PERFORMANCE OF TRANSONIC COMBUSTION OVER HOMOGENIOUS CHARGE COMPRESION INGNITION SYSTEM IN IC ENGINES

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ABSTRACT
Electric and hybrid vehicles (EVs and PHEVs) have emerged on the market, still the internal combustion engines are the most popular automotive power plant. Engine and car manufacturers are experiencing the demand concerning fuel efficiency and low emissions from both consumers and governments. Homogeneous charge compression ignition (HCCI) is an alternative combustion technology that is cleaner and more efficient than the other types of combustion[1]. Homogeneous Charge Compression Ignition (HCCI) combustion can be made to occur in a four stroke engine with smooth and even combustion under some circumstances. It offers the possibility of light load operation without throttling, thus giving fuel economy like a diesel, in the same engine allowing full load operation with homogeneous charge, thus giving a power density comparable to a gasoline engine[2]. In an IC engine, HCCI combustion can the achieved by premixing the air-fuel mixture and compressing it until the temperature is high enough forauto-ignition to occur. The combustion temperature remains low and therefore NOx emissions decrease significantly compared to SI and CI operation[3]. HCCI combustion has several main difficulties such as controlling of ignition timing, limited power output, and weak cold-start capability[1]. A novel combustion process has been developed utilizing supercritical gasoline injection-ignition for light duty compression ignition engines known as Transonic Combustion or TSCi. The TSC icombustion process exhibits similarities withHCCI, LTC, PCCI and RCCI with high indicated thermal efficiencies (greater than 45%) and simultaneous reduction of NOx and PM at high EGR levels. The use of EGR at low and medium loads has shown a strong impact on NOx without compromising particulate emissions. However at higher loads with HCCI, LTC, PCCI and RCCI the operating range is limited by excessive pressure rise rates and control of combustion phasing, whereas the TSCi combustion process, due to its partially premixed and partially stratified mixture preparation, is not limited in the same manner[4].

KEYWORDS:

- **HCCI**
- **TSCi**

I. INTRODUCTION

The characteristic feature of traditional SI engine is flame propagation for combustion. A conventional SI engine uses a homogeneous fuel/air mixture which is prepared in the intake port and then undergoes induction compression. SI engines with accurate control of air/fuel ratio and a three way catalytic convertor are very clean power producing machines but their efficiency is limited because of throttling, knocking and a lean flammability limit. A conventional CI engine uses a heterogeneous fuel/ air mixture. In CI engines, only a fraction of air and fuel is premixed and burns fast, whereas for the larger part of the fuel, the time scale of evaporation diffusion, etc. is more than the chemical time scale. Hence, the air fuel mixture within the combustion chamber can be divided into two regions- the high fuel concentration regions and high temperature flame regions. In the fuel rich regions, the rate of soot formation is high due to absence of oxygen. NOx is produced at high rates in the high temperature regions. CI engines are very efficient power producing machines but they have a constraint in the form of trade-off between oxides of nitrogen (NOx) and Particulate Matter (PM) emission.

