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A Review on Internal Combustion Engines

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***Abstract*—The Internal combustion engines are devices that generate work using the products of combustion as the working fluid rather than as a heat transfer medium. To produce work, the combustion is carried out in a manner that produces high-pressure combustion products that can be expanded through a turbine or piston. The engineering of these high pressure systems introduces a number of features that profoundly influence the formation of pollutants. Internal combustion engines are most commonly used for mobile propulsion in vehicles and portable machinery. In mobile equipment, internal combustion is advantageous since it can provide high power-to-weight ratios together with excellent fuel energy density. Generally using fossil fuel (mainly petroleum), these engines have appeared in transport in almost all vehicles (automobiles, trucks, motorcycles, boats, and in a wide variety of aircraft and locomotives). The review paper highlights the internal combustion engines and suggests technologies for their future.**

***Index Terms*—Review, Internal Combustion engines, Fuel Conversion Efficiency, Fluid Mechanics, Alternative fuels, Future of IC engines.**

I. Introduction

An internal combustion (IC) engine is any engine that uses the explosive combustion of a fuel to push the piston within a cylinder - the piston's movement turns a crankshaft that then turns the car wheels via a chain or a drive shaft. The different types of fuel commonly used for car combustion engines are gasoline (or petrol), diesel and kerosene [1]. The aim of the present paper is to provide a comprehensive review of the IC engines, starting from evolution to their future.

II. History

Many people claimed the invention of the IC engine in the 1860's, but only one has the patent on the four stroke operating sequence. In 1867, Nikolaus August Otto, a German engineer, developed the four-stroke ‘Otto’ cycle, which is widely used in transportation even today. Otto developed the four-stroke IC engine when he was 34 years old [1]. The Diesel Engine was invented in 1892 by another German engineer, Rudolph Diesel. The Diesel engine is designed heavier and more powerful than gasoline engines and utilizes oil as fuel. Diesel engines are commonly used in heavy machinery, locomotives, ships and some automobiles [1].A brief outline of the history of the IC engine is as follows [1]:

- 1680 – An internal combustion engine that was to be fueled with gunpowder was designed by a Dutch physicist, Christian Huygens (but never built)
- 1807 – An internal combustion engine that used a mixture of hydrogen and oxygen for fuel was invented by Francois Issac de Rivaz of Switzerland. He also designed a car for his engine- the first IC powered automobile, which was, however, a very unsuccessful design
- 1824 – An old Newcomen steam engine was adopted to burn gas, by English engineer, Samuel Brown which he used to briefly power a vehicle up Shooter’s hill in London
- 1858 – Belgian-born engineer, Jean Joseph Etienne Lenoir invented and patented a double-acting, electric spark-ignition IC engine fueled by coal gas. Lenoir attached an improved engine (using petroleum and primitive carburetor) to a three-wheeled wagon, in 1863, which managed to complete an historic fifty mile road trip
- 1862 – Alphonse Beau de Rochas, a French civil engineer, patented but did not build a four-stroke engine
- 1864 – Siegfried Marcus, Austrian engineer, built a one-cylinder engine with a crude carburetor. He attached this engine to a cart for a rocky 500 foot drive. Several years later, Marcus designed a vehicle that briefly ran at 10 mph that a few historians have considered as the forerunner of the modern automobile by being world’s first gasoline-powered vehicle
- 1866 – German engineers, Eugen Langen and Nikolaus August Otto improved on Lenoir's and de Rochas' designs and invented a more efficient gas engine
- 1873 – An American engineer, George Brayton, developed a two-stroke kerosene engine (it used two external cylinders), which was unsuccessful. However it was considered the first safe and practical oil engine
- 1876 – A successful four-stroke engine was invented and later patented by Nikolaus August Otto, known as the ‘Otto cycle’
- 1876 – The first successful two-stroke engine was invented by Sir Dougald Clerk
- 1883 – French engineer, Edouard Delamare-Debouteville, built an engine that ran on stove gas which was a single-cylinder four-stroke engine. It is

not certain if he indeed build a car, however, Delamare-Debouteville's designs were very advanced for the time, ahead of both Daimler and Benz in some ways at least on paper

- 1885 –The prototype of the modern gas engine, with a vertical cylinder and with gasoline injected through the carburetor was invented by Gottlieb Daimler (patented in 1887). He first built the two-wheeled vehicle the 'Reitwagen' (Riding Carriage) with this engine and a year later built the world's first four-wheeled motor vehicle
- 1886 – Karl Benz received the first patent (DRP No. 37435) for a gas fueled car, on January 29
- 1889 – An improved four-stroke engine was built by Daimler, which had mushroom-shaped valves and two V-slant cylinders
- 1890 – Wilhelm Maybach built the first four-cylinder, four-stroke engine

Engine design and car design were integral activities, almost all the engineers mentioned above also designed cars, and a few went on to become major manufacturers of automobiles. All of these inventors and more made notable improvements in the evolution of the IC vehicles.

