A Review of Stratified Charged Engines

Rajurkar Sagar Sanjay
Department of Mechanical Engineering
Sandip Institute of Technology and Research Center
Nashik 422213, India

Jangid Niteshkumar Bhawarlal
Department of Mechanical Engineering
Sandip Institute of Technology and Research Center
Nashik 422213, India

Kabra Vikrant Vijay
Department of Mechanical Engineering
Sandip Institute of Technology and Research Center
Nashik 422213, India

Dubey Atul Vijay
Department of Mechanical Engineering
Sandip Institute of Technology and Research Center
Nashik 422213, India

***Abstract*—Growing injunctive authorization of energy economical engines and ever-incrementing vigilance about emission has coerced the engine manufactures to develop the engines, which are energy efficient and at the same time should engender minimum emission** **Both objectives can be completed only if the engine can ascertain the consummate combustion and operate with as minimum categorical fuel consumption as possible. This has led the development of principle in which, the SI engine uses very lean air-fuel charge and high compression ratio for the best possible economy. The leanness withal ascertains the consummate combustion. However, the design of such an engine is rather a challenge because a sustainable flame has to be maintained with such a lean air-fuel charge. This paper expounds the concept of lean combustion and reviews different aspects about design considerations, performance and inhibitions of engines employing lean combustion.**

Keywords—Stratified charged engine; lean air-fuel mixture; energy effiencient engine.

1. INTRODUCTION

Start Ignition and Compression Ignition are two settled techniques in IC Engines to get burning. The motors using both the hypotheses are working by and by. Be that as it may, both the motors have their very own focal points and inconveniences. The SI motors give great execution on full load. For example, great air use, useful burning and high scurry, in any case, their execution on part stack is somewhat poor. Then again, Diesel motors offer great execution at part stack (up to 80% load) however their full load execution is restrained by shocking smoke because of excessive neighborhood richening of air-fuel amalgamation amid full load task (high rate of diesel infusion). This has essentially driven the Engine designers to celebrate of some indicates to mix the benefits of both CI and SI motors. This drove towards the improvement of stratified charge motors. The stratification assigns masterminding into layers. In stratified charged

motors, the charge close to the start plug is basically sufficiently lavish to start the ignition however as we peregrinate far from start connect to the burning chamber, the blend progresses toward becoming more slender and less fatty so that, the generally speaking A/F proportion in the burning chamber is lean. Along these lines, the charge is stratified into wealthy (close start attachment) and lean layers. Be that as it may, what are the results of this stratification. Thus, the charge is stratified into affluent (near spark plug) and lean layers. But, what are the consequences of this stratification?