In recent decades, serious concerns have piled up considering the environmental impact of the gaseous and particulate emissions arising from operation of these engines. As a result, ever tightening legislation, that restricts the levels of pollutants that may be emitted from vehicles, has been introduced by governments around the world. In addition, concerns about the world's finite oil reserves and CO2 emissions have led to heavy taxation of road transport, mainly via on duty on fuel. These factors have led to massive pressure on vehicle manufacturers to research, develop, and produce ever cleaner and more fuel-efficient vehicles. Over the last decade, an alternative combustion technology, commonly known as homogeneous charge compression ignition (HCCI), has emerged and it has the potential to decrease emissions and fuel consumption in transportation. HCCI is a clean and high efficiency technology for combustion engines that can be scaled to any size-class of transportation engines as well as used for stationary applications. These benefits of HCCI (especially relative to spark ignition engines) are acquired by virtue of lean/dilute operation. The two dominating engine concepts commonly used today are the diesel and SI engines. A comparison between the two engines shows that the SI engine equipped with a catalytic converter provides low emissions but lacks in efficiency. The diesel engine on the other hand provides high efficiency but also produces high emissions of NO$x$and particles. An engine concept capable of combining the efficiency of a diesel engine with the tailpipe emissions level of an SI engine is the homogeneous charge compression ignition (HCCI) engine. In other words, HCCI is the auto-ignition of a homogeneous mixture by compression[1]. The Transonic Combustion ignition (TSCi) combustion process has many similarities with Gasoline PPC and other novel combustion processes such as HCCI, RCCI and LTC with high indicated thermal efficiencies (greater than 45%) and simultaneous reduction of NOx and smoke at high EGR levels. To reach the supercritical state gasoline fuel is pressurized greater than 42bar and heated greater than 280degC. This has the effect of decreasing the density by up to 50% and improves the diffusivity of the fuel by an order of magnitude. The TSCi direct injector is designed to heat gasoline fuel to elevated temperatures up to the supercritical state and has larger nozzle-hole diameters and internal volumes than conventional diesel injectors enabling sufficient flow of lower density heated fuel. Once injected into the cylinder, the supercritical gasoline plume exhibits lower density and improved diffusivity and does not undergo droplet breakup and vaporization as found in liquid spray injection. During the injection process, the supercritical state of the fuel is maintained, improving mixing of fuel and air, which enhances premixing and reduces ignition delay[4].

II. LITERATURE SURVEY

HOMOGENIOUS CHARGE COMPRESION IGNITION (HCCI)

The concept of HCCI was initially investigated for gasoline applicationsin order to increase combustion stability of two-stroke engines. They found that significant reductions in emissions and an improvement in fuel economy could be obtained by creating conditions that led to spontaneous ignition of the in-cylinder charge. Stable HCCI combustion could be achievedbetween low and high load limits with gasoline at a compressionratio of 7.5:1 over the engine speed range from 1000 to 4000 rpm. In many researches, gasoline-fuelled HCCI combustion is also called controlled auto-ignition (CAI) combustion. However, the need to reduce emissions from diesel engines led to investigation into the potential of diesel-fuelled HCCI beginning in the mid-1990s. For diesel fuel, port fuel injection is perhaps the most straightforward approach to obtaining a premixed charge and this approach has been used in some of the earlier investigations of diesel-fuelled HCCI[6]. In HCCI mode of combustion, the fuel and air are mixed prior to the start of the combustion and the mixture is auto-ignited spontaneously at multiple sites throughout the charge volume due to increase in temperature in the compression stroke. In this mode, the combustion process is arranged in such a way that the combustion takes place under very lean and dilute mixture conditions, which results in comparatively lower bulk temperature and localized combustion temperature, which therefore, considerably reduces the NOx emissions. Furthermore, unlike conventional CI combustion, in HCCI mode the fuel and air is well mixed (homogeneous). So, the absence of rich fuel regions in the combustion chamber results in considerable reduction in PM generation. Therefore, absence of locally high temperatures and a rich fuel-air mixture during combustion process, the simultaneous reduction of NOx and PM emissions is made possible[9].

To attain HCCI combustion, the following conditions were found to be important:

- The quantity of mixture and the air/fuel ratio supplied to the cylinder must be uniform from cycle to cycle.
- The scavenging directivity and velocity must have cyclic regularity to ensure the correct condition of the residual gases remaining in the cylinder.
- The temperature of the combustion chamber walls must be suitable.
- The scavenging passage inlet must be located at the bottom of the crankcase[2].

In an HCCI engine (which is based on the four-stroke Otto cycle), fuel delivery control is of paramount importance in controlling the combustion process. On the intake stroke, fuel is injected into each cylinder's combustion chamber via fuel injectors mounted directly in the cylinder head. This is achieved independently from air induction which takes place through the intake plenum. By the end of the intake stroke, fuel and air have been fully introduced and mixed in the cylinder's combustion chamber.

