A Study on Dual Fuel Engine Combustion and Emissions

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Abstract – Latest research has been carried out into the introduction of a dual-combustion approach to increase the heat efficiency of internal combustion engines while reducing their emissions at the same time. Compression ignition (CI) motors use double-fuel combustion to facilitate the use of more easily accessible gas oils or modern combustion methods. In this study we have studied about the dual-fuel compression-ignition engines, effects of exhaust emission, conventional dual-fuel compression-ignition engines, advanced dual-fuel compression-ignition engines, dual-fuel spark-ignited engines which is concluded that in compression ignition (CI) engines, Dual-fuel combustion provides an efficient solution for timing and extending engine load limits to regulate combustion. To this end, both a high and low-reactivity fuel is inducted, the concentration is adjusted to one another and hence the reactivity of the fuel mixture is optimized under various operating conditions (on a cycle-by-cycle basis).

Keywords – Natural Gas, Combustion, Emission, Dual Fuel

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INTRODUCTION

Transport energy demand is rising as a result of the population and economic policies are aimed simultaneously at improving productivity and reducing dangerous environmental pollutants including nitrogen oxides (NOx), unburned hydrocarbons (UHC) and particulate matter (PM). This has contributed to considerable concern in the electrification of vehicles as well as safer and more powerful motors. The cost and energy densities restrictions of batteries also present challenges, as electrification and hybridization of vehicles expand. It is anticipated, however, that 60% of light-duty cars would already be driven by internal combustion engines in 2050, and that in the near future most heavy-duty markets will be fueled by engines.

Clean, high-efficiency engines are essential in order to comply with the strict environmental regulations and provide power efficiently. A number of methods for improving the performance of today's engines have been investigated. Technologies such as variable valve scheduling to minimize gas exchange pumping loss and variable geometry turbochargers to harvest exhaust energy in the hope of improving engine power density. More complex injection devices for injecting the fuel at higher pressures were also deployed in order to foster combustion of fuel and air. Improved mixing would improve the quality of combustion and reduce particulate matter pollution. In order to improve dual combustion strategy, more advanced fuel injection technologies may also be utilized.

In both spark-ignited (SI) and compression-ignited (CI) engines the dual-fuel combustion techniques have been shown to be beneficial. Dual fuel technology can be used in the fight against knock in SI engines. Knock usually comes as the fuel air combination creates autoigniting in high-temperature and high-pressure in cylinder environments and pressure shock. Knock will seriously harm the motor which is more common when heavy loads exceed their maximum performance. As such, high output of the engine is mostly restricted to knock with petrol fuel. The combustion phase of the engine is always postponed to a sub-optimal time, to prevent knocking in high load conditions. While this prevents dangerous premature combustion, it often contributes to productivity cuts.

Alternatively, the use of a fuel with a higher amount of fuel octans (typically defined by the octane number of study (RON), engine octane number (MON) or anti-knock index (AKI) may also avoid knock. Fuels that have a high-octane rating will work even at high loads, but are more costly at the ideal combustion phase. If high octane fuel is used in dual fuel motors, it may permit "octane on call" technique. The use of low-RON and high-RON fuel concurrently implements octane-on-demand technologies on dual-carburant engines. The knock tolerance of a fuel combination may be adjusted with dual fuel capability in real time to prevent knocking, thus keeping the combustion phase optimum. Such strategies allow for minimizing fuel costs as a lower priced, low RON fuel in lower operational conditions can be used and a high RON fuel can only be used in knock-prone conditions.

Dual fuel injection techniques for the retrofitting of old diesel engines using less expensive fuel were historically used on CI engines. The introduction has also allowed reductions of PM pollution in addition to the use of an alternate source of electricity. In modern times, dual combustion techniques were employed in order to encourage the usage of less reactive fuels and to make more advanced combustion techniques easier. Some dual-fuel combustion modes have shown considerable potential and have a high performance and low pollutant emission. Typically, over a broad variety of operations, two fuels with different reactivities are concurrently used to encourage fuel prefixation, to reduce the reactiveness of the in-cylinder mixture. This is done throughout.

