking with low-octane fuels. Optimal performance was achieved at 28° BTDC and a compression ratio of 8:1. These findings focus on the importance of precise ignition timing and compression ratio optimization in improving engine performance and fuel efficiency.

2.15 Maddali.V. S. Murali Krishna, Ch. Indira Priyadarsini, Nagini, S.Naga Sarada, P. Usha Sri, Srikanth,(21)

The research studies the performance and emission characteristics of a single-cylinder, four-stroke, water-cooled, variable compression ratio (3–9), variable-speed (2200–3000 rpm) spark ignition engine with a rated brake power of 2.2 kW at 3000 rpm. The engine was tested using a conventional combustion chamber (CE) and a copper-coated combustion chamber (CCE) (300 µm copper coating on the piston crown,

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inner liner, and cylinder head) using alcohol-blended gasoline fuels (20% methanol or 20% ethanol with 80% gasoline by volume). A catalytic converter utilizing sponge iron as a catalyst, coupled with air injection, was employed for emission control. The results show that alcohol-blended fuels increase in engine performance and decrease in carbon monoxide (CO) and unburned hydrocarbon (UBHC) emissions compared to pure gasoline. The optimum ignition timing was 28° BTDC for CE and 27° BTDC for CCE. Ethanol-blended gasoline presence of fine performance, while methanol-blended gasoline significantly reduced pollutant emissions. The CCE configuration further increase performance and decrease emissions compared to CE. Advancing ignition timing led to additional performance and emission benefits. The catalytic converter effectively reduced emissions across all test conditions. These findings highlight the potential of alcohol-blended fuels, advanced combustion chamber modifications, and emission control technologies in enhancing engine efficiency and reducing environmental impact.

2.16 Bambang Sudarmanta[1], Bambang Junipitoyo[2], Ary Bachtiar Krisna Putra[3] and I Nyoman Sutantra[4], (22)

This study examines the impact of compression ratio and ignition timing on the performance of a Sinjai engine fueled with a 50% bioethanol-gasoline blend (E50). Using a water brake dynamometer, engine performance was evaluated at compression ratios of 9.6, 10.6, and 11.6 while optimizing ignition timing for maximum brake torque (MBT) and efficiency within knocking limits. Key performance parameters, including torque, brake mean effective pressure (BMEP), power, brake-specific fuel consumption (BSFC), thermal efficiency, and volumetric efficiency, were tested across variable engine speeds from 2000 to 5000 rpm. Results showed that increasing the compression ratio improved performance, with E50 at a compression ratio of 11.6 yielding higher brake torque (3.68%), power (4.58%), and BMEP (3.68%) compared to gasoline at 9.6. Also, BSFC decreased by 13.42%, with increasing in thermal efficiency by 14.67%. Ignition timing was advanced with engine speed, ranging from 18° BTDC at 2000 rpm to 26° BTDC at 5000 rpm, with higher compression ratios requiring retarded timing to prevent detonation. The results highlight the potential of E50 fuel to enhance engine efficiency and performance through optimized compression ratios and ignition timing.

2.17 MARTH EN PALOBORAN[1], GAYUH AGUNG PAMUJI[2], BAMBANG SUDARMANTA[3], I NYOMAN SUTANTRA[4], DARMAWANG[5],(23)

This research investigates the effect of using pure bioethanol (E100) as a fuel in spark ignition engines, focusing on emissions, performance, and fuel consumption. Experiments were conducted with compression ratios of 12:1, 12.5:1, and 13:1, injection durations ranging from 100% to 200% of the standard (24 cc/s), and ignition timings between 10° and 26° BTDC. Results showed that at a 13:1 compression ratio, bioethanol enhances brake torque, brake power, and brake mean effective pressure (BMEP) by 16.1%, 18.1%, and 18.12%, respectively, compared to gasoline. Additionally, CO and HC emissions were significantly reduced by 75.5% and 17.24%, respectively, though specific fuel consumption increased by 115.8% at low RPMs. Optimal performance was observed with injection durations of 150%-175% and ignition timings of 10°, 14°, and 18° BTDC, depending on engine speed. The results highlight bioethanol’s potential to improve engine performance and reduce emissions.

2.18 Nizar F.O. Al-Muhsen and Guang Hung,(24)

This study asks afterthe dual fuel injection method in a 250cc spark-ignition engine, focusing on varying ethanol direct injection (DI) ratios and spark timings at two engine loads and fixed engine speed at 3500 RPM. Results showed that DI at 100% and advanced spark timing improve indicated mean effective pressure (IMEP), torque, performance and thermal efficiency. At DI56%, IMEP rose 8.28% at optimized spark timing, reducing combustion duration by 41.8%. So, advancing spark timing and higher DI ratios increased hydrocarbon and carbon monoxide emissions due to local fuel-rich mixtures, while nitric oxide emissions declined, attributed to ethanol's charge cooling effect. Nitric oxide emissions at light load decreased by 37.53% at DI56% and 67.39% at DI100% compared to port injection only.