1.1 PHILOSOPHY OF LEAN BURNING

With the utilization of leaner amalgamation and marginally higher compression ratio, In SI Engine a high performance level approaching the diesel engine can be achieved [1]. Consider the Air standard efficiency of an Otto cycle engine for a carbureted engine the value of γ is 1.28 to 1.3 approximately. As the coalescence becomes leaner, this value of γ approaches the value of γ for air i.e. (γ=1.4) thus it is pellucid that with the utilization of leaner coalescence, there is a direct gain in thermodynamic efficiency due to the incremented value of γ for mixture [2]. Further, in a lean amalgamation, the effect of dissociation is diminutively minuscule due to lower peak cycle temperature. This additionally results into the gain in efficiency. Low cycle temperature due to leaner overall A/F ratio will withal reduce the effect of variable categorical heat thus determinately resulting into reduction of concrete fuel consumption. As we know, the gasoline engines are quantitatively governed [3]. The closing of throttle results into a reduced quantity of charge intake resulting into less cylinder pressure but as the A/F ratio remains more or less constant; the peak cylinder temperature remains virtually same. This directly results into incremented losses to the coolant and hence high BSFC at part load operation (30 to 60 % throttle opening). This withal implicatively insinuates that there is a considerable effect of dissociation during Part load operation. Additionally, during idling, the SI engine is subjected to charge dilution due to residual exhaust gases left over in the anterior cycle. The quantity of residual gases increases with the incrimination in clearance volume i.e. reduction in compression ratio for same cylinder dimensions. Thus, it is pellucid from above discussion that, if we utilize higher compression ratio, with overall lean A/F ratio, it can result into gain in part load as well as plenary load efficiency. This is further expounded below in this section. In advisement, the higher compression ratio can ascertain more expeditious flame propagation in lean A/F ratio due to incremented charge density and incremented reaction and conveyance rate in burning charge. As we know, for same compression ratio, the efficiency of Otto cycle is more preponderant than that of diesel cycle. It implicatively insinuates that, for higher compression ratio in SI engines, efficiency commensurable to that of diesel cycle can be achieved. Hence, by keeping the compression ratio of an Otto engine remotely less than that of a diesel engine, and incorporating overall lean A/F ratios in the combustion chamber, most of the advantages of diesel engines such as high thermal efficiency can be achieved. Concurrently, certain disadvantages of compression ignition can be eliminated. Such as compulsory utilization of very high compression ratio for self-igniting a heterogeneous coalescence. The utilization of Sparkplug for ignition in stratified charged SI engine gives a direct control over the combustion thus, eliminating the requisite of low ignition lag of fuel as formidable authorized by the diesel engine. The stratified charged engines employ direct injection of gasoline into combustion chamber like diesel engines. This enables an SI engine to be governed like CI engine and hence eliminates certain disadvantages of quantity governing (employed in SI Engine) like the low manifold pressure during part load, poor air utilization at part load, High cycle temperature and incremented pumping losses in manifold during part load. Utilization of a dedicated injection system can amend fuel injection and hence can abbreviate the physical delay in the process of combustion. Thus, stratified charged engines are customarily fuel tolerant and will operate with a wide range of liquid fuels [4]

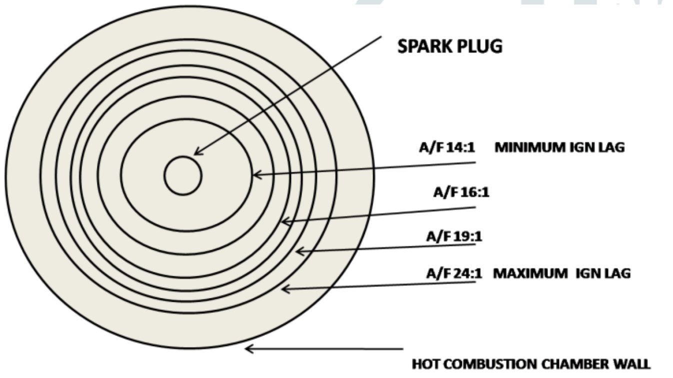

Figure 1 Charge stratification in Combustion chamber [15]

As the engine uses overall lean A/F ratio, the combustion ascertains low NOx due to lower peak cycle temperature. In additament, the fuel injection eliminates disadvantages of non-exhaust type HC emissions from the carburetor body. Additionally, the presence of excess air in the combustion chamber ascertains lowest CO emission and HC emission from Engine exhaust. Stratified charged SI engines do not cause particulate pollution due to the presence of a homogeneous charge. The stratified charged engines offer smooth combustion (good rate of flame propagation) and innate resistance to knock. This can be expounded from figure 1 Fig shows the orchestration of stratified charged combustion chamber. The figure only shows the location of 'Spark Plug' with reverence to the walls of the combustion chamber. This may not be always the same in all engines but for the sake of understanding the effect of stratification, it is shown in this fashion. The charge strata that is in the vicinity of the spark plug is affluent in concentration and gives minimum ignition lag. This ascertains instantaneous pre-flame reactions and hence efficacious burning of charge near the spark plug at all speeds and loads. As the flame advances towards the combustion chamber walls, it compresses the charge ahead of it but since the charge in contact with sultry walls of the combustion chamber is leaner, it is consumed by the flame afore it can auto ignite due to its maximum (longer) ignition lag. This introduces an intrinsical resistance to detonation and hence promotes the utilization of low MON (Motor Octane Number) fuel for use.