III. Fuel Conversion Efficiency

It is largely accepted that the combustion efficiency of a modern IC engine is well optimized, with approximately 98% of the energy contained within the fuel being released on combustion in diesel engines and 95-98% in gasoline engines. However, the useful energy leaving the engine (termed 'brake work') is typically only 40% of the fuel energy. The energy that is used to provide drive to the wheels is less than the brake work, since a fraction of this needs to be used to drive ancillaries such as water pumps and the alternator. This inability to convert all the chemical energy into brake work is termed the 'gross indicated thermal efficiency'. The overall efficiency of the engine is termed the 'fuel conversion efficiency' and is defined in Eq. (1) [2]:

$$\begin{aligned}&Fuel\ Conversion\ Efficiency\\&\qquad = (Combustion\ Efficiency)\\&\qquad * \text{(Gross Indicated Thermal Efficiency)}\end{aligned}$$

IV. Fluid Mechanics Of IC Engines

The major roles of fluid mechanics in gasoline and diesel engines are firstly to prepare the mixture of fuel and air for combustion and secondly to control combustion through large- and small-scale mixing. The mixture preparation in conventional gasoline engines is achieved mainly through the induction system, which generates the bulk motion and turbulence required to mix the two phases prior to ignition. In diesel engines, the induction system and chamber geometry control the air motion and the mechanics of fuel injection plays an important role in air utilization and pollutant formation [3]. Although there are flow characteristics that are common to all engines, the exact character of the in-cylinder flow depends on the particular engine under investigation. However, the hostile environment of internal combustion engines and the lack of appropriate instrumentation have discouraged early attempts to probe the in-cylinder flow. Fortunately, the advent of lasers and the recent development of laser-based techniques for the measurement of velocity and scalar properties under operating conditions have allowed detailed mapping of the flow and improved understanding of the in-cylinder fluid mechanics. The detail that these techniques can provide has encouraged the development of analytical computer methods that offer promise of predictive capabilities that may reduce the time required to evaluate new design concepts in gasoline and diesel engines [3].

V. Measurement And Calculation Of In-Cylinder Flows

The general characteristics of the in-cylinder flows in internal combustion engines that are common in both gasoline and diesel types can be summarized as follows [3]:

- Unsteady or non-stationary flow as a result of the
- Turbulent flow at all engine speeds and for all inlet
- Three-dimensional flow as a result of the engine
- Bulk flow in phase with the engine cycle
- Cycle-to-cycle variations in local flow properties
- Time scales associated with the bulk flow variations of the same order as the turbulent time scales.

Additionally, when analyzing the long term perspectives of the IC technology, oil dependence has been judged a major drawback related to the risk of crude reserves depletion. However, due to technology advancements in oil discovery and recovery, proved oil reserves to production ratio has held relatively constant at 40-43 years since the mid1980s, while probable reserves to production ratio is greater than 130 years. These figures could vary significantly with the increase of the global car fleet, but oil depletion is not the main reason today for technological evolution [4].

VI. New Fuels

Next generation biofuels are to play a significant role in greenhouse gases (GHG) abatement. According to examples of default GHG reductions rate are 19% for palm oil bio diesel, 52% for sugar beet ethanol, and 83% from biodiesel. Bio fuels shares increase may be a cost effective solution for lowering the GHG impact of the automotive IC engines. According to the next generation bio fuels combined with IC engines may provide a CO2 cut similar of the development of electrical vehicles and renewable electricity generation share, but with a lower lifetime incremental cost of the vehicle [4]. Biofuel share is already significant in countries like Brazil, and many other countries are articulating laws for increasing biofuel share. As a consequence, future engines are expected to have an increased tolerance to variations in the fuel quality. Such property will provide freedom to the user when refueling, and also will allow the engine manufacturer to cope with the regional differences in fuel quality. Different fuels may present non-negligible variations in heating value, stoichiometric air-to-fuel ratio, and reactivity, thus influencing engine performance and emissions. Dealing with excessive sulfur content, which poisons after-treatment catalysts, is significantly challenging, as it may be the operation of different advanced combustion concepts with an uncontrolled fuel reactivity [4].

VII. Natural Gas As An Alternative Fuel

Natural gas defuses in air fuel mixing at lower inlet temperature than is possible with either petrol or diesel. This leads to easier use starting more reliable idling, smoother acceleration and more complete and efficient burning with less unburned hydrocarbon present in an exhaust. The higher ignition temperature of gas compared with petroleum based fuel leads to reduced auto ignition delays. Due to the higher ignition temperature, CNG is less hazardous than any other petroleum based fuel. The higher octane rating for natural gas as compared to gasoline allows a higher compression ratio and consequently more efficient fuel consumption. Due to higher compression ratio, CI engines can also use CNG as a fuel [4]. Maintenance cost for gaseous fuel is lower than that of petrol or diesel engines, because gaseous fuel burn clean without carbon deposition. Optimized natural gas vehicles are expected to produce less carbon monoxide near zero reactivity of methane, and may cause less ozone formation than petrol and diesel engines [4]

VIII. Technologies For The Future IC Engine

Although predicting the technological evolution of the automotive market presents difficulties, it must be considered that most changes in the automotive field are progressive. Only regulatory-driven technologies attain a significant market share in less than a decade, as it has happened in the past with Diesel Particulate Filters (DPF) for light duty vehicles, and Selective Catalyst Reduction (SCR) and DPF for heavy duty vehicles [4].

IX. Conclusion

On one hand, legislation is becoming more stringent in terms of pollutants and CO2, while on the other hand globalization, reduced time to market and the variability of fuel quality will change the global scenario. Despite these threats, according to authors' opinion, IC engine will maintain a key role in the next decades, although significant technological evolution is expected for improving the engine efficiency. Technologies already ready for the market include stop-start, some advanced boosting concepts and different systems. Significant advancements in the after-treatment systems have been already implemented to deal with lean combustion. In a mid-term horizon many other technologies could emerge, as low temperature combustion concepts, or modifications in the operation cycle. Since it is not possible to known which will be the winning technology, current situation presents a technological over-diversification, with a huge research and economic effort associated with the wide variety of technologies and combinations. Engine control is an enabling tool at a subsystem level, since many of the advanced concepts need an accurate control for their operation, but especially at a system integration level. The existence of multiple operation modes, and the close interaction between the different subsystems need a holistic approach and the use of a high-level control. Managing subsystem requirements, operation limits and their interaction, providing a systematic calibration procedure and adapting the control system to variations in the environment and to engine ageing, are some of the active fields of research.

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