2.19 Waibhaw H. Meshram[1], S.P.Chincholkar[2], Vikas I. Somankar[3], Dr. J. G. Suryawanshi[4], (25)

This research investigates the effect of ignition timing on the performance of a spark ignition engine, focusing on specific fuel consumption (BSFC) and brake thermal efficiency (BTE). Experimental results showed that at 1500 rpm and fixed load conditions reveal that an optimal spark timing of 18° before top dead center (CA BTDC) decreasing BSFC and increasing BTE, this led to enhancing combustion efficiency. Deviations from this optimal spark timing result in higher BSFC, indicating less efficient combustion. Furthermore, better thermal efficiency is observed at 80% engine load. These findings shed the importance of precise ignition timing for improving engine performance and reducing emissions.

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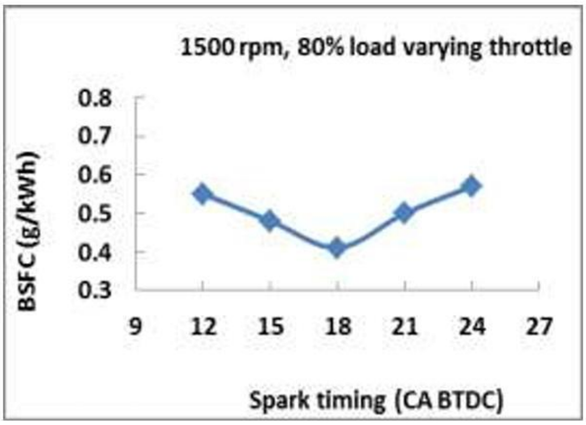

Figure 6: Effect of spark timing on BSFC

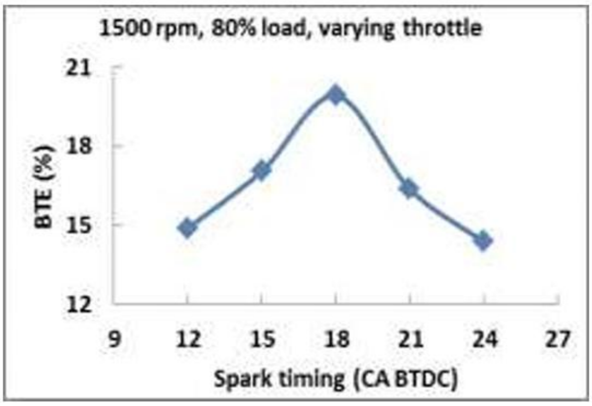

Figure 7: Effect of spark timing on Brake Thermal Efficiency

2.20 Sachin Kumar Gupta,(26)

This research investigates the impact of compression ratio on the performance, combustion, and emission characteristics of a four-stroke, water-cooled, single-cylinder spark-ignition engine using gasoline as fuel. Experiments were conducted at varying engine loads, speeds, and compression ratios (7:1 to 11:1). Results showed that brake thermal efficiency and NOX emissions increased with engine load increase, while flame initiation period, rapid combustion duration, and unburned hydrocarbon emissions decreased.CO emissions exhibited trends similar to equivalence ratio variations. The results gave baseline data for the engine's use with gaseous fuels in small-scale power generation.

2.21 Lukas Tunka[1], Adam Polcar[1]. (27)

This study investigates the effect of ignition timing on the performance and combustion characteristics of a spark-ignition engine. Experiments were conducted on a four-cylinder AUDI engine (maximum power: 110 kW) at2500 rpm with eight different ignition timings (18°CA to 32°CA BTDC) under a stoichiometric mixture, using a Magneti Marelli control unit. Key performance parameters, such as engine power, torque, cylinder pressure, heat generation, burn rate, exhaust gas temperature, indicated mean effective pressure (IMEP), combustion duration, and stability, were evaluated. Results show that advancing ignition timing led to improves engine power, torque, and efficiency by increasing cylinder pressure, particularly near top dead center during the expansion stroke. Combustion stability also benefits from advanced timing, while combustion duration remains unchanged. Optimized ignition timing improves engine efficiency, fuel economy, and may reduce exhaust emissions, although excessive advancement can cause detonation, especially with low-octane fuels.

2.22 Barhm Mohamad[1], Gabor Szepesi[2], Betti Bollo[3], (28)

This research examines the effect of using methanol-gasoline (M35g65) and ethanol-gasoline (E40g60) blends on the performance, combustion, and emissions of a spark-ignition engine. Simulations showed that both blends enhancing indicated thermal efficiency (ITE) and lowered exhaust gas temperature (EGT), improved performance and reducing compression work. The ethanol blend (E40g60) had a higher flame propagation speed, leading to better thermal efficiency, lower NOx emissions, and shorter combustion duration. Despite lower heating values, methanol and ethanol improved knock resistance and volumetric efficiency due to their higher-octane numbers.