2. VARIOUS ASPECTS

In this section, we will optically discern the sundry aspects regarding the charge stratification process and Effects uniquely associated with it. As we know, the combustion is an involute phenomenon and there are sundry aspects associated with this phenomenon. Here we will summarize some of the intriguing aspects cognate with lean-burn combustion. The combustion studies suggest that the ignition cannot be defined as only a chemistry-predicated phenomenon and physical commixing should be included in the presage of ignition delay in case of lean burning [5]. This implicatively insinuates that, the physical commixing of charge in lean combustion chamber has consequential impact on the combustion process. The main challenge for lean burn technology is that, under lean operating conditions, the conventional three-way catalyst TWC system is no longer efficacious in reducing NOx pollutants. A special TWC with NOx trapping and conversion capabilities, known as Lean NOx Trap LNT, has to be used downstream of the conventional TWC. This LNT requires opportune control of storage and purge cycles to get good fuel economy and controlled NOx emission in case of lean burn gasoline engine. [6] Withal researches have reported that higher peak temperatures can increment the pollutant emission level of a stratified lean-charge engine much more as compared to a homogeneous lean-charge engine [7] Further, the NOx storage capacity of the LNT, one of the most critical parameters for its control strategies, varies dynamically. This is because the trap is susceptible to sulphur poisoning. As sulphates build up in the trap, the efficacious LNT trapping capacity is reduced [8]. This restricts the utilization of high Sulphur % in gasoline. An astronomical work has been carried out on hydrogen direct injection for stratified charged engines mainly due to the following reasons.

- Hydrogen has an astronomically higher burning velocity and wider flammable limits compared with hydrocarbon fuels. Hydrogen additament to methane has been reported to be efficacious to promote combustion at lean operation [10]
- Direct injection in spite of its high cost, is still widely utilized in case of stratified charged engines. Bronislaw Sendyka and Mariusz Cygnar [11] reported that the incrementation in the total efficiency of GDI engine determined on the substratum of testbed investigations varies considerably (10 to 17%) depending upon on the rotational speed and the load of the engine.
- DI operation is capable of achieving higher efficiencies and lower NOx emissions [9]
- In case of Direct hydrogen injection stratified charged engines, It is found that, NOx emissions and engine efficiency are vigorously dependent on the parity ratio, which can be facilely modulated with electronic fuel injection system.

There are sundry advances in Stratified charge engine's technology the two of which are mentioned below.

A. The system with better combustion and achieving a sustainable flame front in overall lean amalgamation by implementing high heat release rates in the vicinity of The spark plug as in case of MITSUBISHI® lean burn gas engines. In this case, they adopted pilot liquid fuel injection in lieu of spark plug. The pilot fuel is very minuscule in quantity but has puissant ignition energy 8000 times that of a spark plug, so that combustion is stable and efficiency are amended. Moreover, owing to the potent ignition energy, there is no desideratum to prepare a high-concentration air-fuel coalescence in the precombustion chamber as required in spark ignition engines; hence, engenderment of NOx in the precombustion engine is lowered [13]. Like stratified SI engines, Stratified diesel engines are additionally getting popularity. The main reason is that. Certain modification in Diesel-like stratified charge engines makes it possible to evade unwanted pollutions in the exhaust gas and building frugal engines without Oxicat and soot filters. [14]

B. The system producing effective Rich mixture in Spark plug zone e.g In PSC system, a passage is drilled in the metal cladding of the spark plug to accommodate a small section of capillary tubing, which is used to introduce the pilot fuel. [12]

3. CHALLENGES IN DESIGN

The charge stratification can be done with the avail of engendering swirl and utilizing Spark ignition. This requires open combustion chambers. Some of the examples of this are.