Although these dual combustion modes are a promise, they are not actually used in many manufacturing vehicles as a result of a wide range of challenges including control problems with combustion phases and stable combustion with the most complicated combustion strategy and market adoption and infrastructure restrictions. Most such double combustion techniques are currently tested on single-cylinder engines in tightly supervised laboratory conditions. Once extracted from the laboratory, combustion heterogeneity and phasing difficulties begin to be dominant when applied on multi-cylinder engines. The existence of major cylinder-to-cylinder differences will contribute to uneven power output and potentially to damaging engine conditions is one such problem. Moreover, many dual combustion techniques on CI engines utilize more precipitated combustion and, as a result, chemical kinetics regulate the time of the combustion event. The period of the combustion incident is therefore more difficult. In order to reduce the combustion variations and ensure an optimized combustion phase, advanced control methods are required.

Dual-carburant engines can be very powerful and safe, but can also be constrained by the complexities of customer adoption and infrastructure. In a sufficiently wide area, users must fill out two fuel tanks and have access to required fuels. This section will address technical advances leading to today's dual fuel motors and the progress achieved on dual-fuel CI and SI motors.

DUAL-FUEL COMPRESSION-IGNITION ENGINES

The medium- and heavy-duty industries control diesel or compression-ignition engines with increased performance and high torque output ability. Such engines need a more reactive fuel which automatically ignites at high temperatures and pressures. The fuel used in CI engines is thus restricted. The dual-fuel engines offer a means of using fewer reactive fuels so they can generate ignition by leveraging a second reactive fuel. Dual-fuel principles were also examined to limit pollution from engines. Conventional diesel combustion is powered by diffusion and is usually followed by high oxide emissions of nitrogen (NOx) and particulate matter (PM). Emissions from nitrogen oxides derive from elevated in-cylinder temperatures that allow the mixture of extra oxygen and nitrogen (carried in by the fresh air). Meanwhile, when hydrocarbon species agglomerate, particulate matter or soot is formed in fuel rich areas. High local equivalence ratios can then contribute to the forming of soot and high local temperatures can lead to the formation of NOx as Figure 1 shows. A large number of heavy-duty CI engines, to avoid these problem areas in order to achieve high efficiency and low emissions, are trying to operate under conditions which promote PR mechanization of fuel and air. By allowing further pre-emptied combustion, it is possible to remove nearly the rich areas in which PM is generated and to obtain shorter combustion times that decrease local temperatures and hence the emissions of NOx.

In the heavy-duty industry dual-fueled engines have also been sought for two principal reasons:

1. In order to use easier, but less reactive, fuels as primary power sources and to start combustion with high-reactivity fuel.

2. To build a more dynamic combustion mode that can be more effective to deliver feeds with various reactivities and fewer NOx and PM.

EFFECTS OF EXHAUST EMISSION

Figure 1 represents a breakdown of country's percentage of energy-related CO_2 emissions from fuel combustion. The Transport contributes 13% of CO_2 emissions while the rest of the field, Agriculture (3%), Building (5%), industries (34%), other energy sector (4%) and electricity and heat (41%). The greenhouse and other pollution have disturbing consequences. Such pollutants may lead to dangerous air pollution levels, global climate change, acid weather, and breathing disorders. The most directly affected people of our world are its air pollution. India is obscured by contamination and forces people to take care whether they drive a motorbike or play outdoors. Figure 2 depicts a woman with a mask riding a bicycle in a location where the environment is poisoned by public health exhaust.