2.23 Dao-Yi Huanga, Jer-Huan Janga, b,*, Po-Han Lina , Bo-Han Chena, (29)

This study investigates the effect of ignition timing on exhaust emissions in a compression ignition (CI) engine using an improved spark plug reformer system. The reformer, designed to generate syngas with hydrogen, consists of spark plugs, atomizers, and a control unit. Tests were conducted on a 1988 c.c. 4-cylinder Nissan Sentra at ignition timings of 12°, 14°, 16°, 18°, and 20° BTDC, following the European Emission Standard cycle. Results highlights that the reformer system reduced hydrocarbon (HC) emissions but increased nitrogen oxides (NOx) and carbon monoxide (CO). The optimal ignition timing was 14° BTDC, where HC and NOx emissions decreased, CO2 increased, but CO levels also risen, particularly at high speeds. The study confirmed the importance of ignition timing in improving emission control with spark plug reforming systems.

2.24 A. Birtas[1], N. Boicea[1], F. Draghici[2], R. Chiriac[3,4,*], G. Croitoru[5] , M. Dinca[6] , T. Dascalu[5] and N. Pavel[5,*], (30)

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The research investigates a Q-switched solid-state laser ignition system in a Renault-Dacia K7M 710 engine to improves combustion efficiency and reduce emissions. The laser igniter, designed like a traditional spark plug, was tested under lean mixture conditions at 2000 rpm and 2 bar brake mean effective pressure. Results show a 2% efficiency increasing by optimizing the ignition point location, with stable combustion and reduced cycle variability. Theoretical and experimental results aligned with 3% accuracy, it shed light on the potential of laser ignition for better engine performance and lower emissions.

2.25 Abdülvahap ÇAKMAK[1]*, Murat Kapusuz 2 and [2], (31)

This study experimentally looks into the effects of advancing spark timing on the performance and exhaust emissions of a spark-ignition (SI) engine fueled with a methanol-gasoline blend (M20). M20, consisting of 20% methanol and 80% gasoline by volume, was tested alongside pure gasoline under a constant engine speed of 1500 rpm and altering engine loads (25-100%) at three spark timing advances: -10°CA (standard), -18°CA, and -26°CA BTDC. The results indicate that advancing spark timing enhances engine performance for M20, with the highest thermal efficiency (33.40%) achieved at full load and -26°CA BTDC. Additionally, M20 extensively reduced CO and HC emissions but increased CO_2 and NOx emissions. The study concludes that increasing spark advance timing improves performance in M20-fueled engines, provided NOx emissions are mitigated through pre-combustion techniques or after-treatment methods.

2.26 Özer ÖĞÜÇLÜ[1],(32)

In this research, a thermodynamic cycle model has been developed and used to predict the effects of Exhaust Gas Recirculation (EGR), which is used to decrease the Nitrogen Oxide (NO) in exhaust gas, and performance of a spark-ignition engine. The model simulates full thermodynamic cycle of a spark-ignition engine and includes heat transfer, combustion, gas exchange process, thermal dissociation of water and carbon dioxide, and chemical equilibrium in engine cylinder. For this purpose, a computer program has been developed to simulate thermodynamic processes in a spark ignition engine cylinder. It calculates cylinder pressure, burnt and unburnt gas temperatures, and NO concentration in burnt gases. The program also includes Exhaust Gas Recirculation (EGR) effects. NOx formation mechanisms from the literature were reviewed and incorporated into the model. Graphical representations of key parameters as functions of crank angle are generated, and model results show good agreement with experimental data.

2.27 Esam I Jassim[1], * and Bashar I Jasem[2],(33)

This research investigates how ignition timing affects the thermal performance, emissions, and cooling efficiency of a spark ignition (SI) engine. Experiments were conducted by changing camshaft angles. The results show that advanced ignition timing increases heat transfer but raises NOx and CO emissions while reducing thermal efficiency due to heat loss. Retarded ignition timing lowers NOx emissions but decreases radiator performance and combustion efficiency. Experimental coolant temperature data aligned moderately with 1-D heat exchanger theory, confirming that optimized ignition timing enhances heat dissipation. The study shows the importance of precise ignition timing for reducing emissions and improving engine efficiency.

2.28 Nuthan Prasad B. S. and Kumar N,(34)

This study examines how ignition timing affects the performance and emissions of a single-cylinder, four-stroke spark-ignition engine using an M50 methanol-gasoline blend under wide open throttle (WOT) conditions. Tests were conducted at engine speeds from 1400 to 1800 rpm, with ignition timing varying between 12° BTDC and 26° BTDC. The results show that optimal timing was found at 14° BTDC, increasing brake thermal efficiency (BTE) and brake specific energy consumption (BSEC) compared to gasoline, especially at 1600 rpm. The methanol blends enhanced combustion efficiency, increasing in-cylinder pressure and net heat release (NHR). It also reduced NOx, HC, and CO emissions by 50%, 35%, and 40%, respectively, due to its lower carbon-to-hydrogen ratio and oxygen content, though CO2 emissions rose by 10% due to more complete combustion. These results highlight the potential of M50 fuel and ignition timing optimization to improve engine performance and reduce harmful.