As the piston begins to move back up during the compression stroke, heat begins to build in the combustion chamber. When the piston reaches the end of this stroke, sufficient heat has accumulated to cause the fuel/air mixture to spontaneously combust (no spark is necessary) and force the piston down for the power stroke. Unlike conventional spark engines (and even diesels), the combustion process is a lean, low temperature and flameless release of energy across the entire combustion chamber. The entire fuel and air mixture is burned simultaneously producing equivalent power, but using much less fuel and releasing far fewer emissions in the process. At the end of the power stroke, the piston reverses direction again and initiates the exhaust stroke, but before all of the exhaust gases can be evacuated, the exhaust valves close early, trapping some of the latent combustion heat. This heat is preserved, and a small quantity of fuel is injected into the combustion chamber for a pre-charge (to help control combustion temperatures and emissions) before the next intake stroke begins[9].

Figure 1 shows the NOx, CO, and HC emissions for various intake temperatures in the same engine. By decreasing the temperature and retarding the ignition timing, the NO$x$emission has decreased, but CO and HC emissions have increased. These adverse trends of CO and NO$x$emissions are one of the main difficulties for controlling the emissions since by reducing one of them, another one increases. Also as demonstrated in this figure, the trend of emissions at intake temperature of 525 [∘K] has changed and NO$x$emission has suddenly increased because of some misfiring occurring in this point that was mentioned before.

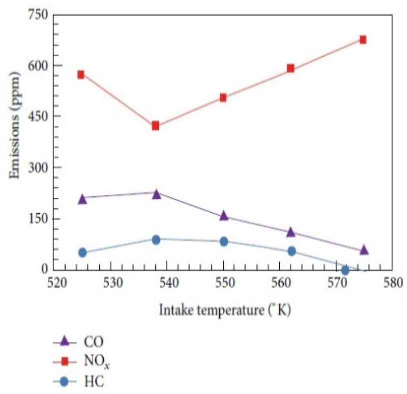


Fig: 1 CO, NOx, and HC emissions for various intake temperatures[1].

ADVANTAGES

- Higher efficiency than SI & CI engines.
- Can achieve up to 15% fuel saving.
- Lower peak temperature (than SI &CI engines) leads to cleaner combustion/lower emissions.
- Can use gasoline, diesel or most alternative fuels.
- It avoids the throttle losses, which further improve efficiency.

DISADVANTAGES

- At lean air-fuel ratio and at low combustion temperature (below 1500) incomplete combustion is occurring and it decreases combustion efficiency with increase in CO and HC emission.
- At rich air fuel ratio or at higher loads knocking is occurring due to high pressure and leads in high NOx emission due to high temperature.
- Higher cylinder peak pressure may damage the engine.
- Auto-ignition is difficult to control.

TRANSONIC CUMBUSTION IGNITION (TSCi)

The Transonic Combustion system (TSCi) brings together the injection and ignition processes to become Injection-Ignition. The characteristics of TSCi address all of the issues identified above as limiting the efficiency of the gasoline engine; it is capable of operating over a wide range of air/fuel ratios and so does not require a throttle for load control. TSCi has inherently short combustion delay and fast combustion that combine in heat release phasing for optimal efficiency. TSCi can be operated at an optimal compression ratio since it is not dependent on high octane gasoline. The ignition mechanism, discussed in more detail below renders the combustion system fuel neutral in the sense it is not reliant on either Octane or Cetane values. The basis of the TSCi combustion process is that injection of the fuel is delayed to the extent that the heat release predominantly takes place after TDC of the engine power stroke. In order to achieve this, the combustion process must have a short delay period, followed by rapid air-fuel mixing and combustion. Such characteristics can be achieved by injecting the fuel in the form of a supercritical fluid. A supercritical fluid is any substance at a temperature and pressure above its critical point; it is not a solid, liquid or a gas as shown in Figure 2. Generally supercritical fluids have properties between those of a gas and a liquid.