1. FCP (Ford® combustion process)
2. AD Process
3. TCP (Texaco combustion process)
4. PROCO (Developed by Ford®)
5. Witzkey Swirl Combustion Process

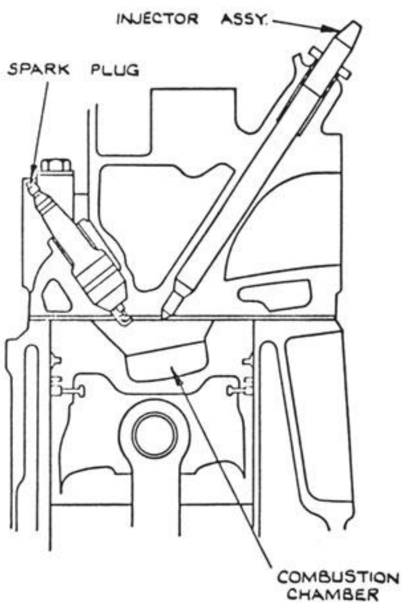

Figure 2:- The Ford PROCO Engine [16]

The PROCO engine is an early injection engine where fuel is injected during the compression stroke directly into the cylinder by a conical spray nozzle. The combustion cavity, as shown above, is composed in the piston crown. The degree of stratification is controlled by timed fuel injection rather than a precombustion cavity. Injection timing sanctions some control on detonation through the stratification process. Early injection timing during the intake stroke is employed for ameliorated commixing and air utilization at heavier loads, thus resulting in good puissance output. Later injection timing still during the intake stroke provides the high degree of stratification required for emission control and fuel efficiency at light loads. Combustion is initiated in the opulent region with spark plugs. Relatively expeditious combustion occurs due to turbulence caused by an intentionally induced intake swirl and squish action. The degree of stratification is controlled by injection timing during the intake stroke with some control on detonation.

Additionally, the stratification can be engendered by parting the combustion chamber as in case of Broderson method. In this case, the load control is achieved by variation in injection timing i.e. injecting during compression stroke or Suction stroke. However, parting the combustion chamber can lead to over richening of charge at high load and poor scavenging of prechamber. To achieve combustion in the stratified combustion chamber, the rate and most consequential the timing of fuel injection has to be precisely controlled. E.g., Broderson method of stratification works on the felicitous timing of fuel injection [1]. Even a diminutive error in injection timing can worsen the performance of engine leading to poor power output and efficiency or even misfire. In additament to this, the design of the intake port and overall design of the combustion chamber is rather an arduous task for charge stratification. Especially in swirl stratified charged engines. In these engines, the stratification is obtained by the high degree of swirl (As in the case of 'Texaco combustion process' and 'Witzkey Swirl Combustion Process'). For opportune charge stratification, it is utmost consequential that a swirl of a very high degree has to be engendered inside the combustion chamber. This is possible only when the intake manifold, intake port, shape of the combustion chamber are opportunely designed. In additament to this, the location of Sparkplug plays a vital role in initiation of combustion (e.g. in TCP) and placement of fuel injector at congruous location ascertains congruous breaking of jet which is compulsory for efficacious stratification. Thus the design cost of Stratified engines is much more than that of conventional SI and CI engines.

4. SUMMERY AND CONCLUSION

The engines employing charge stratification offers good part as well as plenary load efficiency. In additament, they exhibit an innate resistance to knocking. Hence are felicitous to utilize a wide range of liquid fuels. There is a scope of supercharging in stratified charged SI engines, provided that, the swirl should be opportunely engendered inside the combustion chamber. An unthrottled SI engine is liberated from pumping losses and is good in volumetric efficiency. Additionally, they incline to emit less NOx as well as less CO.Parting the combustion chamber for charge stratification as in case of Broderson method can lead to over richening of fuel at high load and poor scavenging of pre-chamber resulting in poor full load performance. As far as EMS (Engine Management System) is concerned, it should be precise to control load variations. The design of the stratified combustion chamber is rather involute and requires advanced techniques like CFD to validate the required charge kineticism inside the combustion chamber. Their potency to weight ratio is marginally less due to the employment of high compression ratio and induction of less heating value charge (lean mixture) per working cycle.