2.29 M S Ajmir [1], AB Elmi [1], A Mohammad Nazir [2] and J Muhammad Nabil Asyraf [3],(35)

Automated Spark Ignition Timing Controller (ASITC) can be design for the suitability of the study. For this purpose, Arduino microcontroller is used. It is equipped with potentiometer and 1.8 in TFT display. Through ignition timing, a misfire condition and knocking are actuated by advance spark. Instrustar DAQ is used to record data from spark ignition to examine the ASITC to be made for specific features as needed. Based on the analysed CPS signals, the peak-to-peak signal is the main trigger to spark plug timing using Arduino controller. Signal within 5V is detect to trigger the spark. The signal manages to detect the peak-to-peak

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ISSN (Online): 2583-7257
Article DOI: https://doi.org/10.47001/ICJES/2025.407001

signal to initiate good timing based on the air fuel ratio and engine speed. Through model based, misfire condition can be design through the control unit. Over testing for hours, accuracy of 75% detection model-based misfire condition. The knock sensor would able to detect misfire condition. In the same monitoring condition of knocking condition. [ok]

2.30 NAGINI YARRAMSETTY[1], MADDALI VS MURALIKRISHNA[2]& S. NAGASARADA[3],(36)

The study investigates the reduction of major pollutants— (CO),(UBHC), and (NOx)—emitted by spark ignition engines. These pollutants represent great importance in health risks, require effective control measures. Experiments were conducted on a 4-stroke variable compression engine, modified with a copper-coated combustion chamber (300 µm thickness on the piston, liner, and cylinder head) and fueled with gasohol (20% ethanol and 80% gasoline by volume). Pollutant levels were measured under variable ignition timings, utilizing a catalytic converter to control CO and UBHC and a selective catalytic reduction (SCR) system for NOx. Results demonstrated that the copper-coated engine (CCE) achieved lower emissions compared to the conventional engine (CE), with the optimum ignition timing being 28° BTDC for CE and 27° BTDC for CCE. Gasohol (20E) reduced CO, UBHC, and NOx emissions more effectively than gasoline alone. Sponge iron as an oxidizer in the catalytic system further reduced emissions, especially at optimum ignition timing. However, advancing ignition timing increased NOx levels in both CE and CCE. The study mentioned the potential of modified combustion chambers and optimized ignition timing to mitigate automotive pollution.

2.31Yasin Karagöz PhD, Hasan Köten PhD, Övün Isın PhD, Özgün Balcı MSc, Onur Gezer MSc,(37)

This research investigates and compares the performance, emissions, and combustion characteristics of petrol- and methane-fueled spark-ignition (SI) engine under full load, stoichiometric conditions, and variable engine speeds (2650–3650)rpm. Experimental data were collected for petrol and methane at selected engine speeds, and a validated theoretical model was developed to simulate and analyze the differences. Methane's high knock resistance allowed optimization of ignition advance for maximum thermal efficiency. Results showed that methane reduces maximum in-cylinder pressure and heat release rates due to its lower energy density, flame velocity, and energy content. Indicated thermal efficiency (ITE) and indicated mean effective pressure (IMEP) decreased by 12.1% and 13.82%, respectively. Methane-fueled engines achieved slight enhancement in carbon monoxide emissions (5.4%) and significant reductions in NOx emissions (14.7%) but exhibited a 28.5% increase in total hydrocarbons (THC) emissions. The observations emphasize methane's potential as a clean-burning alternative fuel for improving emission profiles.

2.32 Nguyen Anh Ngoc[†]*, Nguyen Xuan Khoa[†]& Chu Duc Hung[1],(38)

This study examines the impact of combustion duration on the emission characteristics and performance of a motorcycle engine. An experimental system equipped with a dynamometer and a simulation model using AVL-Boost software was employed to determine the residual gas ratio and engine emissions. Combustion duration was varied from 40° to 110° crank angle with variable engine speeds of (6000-7000-8000) rpm. Results showed that combustion duration significantly influences residual gas ratio, effective release energy, and emission trends, which vary across engine speeds. At 6000 rpm, the optimal performance was recorded at 60° combustion duration, achieving a maximum effective release energy of 0.826 kJ and a minimum residual gas ratio of 0.22%. Meanwhile, engine speed increases to 7000 rpm and 8000 rpm yielded minimum residual gas ratios of 0.14% and 0.15%, respectively. It was found that higher residual gas ratios reduced effective release energy and increased CO emissions, while NOx and HC emissions decreased with prolonged combustion durations. The study concludes that optimal combustion duration improves engine performance, with brake torque maximized at specific durations for each engine speed. For 6000 rpm, peak brake torque of 22.7 Nm was achieved at 60° combustion duration, surpassing performance at higher engine speeds.