Supercritical fluids also have other unique properties such as having no surface tension, the ability to solvate other liquids and solids and the formation of small particles with a narrow size distribution during a phase change to liquid. Supercritical fluids possess rapid mass transfer properties with diffusion coefficients more than ten times that of a liquid near the critical point. The density ranges between one third and two thirds of that of the corresponding fluid and varies significantly with temperature and pressure. Gasoline is a blend of C4 to C12 hydrocarbons, contains hundreds of different molecules, and varies in composition. The critical point for a mixture of compounds is difficult to predict exactly, however, indications are that the Tc and Pc for a mixture will be lower than that of its constituents

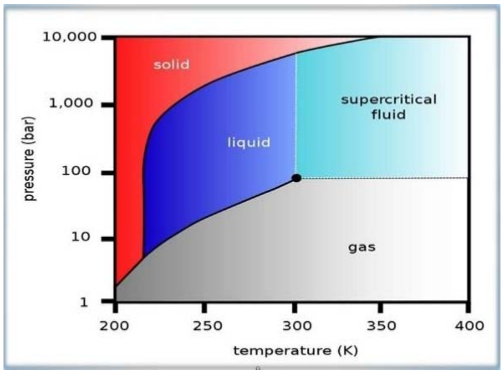


Fig: 2 phase diagram for pure material

Transonic Combustion or TSCi is based on the direct injection of fuel into the cylinder as a supercritical fluid. Supercritical fuel achieves rapid mixing with the contents of the cylinder and after a short delay period spontaneous ignition occurs at multiple locations. Multiple ignition sites and rapid combustion combine to result in high rates of heat release and high cycle efficiency. The injection ignition process is independent from the overall air/fuel ratio contained in the cylinder and thus allows the engine to operate un-throttled. Additionally, the stratified nature of the charge under part load conditions reduces heat loss to the surrounding surfaces, resulting in further efficiency improvements. The short combustion delay angles allow for the injection timing to be such that the ignition and combustion events take place after TDC. This late injection timing results in a fundamental advantage in that all work resulting from heat release produces positive work on the piston. Other advantages are the elimination of droplet burning and increased combustion stability that results from multiple ignition sources[5]. The transonic technology provides a heated catalysed fuel injector for dispensing fuel predominately or substantially, exclusively during the power stroke of an IC engine. This injector lightly oxidizes the fuel in a supercritical vapour phase via externally applied heat from an electrical heater or other means. The injector may operate on a wide range of liquid fuels including gasoline, diesel and various bio fuels. The injector fire at room pressure and up to the practical compression limit of IC engines. Since the injector may operate independent of spark ignition or compression ignition[8].

Once injected into the cylinder, the supercritical gasoline plume exhibits lower density and improved diffusivity and does not undergo droplet breakup and vaporization as found in liquid spray injection. During the injection process, the supercritical state of the fuel is maintained, improving mixing of fuel and air, which enhances premixing and reduces ignition delay. Therefore, increased fuel temperature can be seen as an alternative to increased fuel pressure to provide an additional degree of freedom for combustion control of partially premixed combustion (PPC) processes, and reduce cost associated with high pressure fuel injection equipment(FIE)[4].

Transonic fuel injector is a specially designed and a superefficient fuel injector designed to integrate easily into conventional cars.Unlike standard injectors, the TSCi injector pressurizes and heat gasoline to 400 degree Celsius, bringing it to a supercritical state that is partway between liquid and gas.It has larger nozzle diameters and internal volumes tan conventional diesel injector enabling sufficient flow of lower density heated fuel.

Fig: 3 TSCi injector [5]

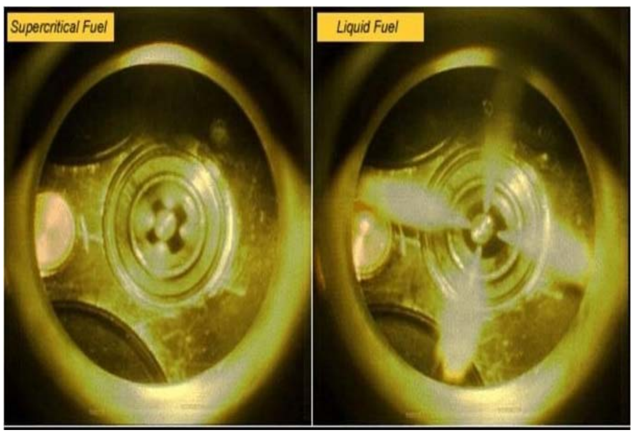


Fig: 4 High speed injection photography[8]

Figure 4 shows a comparison of standard direct injection of liquid fuel and transonic novel supercritical injection process (as viewed through an optical engine fitted with a quartz window) shows that the new TSCi fuel delivery system does not create fuel droplets .