Figure 1: Global carbon dioxide emissions from fuel combustion

Figure 2: A woman protects herself from smog

CONVENTIONAL DUAL-FUEL COMPRESSION-IGNITION ENGINES

With the world seeking to be less dependent on traditional diesel and petrol, the interest in the use of fuels such as natural gas is growing. Some of them are less reactive than traditional diesel fuel, making use of compression-ignition engines in which auto-ignition of the fuel is essential more difficult. One means of using fewer volatile fuels on heavy engines is by double-fuel systems. One of such fuels is natural gas, which is an illustration of the advantages and challenges of this method of motor activity.

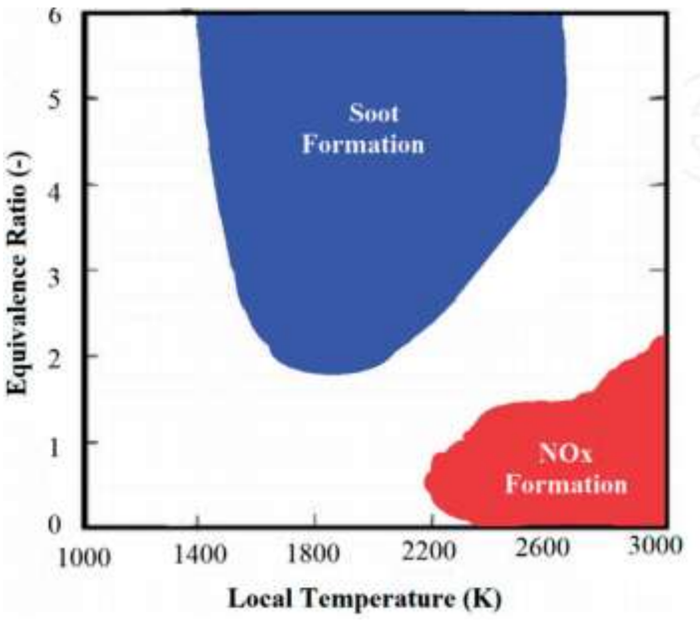

Figure 3: Emissions with respect to local temperature versus local equivalence ratio

Natural gas is harder to fire than standard motor fuel and is therefore easier to integrate into spark-energized motors. Natural gas requires a source of inflammation for heavy-duty vehicles, because it is generally port-injecting and directly injection gasoline. Port-injected fuel is premature to the air and usually has a rapid combustion event controlled by the chemistry of the combustion reaction, although fuel which has to be injected directly into the air and has to be combined with the air is more likely to have a longer combustion case, dominated by the time required for air and fuel to properly combine. Since dual-fuel engines have a fuel that is piped and directly pumped, a two-stage combustion phase also takes place. In pre-measured versus diffused mode, the portion of combustion would greatly rely on the quantity of each fuel used. In the case of a less reactive fuel such as natural gas in CI engines, the combustion procedure is difficult, however the double injecting of fuel will ensure safe combustion. In operation of this form of mode, fuel efficiency reductions of approximately 10% were observed.

The fuel economy or reliability is not only affected, but pollutants of dual combustion are also altered. Up to 60% decreases in NOx and PM have been observed in natural gas diesel dual-fuel motors. These pollutants, however, rely on the fuels used and on the volumes of each combustible used. For example, emissions of particulate matter and particulate size distribution have been shown to rely heavily on the properties of the direct injected combustible and degree of natural gas substitution. High density, reduced viscosity and higher volatility directly injected fuels yield lower particulate quantities. Higher replacement rates for natural gas will therefore increase soot because local supply of oxygen is decreased.

Higher CO and UHC pollutants are normally seen, as in many natural gas engines. Different natural gas replacement patterns were investigated and found that, because of pollution restrictions, only lower quantities of natural gas could be used at low loads, whereas higher proportions of the gas could be used at high loads. The aim was to prevent these pollution limitations with the direct injection of all gases, higher fuel injection pressures and modified engine control systems. Induction of double-fuel engines to minimize pollution was also implemented after treatment technologies including diesel catalysts for oxidizing and diesel particulate filters and urea-selective catalytic reducing systems. However, advanced combustion technologies and methods of optimization are probably necessary to make effective usage of high volumes of natural gas.