2.33 Peng Zhang, Jimin Ni, Xiuyong Shi *, Sheng Yin and Dezheng Zhang,(39)

This study examines the combustion characteristics of a gasoline/natural gas dual-fuel direct-injection turbocharged engine to explore the synergistic effects of cooperative combustion. A modified engine platform enabled coordinated control of gasoline direct injection and natural gas port injection under low-speed, low-load conditions. Results showed that advancing the ignition timing increased maximum cylinder pressure, heat release rate, pressure rise rate, and combustion temperature, with 28°CA-BTDC achieving optimal power performance. The synergistic effect of the dual-fuel combination was most effective at PES40, providing the best balance of pressure and heat release. Additionally, ignition delay and combustion duration peaked at 20°CA-BTDC to 22°CA-BTDC, with improvements more significant at PES60. This study illustrates the advantages of coordinated

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gasoline and natural gas dual-fuel combustion, emphasizing optimal ignition timings and PES ratios for enhanced performance and efficiency.

2.34 Ahmet Alper Yontar[1*], Duygu Sofuoğlu[2], Hüseyin Değirmenci[2], Tahir Ayaz[2], Mert Şevket Biçer[2],(40)

This study numerically examines the effect of ignition advance on the performance and emission characteristics of a dual-sequential ignition engine using a gasoline-methane mixture. Computational fluid dynamics (CFD) analysis, conducted via ANSYS software, examines parameters such as in-cylinder combustion, flame propagation, and emission trends at an engine speed of 2800 rpm under wide open throttle conditions. Variable ignition advance angles of 5, 10, 15, and 20 crank angle degrees (CAD) before the top dead center (TDC) for both spark plugs were analyzed. Results showed that increasing the ignition advance leads to higher in-cylinder pressure, enhanced mean effective pressure, and decreased specific fuel consumption. However, NOx emissions also increased with greater ignition advance. The study recognizes an optimal ignition advance angle of 695° CA for maximizing engine performance while minimizing emissions.

2.35 N.F.O. Al-Muhsen[1,], G. Hong[2] and F.B. Ismail[3],(41)

This study inspects the combustion and emissions characteristics of a DualEI engine under varying direct injection (DI) ratios and engine speeds (3500 and 4000 RPM). DI ratios were adjusted from 0% (DI0%) to 100% (DI100%), and the spark timing for maximum brake torque (MBT) conditions was determined. Results show that MBT timing occurred at DI330 and 30 CAD BTDC, attaining an increase in indicated mean effective pressure (IMEP) from 0.47 to 0.50 MPa as DI ratios increased. Combustion temperatures were reduced due to ethanol's cooling effect, leading to an 8.32% decrease in peak combustion pressure and a 4.04% increase in volumetric efficiency. While emissions of carbon monoxide (CO) and hydrocarbons (HC) increased due to fuel impingement, nitrogen oxides (NO_x) emissions decreased significantly due to cooler combustion temperatures. The optimal engine performance was observed at DI timing of 330 CAD and spark timing of 30 CAD, improving IMEP by 1.52%–2.57% and minimizing coefficient of variation (COVIMEP). Increasing the DI ratio to 60% resulted in a slight enhancement of IMEP and indicated thermal efficiency.

2.36 Rendy Adhi Rachmanto[1*], Martinus Darmawan Bagas Wijayanto[1], Wibawa Endra Juwana[1], Pramodkumar Siddappa Kataraki[2],(42)

This study explores the effects of ignition angle variations on engine performance using a programmable Capacitor Discharge Ignition (CDI) system. Experiments were conducted on a single-cylinder, four-stroke Otto engine with ignition angles set at standard timing, +3°, +6°, and +9° before top dead center (TDC). The results show that advancing the ignition timing enhances torque, power output, and thermal efficiency while reducing brake-specific fuel consumption. The optimal ignition angle was found to be +9°, yielding a peak torque of 6.91 Nm at 6,000 rpm, maximum power of 4.80 kW at 8,000 rpm, and the lowest specific fuel consumption of 0.234 kg/kWh at 6,000 rpm. Additionally, the highest thermal efficiency recorded was 36.04% at 6,000 rpm. These findings exhibit that ignition timing optimization using a programmable CDI can significantly enhance engine performance and fuel economy.

2.37 Jakliński P, Czarnigowski J, Ścisłowski K,(43)

This study examines the performance and emissions characteristics of a spark-ignition engine fueled with 95-octane gasoline (ES95) and ethanol (approx. 92%). Experiments were conducted at a constant engine speed of 1500 rpm.Key variables included ignition crank angle (0°–40°) and air-fuel mixture composition (λ = 0.85–1.25).Results showed that ethanol-fueled engines exhibit lower efficiency compared to gasoline, with the highest efficiency achieved at high ignition advance angles and rich mixtures (λ = 0.85–1.0). Ethanol substantially reduces harmful emissions, with average reductions of 14.8% in carbon monoxide, and 80% in hydrocarbons and nitrogen oxides. However, ethanol's lower heating value led to a 90% increase in temporary fuel consumption and a 115% rise in specific fuel consumption, resulting in a shorter vehicle range.

