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A Study on the Emission Reduction in CNG BI-Fuel Engines with Low Flow Rate Manifold Injection

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ABSTRACT

In Air pollutions, Hydrocarbons are one the most polluting emissions with the global warming potential 28 to 36 times that of Carbon dioxide. Thus, it is important to move towards alternate fuels like CNG. However, the main component of CNG – methane, is particularly hard to oxidize through after-treatment and can lead to a significant increase in the cost of a vehicle. Thus, this thesis explores the interaction of CNG and air in Gasoline and CNG Bi-Fuel Engine. It attempts to reduce the emissions by modifying the intake manifold geometry by inserting turbulence generators in the inlet manifold and studying its effects on the performance and emission characteristics of the engine. Other factors such as injection angle, injection timing and even injector nozzle geometry were further varied to reduce the emissions. A final attempt was made to design an optimum intake manifold runner by combining the features listed above. The emissions level of vehicle has been restricted by strict emission limits; not only in India practically in all countries. And trend can be seen in the market day by day increasing the demand of vehicles with Bi-fuel consumption is motivated by economics as well as social-political considerations.

Keywords: CNG Bi-Fuel Engine, Manifold Injection, Turbulence Generators, Injector Geometry

INTRODUCTION

In recent years, Due to global warming, poor air quality, and public health concerns, vehicle emissions have been limited by tight emission standards. Not only in India, but in almost every country. A report published by PwC claims that the automotive sector is responsible for about 21% of the greenhouse gas emissions. Even though reciprocating internal combustion engines look quite simply but they are highly complex machines.It converts chemical energy to mechanical energy after burning of fuel which is somewhere concern for global warming. Hydrocarbons are one the most polluting emissions with the global warming potential 28 to 36 times that of Carbon dioxide [1]. It is important to move towards alternate fuels like CNG. However, the main component of CNG – methane, is particularly hard to oxidize through after-treatment and can lead to a significant increase in the cost of a vehicle [2]. Thus, this thesis explores the interaction of CNG and air in a Gasoline and CNG Bi-Fuel Engine. As it is increasing more and more every day, it is imperative to take corrective action in whichever way is possible. Hydrocarbons are one of the most harmful emissions produced by internal combustion gasoline/diesel engines. Which has a potential for global warming of 28 to 36 times that of carbon dioxide.As the public's awareness about global warming grows day by day, it's critical to take action in every feasible manner. According to a PwC analysis report, the car industry is responsible for around 21% of all greenhouse gas emissions. [3]. Increase the turbulent kinetic energy (TKE) inside the cylinder which should lead to higher in-cylinder pressures and velocity leading to better mixing [4].

LITERATURE REVIEW

Various concepts and case studies of THC emissions and which of these could be responsible in the baseline engine model. Study was conducted basically from textbooks, published papers and presentations available on the internet. Essentially, a CFD simulation was conducted and the cross-sectional images of the intake system and the combustion chamber were obtained. The images were of the mass concentration the fuel which was broadly classified into different zones each given a different shade. The idea was that, for a good homogenous mixture, only one shade should exist throughout this viewable area. Higher number of shades meant a highly non-uniform mixture. This could be one possible way to analyze the mixture formation inside the combustion chamber [6,8-9]. An experimental investigation of CNG as an alternative fuel for a retrofitted gasoline vehicle [7].The mixing of gasses depends on their diffusion rates which, in turn, depend on the difference in molecular masses of the gasses [10]. Reduction of THC emissions can be done in several ways. Using CNG with diesel (dual fuel engines) is one solution to this problem as diesel has relatively lower THC emissions. A paper by Jie Liu et al. [11] researched on the effect on quantity of pilot fuel injection and found that increasing it can result in a significant decrease in HC emissions. A study conducted by S. Orhan Akansu et al. [12] found that an increase in the hydrogen percentage can not only improve the performance but also decrease the HC emissions significantly. Though the addition of H2 may lead to an increase in NOx, these can be controlled via EGR, lean burn, catalytic converter techniques. The same paper goes on to show how an increase in H2 content leadsto a decrease in HC and CO emissions. A similar study by Fanhua Ma et al. [13] showed that the efficiency of the engine can be increased with the help of optimizing the spark timing to the MBT timing. This would also minimize the offset in NOx emissions caused due to the addition of H2. Multiple production methods which use fossil fuels thus leading to more pollution during generation of the hydrogen and hence defeating the original purpose [14].