A majority of traditional dual-powered experiments have concentrated on natural gas but even a range of fuels which are not reactive enough to be used as the sole fuel on a pilot ignition engine can use this method to pilot diesel. Dual fuel principles, including methanol and gasoline, biogas and biodiesel and biogas and diesel were also discussed in tandem with fuel combinations.

ADVANCED DUAL-FUEL COMPRESSION-IGNITION ENGINES

There has been much research of more dynamic combustion modes to drive the engines to higher efficiencies. In order to produce an effective and cleaner combustion, all of these innovative combustion systems also tried to precipitate fuel and air, but could only be used at lower torque ranges. One approach to extend these increasingly modern techniques' operational area is to jointly use two fuel sources with different reactivities such that combustion delays continue to rise and pre-exhaust in more operating regions. This technique is recognized as a compression ignition powered by reactivity (RCCI). In RCCI petrol is pumped separately from high reactivity diesel fuel with low reactivity, such as gasoline. The amount of each fuel should be changed to allow for a postponement of the combustion case, allowing for a sufficient mixing period and for the optimal form of the combustion event. Recent work in RCCI has shown that fuel characteristics different from traditional fuels can be used to form the combustion process and improve motor performance in this mode from 45% to almost 60%. Although the performance gain is important, the usage of RCCI may also be limited by high CO and UHC pollution and high-pressure rates.

- **Reactivity controlled compression ignition**

The use of petrol as a port-injected fuel with a low reactivity and diesel as direct injected fuel with high reactivity at the University of Wiscons in Madison was initially an RCCI style combustion. Two fuels with differing properties may be used to stratify the in-cylinder mixture reactivity, resulting in longer ignition delays and an improvement in premature time. Under these settings, diesel combustibles with lower reactivities have shown advantages as the local reactivity gradient has been increased. In these modes the more volatile fuel elements are used at higher rates and a greater proportion of UHC pollutants are absorbed by the slower burning competent

Alternative sources, such as ethanol and natural gas, have also shown positive outcomes in operating environments such as RCCI, and these options seem to benefit more effectively. The researchers from Navistar, The National Laboratory of Argonne, and Wisconsin Engine Research Consultants have concluded that the use of E85 as a low reactivity fuel could lead to increased loads and efficiency with RCCI. Although more conventional petrol and diesel double-fuel use achieved a BMEP of 11,6 bar and BTE (43,6%), it enabled the use of E85 diesel to be expanded to 19 bar BMEP with a BTE of 45,1%. Subsequent research conducted by RWTH and FEV University found that higher amounts of ethanol could be leveraged under lower load conditions when used with diesel and ethanol and would have more stable combustion and less UHC emissions. However, as the load rose, more diesel was needed in order to maintain a reasonable cylinder pressure volume.

Any of these harmful effects on CO and UHC pollution may be offset by more advanced fuel injection techniques. More recent study, for example, has examined the usage of port-injections of ethanol with a direct multi-pulse diesel injection. In RCCI-type settings, a double pilot injection reduced the UHC and CO emissions. Additional approaches including using higher injection pressure have also been demonstrated to improve performance and to further reduce NOx, CO, UHC and PM pollution.

- **Challenges with reactivity-controlled compression ignition**

While RCCI approaches are promising, they face many technological challenges. Firstly, the difference from cycle to cylinder and cylinder to cylinder can be more pronounced than with traditional diesel combustion. As the mixing of fuel and air is important and large volumes of recirculated exhaust gas are normally leveraged in such modes, minor changes in the volume of fuel on the in-cylinder and gas mixing will result in major changes in the phase of combustion. The regulation strategies and additional engine sensors are likely to be more difficult to fight against such variations.