2.38 Bakhshi Mehul, Pritanshu Ranjan, Anuj Kumar Shukla,(44)

This study investigates the effect of spark plug position and timing on the performance of single and twin-spark engines through computational simulations using Open FOAM. The Xi Engine FOAM solver, integrated with a transport equation for flame front modeling and the Standard k-ε turbulence model, was employed to simulate combustion dynamics during the compression and power strokes. Four cases with variations in spark plug configuration were analyzed. Results indicate that in single-spark engines, early ignition with the spark plug centrally positioned yields optimal performance by facilitating uniform flame propagation. For twin-spark engines, performance is maximized by appropriately timing the flame front collision, with the optimal

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configuration involving a significant time difference between the ignition of the two spark plugs. The results highlight that early ignition improve cylinder pressure and power, provided knocking is avoided, and the flame collision in twin-spark engines must strike a balance between irregular and weak propagation. This study provides insights for optimizing engine configurations to achieve superior performance.

2.39 Kamiński A, Krakowian K, Skrętowicz M, Kupski M, (45)

This study highlights the benefits of optimizing the ignition advance curve, which improve engine efficiency, torque, and power while reducing fuel consumption due to lower airflow mass per second, as measured by the MAF sensor. The most substantial enhancement occurs in the range of highest volumetric efficiency and torque output, with minimal effects at high engine speeds. Increased engine load and speed raise the risk of knocking, which can compromise engine durability. Using the Ford EEC V computer control unit, adjustments to fuel maps, spark advance maps, and injection angles were achieved, demonstrate the flexibility of PCM recalibration. Emissions compliance shifted successfully from CARB to EURO 3 standards without unintended engine behavior or transmission performance issues. Key enhancement included a power increase of 11.5% at 2400 rpm, a torque gain of 13% at 2000 rpm, and a peak efficiency improvement of 3.3% at 3200 rpm. The largest spark advance adjustment occurred at 2400 and 2600 rpm, amounting to 10.75°.

2.40 Suyatno [a], Helen Riupassa [a], Susi Marianingsih [b], Hendry Y. Nanlohy [a],*,(46)

This research investigates the effect of varying ignition timing on spark ignition (SI) engines using bioethanol-isooctane mixtures. Three ignition angles—9°, 12°, and 15° BTDC—were tested to optimize combustion pressure and enhance engine performance. Experiments were conducted at both macroscopic levels (engine performance) and molecular levels, focusing on atomic bonds and bond angle properties of the fuels. Results show that isooctane's carbon chain possesses more non-rotatable bonds and a wider bond angle (~121.17°) than bioethanol (~110.05°). Bioethanol's lower viscosity enhances its reactivity and flammability, with the optimal ignition timing for bioethanol and isooctane observed at 12° and 9° BTDC, respectively. The BE50 mixture illustrate superior performance at 12° BTDC, offering enhance power, torque, and thermal efficiency alongside lower CO and HC emissions. The presence of OH groups and bioethanol's bent molecular geometry contribute to increased polarity, reactivity, and environmentally friendly combustion.

2.41 Zdeslav Juri´c[1], Tino Vidovi´c[2], Jakov Šimunovi´c[2],(47)

This study assesses the effect of adding hydrogen to gasoline in a four-stroke engine, using comprehensive thermodynamic comparative analysis conducted with self-developed engine model on the performance, emissions, and efficiency of the engine when using gasoline–hydrogen blends. The scope of the study extended across various engine operational points to assess how hydrogen enrichment affects engine performance and pollutant emissions. The results show that adding hydrogen to a fuel blend generally leads to a decrease in the engine's effective power, with a considerably reduction of 9.45% observed for blends containing 20% hydrogen. This reduction is attributed to the resultingly leaner air–fuel mixture when hydrogen is added. That is show us integrating hydrogen with gasoline emerges as a viable strategy to improve engine efficiency and lower CO2 emissions. However, this method introduces the challenge of controlling increased NOx emissions, requiring a delicate optimization of engine operational parameters to leverage the advantages while overcoming the negatives.

2.42 Happy Sinkala[1]*,Saliha Özarslan[2], Abdallah Benarous[3,4],(48)

The study show that air-fuel ratio is an important factor in combustion as it controls the amount of energy released, the number of undesired pollutants generated during the process, and whether a mixture is combustible or not. The COVIMEP, the value indicating combustion stability, since the indicated mean effective pressure decreases as the value of λ increases, resulting in a decline in performance utility caused by the depletion excess air ratio mixture, this value to increase. When the combustion stability is achieved, the Indicated Specific Fuel Consumption typically drops because there is less pumping loss as the extent of lean conditions rises. In the case of combustion instabilities, i.e. in higher excess air ratio values in conventional engines, the ISFC value increases. The reduction in thermal efficiency as a result of reduction in heat release under lean combustion. Given that the specific range where fuel to air ratios must fall for ignition to occur, various methods, including adjustments to engine design, operational parameters, and enhancement of fuels, can be utilized to attain stable combustion. Achieving stable combustion, particularly in ultra-lean conditions, results in better efficiency, reduced fuel consumption, and lower emissions compared to a conventional spark ignition engine operating in lean combustion mode.