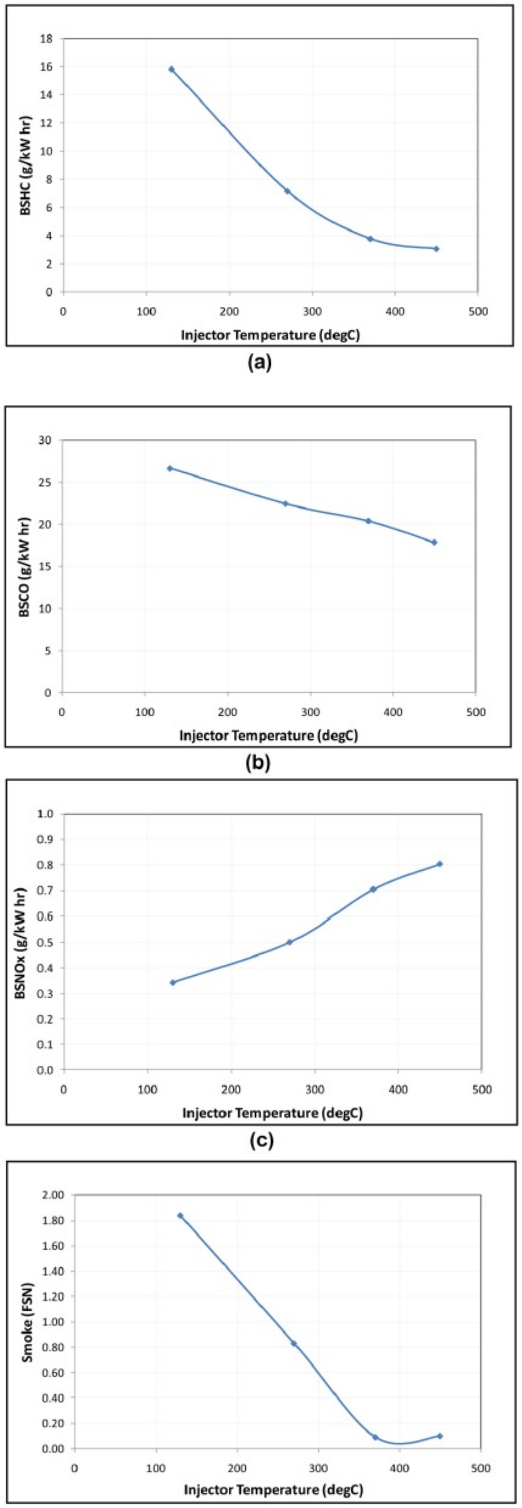
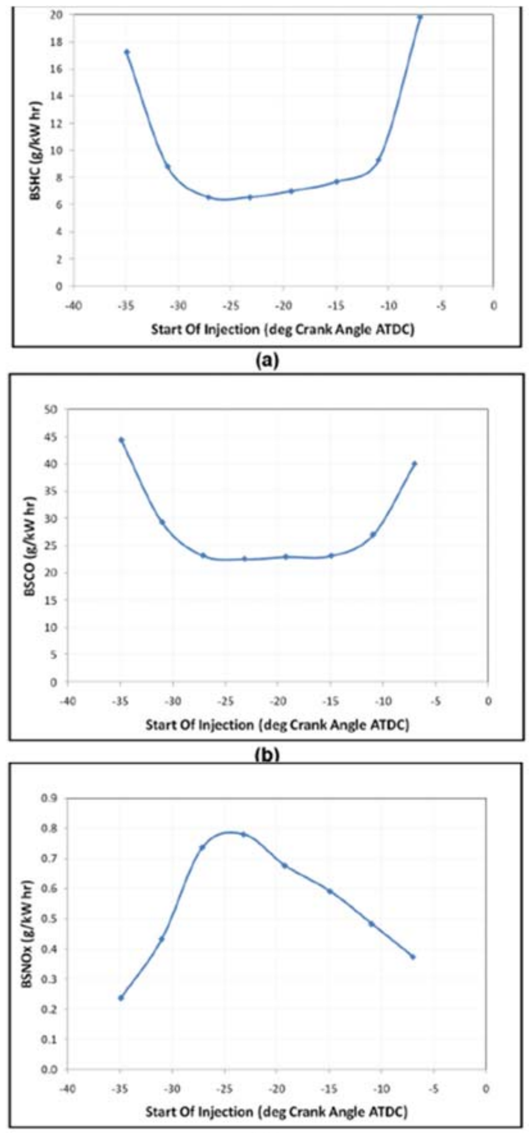
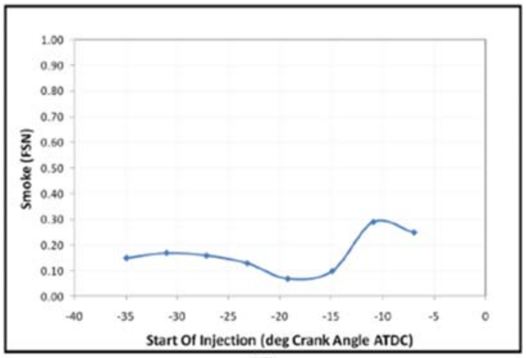