REFERENCES

[1] M.L Mathur, R.P. Sharma, Internal Combustion Engine, pp 778-798, Eight edition, Dhanpat Rai publication (P) Ltd. ISBN 978-81-89928-46-9 R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[2] Yunus A. Çengel, Michael A. Boles, Thermodynamics – An Engineering Approach, pp 494- 498, Fifth edition McGraw Hill Education.

[3] V Ganesan, Internal Combustion Engines, pp 189- 200, fourth edition, McGraw Hill Education (India) Pvt. Ltd ISBN 1-25-900619-0.

[4] John B. Heywood, Internal Combustion Engine Fundamentals chapter 1, McGraw Hill,Inc.

[5] S. HONG, M. S. WOOLDRIDGE and D. N. ASSANIS; Modeling of Chemical And Mixing Effects on Methane Auto Ignition Under Direct Injection, Stratified Charged Conditions; Proceedings of the Combustion Institute, Volume 29, 2002/pp. 711–718.

[6] Feng Zhang, Karolos M. Grigoriadis, Matthew A. Franchek, Imad H. Makki; Linear Parameter- Varying Lean Burn Air-Fuel Ratio Control for a Spark Ignition Engine, Transactions of the ASME, Vol. 129, July 2007, 404-414.

[7] C. Jimènez, D. Haworth, T. Poinsot, B. Cuenot And R. Blint; Numerical simulations of combustion in a lean stratified propane-air mixture, Center for Turbulence Research, Proceedings of the Summer Program 2000, pp 133-144.

[8] Jing Sun, Yong Wha Kim and Leyi Wang; Aftertreatment control and adaptation for automotive lean burn engines with HEGO sensors, Int. J. Adapt. Control Signal Process. 2004; 18,145–166.

[9] Vahid FATHI, Arash NEMATI, Samad JAFARMADAR ,Shahram KHALILARYA; Influence of initial charge conditions on engine performance and emission of a DISI Hydrogenfueled engine under various injection timings, Turkish J. Eng. Env. Sci. 35 (2011) , 159 – 171.

[10] Toshio Shudo, Koichiro Tsuga, Yasuo Nakajima; Analysis of Direct Injection Spark Ignition Combustion in Hydrogen Lean Mixture, Seoul 2000 FISITA World Automotive Congress ,June 12-15, 2000, Seoul, Korea.

[11] Bronislaw Sendyka and Mariusz Cygnar; Stratified Charge Combustion in a Spark-Ignition Engine With Direct Injection System, http://dx.doi.org/10.5772/53971.

[12] Danaiah P., Ravi Kumar P,Vinay Kumar D; Lean Combustion Technology for Internal Combustion Engines: a Review, Science and Technology 2012, 2(1): 47-50.

[13] Akira Tsunoda, Hiromi Shimoda, Tatsuo Takaishi; MITSUBISHI Lean-burn Gas Engine with World's Highest Thermal Efficiency, Mitsubishi Heavy Industries, Ltd. Technical Review Vol.40 No.4 (Aug. 2003).

[14] H. Heitland, Prof. Dr.-Ing, G. Rinne, Prof. Dr.- Ing; New Concepts To Avoid Unwanted Pollutants From D.I. Diesel Engines In Passenger Cars, Journal of KONES Internal Combustion Engines 2003, vol. 10, No 1-2.

[15] Rahul Mahajan, Rizwankhan Saudagar, A Review of Stratified Charged SI Engines, International Journal of Research in Advent Technology, Vol.3, No.3, March 2015 E-ISSN: 2321-9637.

[16] U.S. Environmental Protection Agency, " A Study of Stratified Charge for Light Duty Power Plants," EPA-460/3-74-0llA, 1975.

.