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2.43 Ravindra S. Deshpande[1] *, Ashok P. Tadamalle[1], R. S. Katikar[1], P. G. Kadam[2] , A. K. Biradar[3] and Sukrut S. Thipse[4] ,(49)

This study shows the effects of mixing of Gasoline-Methanol (GM) fuel on SI engine performance by using M15 fuel blends at Wide Open Throttle (WOT) with dissimilar speeds between 1200 up to 1800 rpm. The study demonstrates that BSFC of M15 blends increased as much as regular gasoline for all engine speeds at full load, while engine torque and brake power (BP) is less than regular gasoline. It locate that M15 fuel blend was appropriate for both increasing engine performance and reducing emissions. Experimental test results show that, compared with standard gasoline (M0), the M15 blend requires more fuel consumption because of its lower calorific value, and the brake power obtained was less than regular gasoline. At speed 1800 rpm, BP will drop as the percentage of GM blends increases. At constant engine speed the BSFC obtained when using the M15 blend is lower than the regular gasoline. Also, The Brake Torque (BT) obtained by using an M15 fuel blend, which is more than regular gasoline (M0) at constant engine speed conditions.

2.44 Xiongbo Duan[1] |Lining Feng[1] |Yan Xia[2],(50)

This paper comprehensively reviewed the fundamental reasons and mechanisms of the combustion cycle-to-cycle variations (CCV) of the SI engine. In addition, the characteristic parameters and characterization methods of the CCV, the laws and influencing factors, numerical simulation methods were introduced in detail to quantitatively analyze the performance, combustion, and emissions characteristics of the SI engine. The current state of research of the CCV of the SI engine from the experimental and numerical simulation aspects was also presented and discussed. Lastly, effective methods and strategies were proposed to improve the combustion process and fuel economy, and reduce exhaust emissions of the SI engine for high efficiency and clean combustion.

2.45 Marietta Markiewicz,(51)

This study examines the effect of E100 (pure ethanol) fuel on the performance, emissions, and noise of spark-ignition engines, addressing the need for alternative, eco-friendly fuels amid stringent emission norms and resource depletion. The research analyzed parameters such as power, torque, emissions (oxygen, carbon dioxide, hydrocarbons, solid particles), and noise, along with the effects of control system software adjustments. Results indicate that E100 reduces exhaust emissions, particularly carbon dioxide and hydrocarbons, while maintaining adequate performance with a 10% fuel dose increase. The fuel blend composition substationally influenced emissions, with ethanol showing a positive environmental effect. Adjusting engine software enhanced power and torque, demonstrating the viability of alternative fuels for reducing emissions and conserving natural resources without compromising engine performance.

2.46 ISAM E. YOUSIF*, ADEL MAHMOUD SALEH,(52)

This study inspects the blending of Iraqi neat gasoline with ethanol and butanol in various volume fractions, including E50B20 (50% ethanol, 20% butanol), E20B50 (20% ethanol, 50% butanol), E50 (50% ethanol), and B50 (50% butanol). Engine performance and pollutant emissions were evaluated using LOTUS Engine Simulation v6.01a, focusing on brake-specific fuel consumption (BSFC), thermal efficiency, and pollutant emissions (CO, UHC, and NOx). Results indicate that the B50 blend demonstrated optimal engine performance with the lowest BSFC and enhance thermal and volumetric efficiencies. All blends showed reduced CO and UHC emissions compared to gasoline, with minor reductions in NOx. The analysis shows that alcohol-gasoline blends are viable replacements for traditional gasoline in SI engines, with B50 being the most promising blend.

2.47 Ivan Arsie [1], Emmanuele Frasci [1,2], *AdrianIrimescu[2] and Simona Silvia Merola [2],(53)

This methodology, tested with commercial gasoline, provides a framework for future evaluations of low and zero-carbon fuels, including hydrogen and methanol. So, the study focuses on converting a small passenger car with a three-cylinder spark ignition (SI) engine to use alternative fuels. A spark timing optimization methodology was developed using MATLAB/Simulink® R2024a–GT-Power co-simulation to independently optimize the ignition timing for each cylinder, targeting to minimize indicated specific fuel consumption (ISFC) while mitigating knock risk. Performance analyses were conducted across varying speeds and load conditions. At full load, significant advancements in spark timing for individual cylinders reduced ISFC by up to 2% under optimal conditions. At part load, the optimized spark timing improved combustion phasing and fuel efficiency, particularly at 3000 rpm and 50% load, achieving early combustion phasing (CA50 around 5°CA ATDC). Results showed reduced knock tendency and cylinder-to-cylinder variations under lighter loads.