Use of such an SPFI which can increase the turbulence characteristics inside the chamber thus leading to better mixing and hence lower emissions [16]. The effects of different injector angles, injector nozzle geometries and turbulence generators have been studied with the help of CFD. Thus, they present a qualitative analysis of the mixing taking place and virtually no physical parameters have been calculated to substantiate these claims [19] [20]. A paper by Mofid Garjibanpy et al. on the other hand shows that 12 holes give better mixing characteristics when compared to 4 or 8 holed venturis. Unfortunately, their paper also goes on to say that while using an air-CNG mixer; there is a high variance in the fuel mixtures between consecutive combustion cycles in the engine [21]. Ultra-lean and stratified charged combustion in natural gas spark ignition engines are two examples of cleaner combustion techniques being studied in internal combustion engines. Additionally, it looks into how gaseous fuels like compressed natural gas (CNG) and hydrogen-enriched CNG might lower pollution. The design and development of heavy-duty diesel engines as well as the conversion of diesel engines for CNG operation are also examined, with a focus on the numerical analysis of bi-fuel engines with variable compression ratios, combustion characteristics, and emission control[25-30].

Modifying the Combustible Mixture

Reduction of THC emissions can be done in several ways. Using CNG with diesel (dual fuel engines) is one solution to this problem as diesel has relatively lower THC emissions. A paper by Jie Liu et al. [11] researched on the effect on quantity of pilot fuel injection and found that increasing it can result in a significant decrease in HC emissions. Moreover, it also resulted in lower NOx emissions due to lower combustion temperatures and appropriate lean mixtures. But, the focus of this thesis is to control the emissions in a bi-fuel engine, where CNG and gasoline do not interact with each other. In this case, the engine acts as a pure CNG SI engine when it is not operating in Gasoline mode. The Gasoline tanks are usually present as a limp-home mechanism when the CNG fuel runs out.

Switching to Direct Injection

As seen in the previous sub-section, the fuel can't be changed. Thus, an alternative is to change the method of injection and opt for Direct Injection systems (DI). Since this allows the fuel to be injected directly in the combustion chamber, the amount of air displaced by the gas reduces drastically. This leads to an increase in volumetric efficiency which, in turn leads to more power. Moreover, charge stratification can also be achieved through this technique along with more accurate injection timing [15].

Operating At Leaner Air-Fuel Ratios

A leaner combustion mixture allows for more oxygen presence which in turn means that there are higher chances of the fuel getting oxidized thus reducing the THC emissions. Unfortunately, this could also lead to an increase in the amount of NOx depending on the A/F ratio. Moreover, lean burn also increases the cycle-to-cycle variance [17]. Now, the calorific value of methane is higher than that of gasoline. But, when used as mixture with air, due to the gaseous nature of CNG, the volumetric efficiency reduces (especially in the case of port or throttle body injection). As a result, the volumetric calorific value (calorific value of the A/F mixture) of CNG turns out to be lower than that of gasoline. Thus, in case of using leaner combustion mixtures, there would be a noticeable power loss in the already lower-powered CNG engines [17]. Additionally, new sensors and software will be required (lambda sensors) so the ECU can handle these higher air fuel (A/F) ratios [18]. Thus, this idea was not pursued further.

Varying The Injection Strategy – Timing, Position, Angle And Nozzle Geometry

The injection strategy has a high impact on the amount of emissions as it can decide the charge distribution in the chamber prior to combustion [17]. Studies have been conducted that vary the injection timing and study the effects on emissions. Moreover, a split injection strategy was also studied, which injected various quantities of fuel at different intervals. This achieved a partially stratified charge for an engine operating under lean conditions, leading to good performance characteristics while maintaining low emissions [5]. The implantation of such injection strategies requires a lot of software modification too. Thus, this paper would focus primarily on the injection timing as a function of the injector position.

Improving The Mixture Formation By Inducing Turbulence

An attempt has been made to increase the turbulent kinetic energy (TKE) inside the cylinder which should lead to higher in-cylinder pressures and velocity leading to better mixing [4]. This has been done by modifying part of the intake manifold to include features that will change the flow of the air/charge as it passes through them. Numerous studies in the past have attempted to add turbulence generators inside the manifold to give the air a turbulent flow to induce mixing with the fuel. These include various shapes of vanes and grooves and even other complex shapes that should lead to better mixing [22], [23], [24] and [25]. Various combinations of these features have also been attempted.

CONCLUSION

The aim of this paper was to reduce the raw engine-out THC emissions. The root cause identified after various simulations and literature survey was that CNG wasn't mixing homogenously with air before combustion. To remedy this, the idea was to introduce turbulence generators inside the intake manifold to induce mixing. Additionally, the injector position, timing and angle were changed as well to gain an additional advantage. The injector nozzle geometry was also changed to create multiple plumes and enhance mixing. This was done while keeping the other emissions in check and ensuring the performance did not drop below a certain point. In papers which did, the drop in volumetric efficiency or performance was not listed. Other papers listed various injector nozzle angles, positions and geometries which could have a positive effect on mixing but similarly, the negative effects that the modifications might have had at performance was ignored.

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