Secondly, regulation in the combustion phases of these modes is difficult, since the combustion mechanism is dominated by chemical kinetics rather than by an injection event directly. Control methods should aim to keep the fuel blend ratio and direct injection time to an optimum burning stage while maintaining the pressure increase intensity and combustion fluctuations do not reach reasonable limits. Successful usage of RCCI will also entail swapping between conventional lower-load diesel combustion and dual-load service. The clean and effective medium combustion technologies that can be used by themselves and in transformations from traditional diesel combustion to RCCI can be implemented in intermediate modes such as the 'double fuel combustion premixed' and the 'partly premixed compression ignition'

UHC and CO emissions are often higher in RCCI modes, as mentioned before. It is assumed that local equivalence ratios can fall below the natural gas inflammability limit and lead to emissions of unburned hydrocarbons, but that new after-treatment systems will be necessary for such engines. Consumer adoption of dual-fuel engines is also a problem. Since users cannot fill two fuel tanks, Splitter et al. have been exploring a way to allow RCCI to use gasoline and di tert-butyl period enhance cetane (DTBP). This research used gasoline as the low-reactivity fuel, but gasoline combined with different DTBP concentrations as the high-reactivity fuel. A maximum gross ITE of 57 percent was reached with emissions close to RCCI dual fuel norm.

DUAL-FUEL SPARK-IGNITED ENGINES

Dual combustion techniques were mainly addressed in the preceding segment on medium- and heavy-duty engines. These use of dual-fuel combustion strategies was normally limited to compression-ignition engines with traditional diesel fuels. Nevertheless, the light-duty spark ignited motors have also been set up with a dual combustion mechanism in recent years. This segment would explore how dual fuel combustion is carried over and used on light-service SI motors.

The SI engines often encourage the use of alternative fuels such as ethanol and methanol through a double-fuel combustion approach. More and more legislation is enforced by the government which promotes the use of biofuels in transport. Current law mandates EU Member States to meet by 2020 a minimum target of 10 percent for the usage of sustainable fuels (biofuels or renewable fuels). In the US, the usage of ethanol in petrol was encouraged by fiscal motivation to emulate Brazil's performance. The attempt to profit from opportunity or comply with regulations has driven engine producers to consider the use of biofuels and other alternative fuels to introduce dual-fuel combustion in spark-induced engines.

Furthermore, the advancement of improved motor knock control strategies was one of the main reasons for implementing dual fuel combustion in SI motors. The auto-ignition of fuel inadvertently knocked engine will lead to major engine damages in localised high pressure and temperature areas inside the cylinder and is one of the key obstacles for the SI motors. The traditional solution to prevent knocking in spark-ignited (SI) motors involves delaying the burn phase by slowing down the chimney. A combustion accident that occurs later in the combustion stroke (a little farther from the dead center) is less likely to crash as combustion friction and temperature are less. Delaying the combustion phase decreases fuel efficiency, since the late combustion will extract less work.

An alternative way to prevent knock without losing fuel quality is to supply Si motors with a dual combustion approach. The fuel's propensity to auto-ignite is based not just on the cylinder conditions but also on the knock resistance. Increasing the octane rate of the fuel therefore prevents knocking without compromising fuel efficiency. Dual-fuel motors will respectively use a low RON fuel and a high RON fuel to maximize the knock resistance of the fuel mixture by control the proportion of each fuel injected. Many researchers have examined how a dual-fuel approach can be implemented to stop knocking.

The Massachusetts Institute of Technology researchers have suggested an ethanol enhanced engine design that eliminates the knock-on engine at high pressure by using direct ethanol injection. Their studies show that implementing the secondary fuel injection method will allow engine activity at significantly higher turbocharging speeds and potentially improve driving cycle performance by some 30%. In order to reduce the knock on a single cylinder SI turbine, researchers have applied a dual-fuel approach. The analysis indicates that the double injector strategies (using the high RON fuel of ethanol or methanol) had advantages over nearly every load relative to a single gasoline-direct injection (GDI) strategy to achieve indicated performance and emissions (HC, CO, CO2). In addition, a well-to-wheels greenhouse gas (W-t-W) pollution evaluation was performed to quantify total emission benefits of the knock-mitigating method for dual-fuel gases. Their research has shown that the overall loss of CO2 with the use of a dual fuel injection system is 30 percent W-t-W.