Fig: 5*Brake Specific Emissions for (a) HC, (b) CO, (c) NOx, (d) Smoke with Varying Injector Temperature*[5].

The HC and CO emissions, shown in figure 5 are shown to significantly reduce as the fuel temperature increases. However, NOx emissions increase as the combustion rate increases, but remain below 1g/kWh throughout the range tested. A supercritical fluid injection contains no liquid droplets; the transition from liquid to supercritical fluid injection shows a dramatic decrease of smoke emission. As shown in figure 6, both HC and CO emissions increase outside the tolerance window. Over advancing injection may result in local lean conditions which result in high unburned HC and CO (lean fringe). On the contrary, over-retarded injection limits mixing time which results in local rich conditions. NOx emission is seen to be sensitive to injection timing with a maximum at around 25° BTDC. Thus, within the tolerance window, injection timing can be selected based on the emission level with only limited compromise of fuel consumption[5].





(d)

Fig: 6*Brake Specific Emissions for (a) HC, (b) CO, (c) NOx, (d) Smoke with Varying Injection Timing*[5].

III. DISCUSSION

In HCCI, the knocking tendency is higher and the auto ignition is difficult to control.

The attainment of peak pressure will damage the engine and at low loads incomplete combustion and emissions increases. The TSCi is a suitable alternative to the HCCI. It is having the following advantages over the HCCI:

- Improved fuel efficiency.
- Lower greenhouse emission.
- Multi-fuel compatible.
- About 50% increase in efficiency.
- Perfect combustion of fuels.
- Knocking is eliminated.
- Energy independence.

IV. CONCLUSION

- By eliminating the spark ignition and introducing a completely redesigned fuel injection system, TSCi realize a 50% increase in efficiency.
- With the influence of supercritical fluid enhance a complete combustion and thereby increasing engine efficiency and reduced the emission.
- The transonic combustion engine technology would improve fuel economy by far and also reduce exhaust emission.
- Lab testes results in the determination that most of the losses associated with IC engines were drastically reduced.
- However the only disadvantages faced by the TSCi system is the maintainence and obtaining supercritical stage.

V. FUTUREWORK

From the above discussion the use of TSCi technology in our vehicles is advantageous. So the application of this technology requires further research. The characteristics and the changes required in the current engine design to apply the TSCi technology must be evaluated .

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