2.48 Saraschandran Kottakalam[1,*,†], Ahmad Anas Alkezbari[2,*,†], Gregor Rottenkolber[1,†] and Christian Trapp [2,†],(54)

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This research presents a comprehensive experimental methodology to study the spark ignition phenomena under engine conditions, aimed at enhancing simulation models for accurate prediction of combustion processes. High-speed cameras were used to observe the temporal evolution of visible spark plasma and its interaction with the surrounding flow. A modified Background-Oriented Schlieren (BOS) technique was employed to visualize heat transfer from the plasma, providing high-resolution density gradient measurements. Experimental observations indicate slower plasma velocities compared to the surrounding flow, leading to the inclusion of a user-defined Velocity Multiplier (VM) in the simulation model. The VM was calibrated to match simulated spark lengths with experimental measurements, yielding a calibrated value of 0.675 that improved simulation accuracy across various conditions. Furthermore, heat transfer mechanisms were incorporated into the model, improving the representation of the heated plasma volume. The resulting improved ignition simulation model, CADIM-VM-TWP, demonstrated excellent agreement with experimental data, offering a more accurate physical representation of spark ignition phenomena. This work contributes to accelerating the development of advanced ignition technologies for optimized renewable fuel combustion in internal combustion engines.

2.49 Rafiu K. Olalere [a,b,1] , Gengxin Zhang [a,1] , Haoye Liu [c] , Xiao Hongming Xu [a,d,] ,*Ma [d] , (55)

This study investigates the combustion and emission characteristics of MF20 (20% 2-methylfuran, 80% gasoline by volume) and MTHF20 (20% 2-methyltetrahydrofuran, 80% gasoline by volume) blends compared to neat gasoline in a direct-injection spark-ignition (DISI) engine. Tests were conducted under different loads (3.5–8.5 bar IMEP) and fuel injection timings (180–280°CA BTDC) at 1500 rpm. Results exposed MF20's superior anti-knock performance and extended spark timing flexibility due to its higher research octane number (RON). MTHF20 illustrate improved in fuel economy and the highest thermal efficiency under medium loads. Both blends showed reduced ignition delay, shorter combustion durations, and increased NOx emissions compared to neat gasoline. Emissions analysis showed unburned furans accounted for approximately 3% of hydrocarbon emissions. Advanced injection timing decreased unburned furan emissions for both blends. While the blends improved combustion efficiency.

2.50 Turan Alp Arslan[1*], Hüseyin Bayrakçeken[1], Ahmet Altuncu[2], Emin Çengelci[3], Hamit Solmaz[4],(56)

This research represents a comparative numerical analysis of spark and laser ignition systems in an internal combustion engine using a dynamic CFD model. ANSYS Fluent 2021 R1 was employed to simulate the complete engine cycle with an iso-octane–air mixture working atconstant engine speed.. The results indicates that the laser ignition system improve engine performance, reduced knocking tendencies, and ensured smoother combustion. The optimum performance was obtained at 680 °CA ignition timing with the laser ignition system, yielding power, torque, IMEP, MPRR, and peak pressure values of 16.43 kW, 62.76 Nm, 14.17 bar, 2.47 bar/°CA, and 61.56 bar, respectively. Compared to spark ignition, laser ignition reduced in-cylinder temperatures and combustion duration while maintaining stable combustion. The observations confirm that laser ignition can significantly contribute to future engine development by improving combustion efficiency and performance.[ok]

III. Conclusion

Ignition timing plays essential role in optimizing the performance and emissions of spark-ignition (SI) engines. Advancing the ignition timing (firing the spark earlier) generally increases efficiency and power by allowing for more complete combustion and higher peak pressures at the right point in the cycle. However, excessive advancement can lead to knock (detonation), increased NOx emissions, and potential engine damage.

On the other hand, retarding the ignition timing (firing the spark later) drops the chances of knock and lowers NOx emissions due to lower peak temperatures, but it also reduces power and efficiency while increasing hydrocarbon (HC) and carbon monoxide (CO) emissions due to incomplete combustion.

For optimal performance and emissions control, ignition timing must be carefully calibrated based on engine load, speed, fuel quality, and operating conditions. Modern engines use electronic control units (ECUs) with knock sensors and variable timing systems to dynamically adjust ignition timing for the best balance of power, efficiency, and emissions.

Finaly, conclusion obtained that ignition timing can be used as an alternative method for predicting the performance of internal combustion engines, also engine speed were all found influence performance in this engine.

Future research will explore variations in fuel mixtures, spark plug configurations, and combustion chamber geometries to further optimize system performance.

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ISSN (Online): 2583-7257
Article DOI: https://doi.org/10.47001/ICJES/2025.407001

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Article DOI: https://doi.org/10.47001/ICJES/2025.407001

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Citation of this Article:

Mohammed Zuhair Mala Ali, & Abdulrahman Habo Mohammed. (2025). Spark Timing Influence on the Emissions and Performance of Spark Ignition Engines (Review). *International Current Journal of Engineering and Science - ICJES*, 4(7), 1-17. Article DOI: https://doi.org/10.47001/ICJES/2025.407001

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