The dual fuel SI configuration offers three main advantages: (1) the engine can be further downsized and used under high-pressure conditions. (2) The fuel knock resistance can be adjusted based on operating point while maintaining the optimal combustion phase (maximizing engine efficiency). The advantages of a manufacturing passenger car have been shown in cooperation with IFP Energies new at the Saudi Aramco team. "A chance to increase fuel economy by utilizing octane only when you need it," says dual-fuel technology. Researchers indicate that the system would increase the quality of fuel and at the same time reducing total energy needs for fuel production in the future. ARFC researchers describe construction of the production car as just the start and outline the near-term aim of a 2-car tank vehicle using only one fuel to one that uses a single onboard fuel upgrade device. ARFC researchers also identify production vehicle creation as just the starting point.

As with the efforts made by Saudi Aramco, the advantages of a dual combustion approach for traditional SI engines are currently being used. The researchers studied the usage of dual fuel on a commercial car and a medium-sized truck at the Massachusetts Institute of Technology. In conjunction with experiments, their modelling studies conclude that substantial improvements in engine brake efficiency can be achieved: 30% for the UDDS and 15% for the US06 cycle. Studies conducted by the researcher at Institute Motor, CNR indicate a considerable improvement in thermal performance (~ 10 percent) and substantial reduction in emissions of both particulates and particulates (60–80 percent) as a secondary fuel for port ethanol injection.

The combustion of double fuel offers a promising way to enhance the thermal performance of sparked engines. There has been a growing focus on technologies with the potential to leverage other fuels such as ethanol and methanol and the capacity to eliminate knocking without affecting thermal performance. Nonetheless, researchers would look for pathways to render the technology available to daily market multiple tank and multiple fuels.

CONCLUSION

Since the beginning of the dual-combustion technique, its use has been critical in stationary and heavy-duty applications as a method for improved regulation of combustion. The incorporation of dual combustion into transport offers great advantages both in terms of improved fuel economy and reduced harmful pollution. This technology is being made significantly for heavy-duty, medium and light-duty engines in the car industry. The ongoing study on combustion of dual-fuel promises to promote ways of using gaseous fuels and green energies that are easier to use. The identified advantages both for compression and spark-induced engines require further funding, experiments and endeavors to make greater use of these gains.

Dual-fuel combustion provides an efficient way of controlling combustion times and extending engine load limits in compression ignition (CI) engines. This can be accomplished by the injection of high and low reactivity combustion fuel and the reactivity of the fuel mixtures (by cycling) for various operating environments. This can be done by changing the proportion of one fuel to the other. The optimization of the fuel octane rating in ignited (SI) motors is an alternative way of avoiding abnormal combustion (engine knock due to auto-ignition). In order to prevent knocks, the traditional SI engine depends on late spark timings to reduce reliability and produce greater emissions. Two oils with high and low octane ratings can be used to change the octane of the fuel combination to prevent knock without scarification engine performance with double-fuel combustion techniques.

Although there are several possible advantages for dual fuel operations, the application of these techniques on CI and SI motors is often challenging. These problems are aggravated in connection with other advanced combustion techniques, including various valve times and high

EGR circulation, if dual combustion is applied. The fundamental challenges involve increased combustion variance and difficulty in changing the fuel mixture to manage the time of burning efficiently (in CI engines and SI engines). Although technology has been used effectively in stationary applications, it still faces limited challenges to put in place a dual-fuel strategy for mobile applications, especially in transport. In addition to the technological difficulties involved with the double fuel engine, the societal opposition to the need for and loading of two fuel tanks is a key concern for its introduction into the automobile industry. To ensure that the technology effectively enters the market, it is essential to overcome the technological and social hurdles in terms of improving fuel quality and reducing harmful pollution clearly.

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