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Experimental Investigations on LHR CI Diesel Engine with varied Operating Parameters and its Simulation

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Abstract— ***Fuel consumption and the performance are two important in the dependent parameter for any internal combustion engines. The present future generation is being looking towards the pollution free environment. Hence there is a need to search suitable automotive engines to meet low emission levels in their long run. The demand for diesel engines is growing rapidly; therefore it is necessary to increase the fuel efficiency. It is known that, the most of energy developed in any IC engines during combustion is rejected through cooling media. To minimize this heat loss to the coolant, a low heat rejection concept was developed. In LHR engines the effective utilization of heat takes place due to insulation coatings applied to cylinder and piston. At the same time problems associated with LHR engines were solved due to its high combustion temperatures. Heavy exhaust blow-down energy and high NO_x emissions were identified, which leads to decrease in thermal efficiency and inability to achieve emission legislation levels. The blow down losses can be overcome by using a concept of extended expansion cycle, in which the expansion ratio is greater than that of the compression ratio. This higher expansion ratio can be achieved by late closing of intake valve. In view of this the compression ratios for both LHR and LHR (EEE) engines are varied and compared with the conventional engine. The cumulative work done and thermal efficiency are high for conventional engines at lower compression ratios. The thermal efficiency is increased as the compression ratios increases for LHR and LHR (EEE) engines.***

Index Terms— ***LHR, LHR (EEE), Simulation, Crank angle, Compression ratios***..

I. INTRODUCTION

Diesel engines are widely used as prime movers in transport industry, for power generation and used quite extensively in agricultural operations, due to their high efficiency, compared to other types of prime movers like gas turbine. The field of application is increasing steadily. The technological advancement in this century, the awareness of the pollution effects on mankind has made the job of engine modeling highly professional, competitive and rewarding. Added to this, the increased cost and scarcity of hydro-carbon fuels have made the study of I.C. engines more and more attractive and the complexities in the 'process study' made the job challenging [1]. The expensive test procedures and the time spent in the engine design has necessitated in the formulation of numerical Models. Numerical approach to the problem formulation and solution, ultimately enables in the design optimization, cost reduction and time spent in engine testing and development. The purpose of this investigation is to formulate a thermodynamic model and to develop and simulate the LHR based extended expansion direct injection diesel engine. It includes a gas flow model, a heat transfer model and a two-zone combustion model [2].

Using the two-zone combustion model, the combustion parameters and the chemical equilibrium compositions were determined. The chemical equilibrium compositions were used to calculate the Nitric oxide formation rate by assuming a modified Zeldovich mechanism. The accuracy of this model is scrutinized against actual test results from the engine. The factors which affect thermal efficiency and exhaust emissions were deduced and their influences were discussed [3]. In the final analysis it is seen that there is an excellent agreement in all of these evaluations.

The net result of extended expansion alone is an improvement in fuel consumption and efficiency and further improved by making the Extended Expansion Engine a Low Heat Rejection type. A Low Heat Rejection (LHR) engines employs suitable insulation coatings such as a ceramics etc to the cylinder and piston. Due to the insulation provided on the required surfaces of the cylinder, the amount of heat loss to the coolant is reduced and hence results in high combustion chamber temperatures. This leads to several problems such as high NO_x emissions and exhaust blow-down losses.

The blow-down losses are mainly associated with the difference in pressure between the engine cylinder and turbine inlet duct prevailing at the beginning of the exhaust stroke. This can be overcome by using a concept called expanded cycle, in which the expansion ratio is greater than that of the compression ratio. This higher expansion ratio can be achieved by late closing of intake valve. Simulation is done for various compression ratios and compared with the conventional engine [4-6]. The simulated values are then validated with the experimental results.

II. EXPERIMENTAL SETUP

An experimental set-up is developed to conduct tests on a four cylinder, four stroke water cooled DI Diesel engine. The test engine is coupled with eddy current dynamometer. In addition to this, fuel measuring burette, air flow measuring U-tube manometer are also fitted to the test engine set up.

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A provision is also made to mount a piezoelectric pressure transducer flush with the cylinder head surface to measure the cylinder pressure. The experimental set-up layout is shown in Fig. 1.The equipment and instrumentation used in this work is briefly described below.

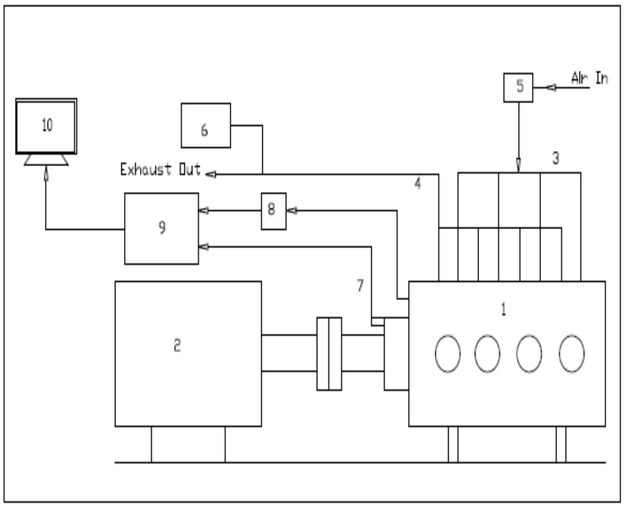

Fig: 1 Experimental Set up Layout

1. Engine 2. Eddy current dynamometer 3. Inlet line 4. Exhaust line 5. Air surge tank 6. Exhaust gas analyzer 7. Crank angle encoder 8. Charge Amplifier 9. CRO 10. Computer

III. EXPERIMENTAL AND SIMULATED OPERATING PARAMTERS FOR DIFFERENT COMPRESSION RATIOS

The variations in the combustion parameters will directly affect the efficiency, performance and emission characteristics of the diesel engine. The effects of combustion parameters such as cylinder pressure, cylinder mean temperature, rate of heat release, cumulative heat release and performance of the engine through work done, total heat transfer, brake thermal efficiency, brake specific fuel consumption for different compression ratios are presented and discussed. The presentation is supported by experimental results along with simulated results. As very high combustion temperatures involved with LHR engines resulting in higher NO_X formation. Hence the discussion is also focused on NO_X emissions along with other emissions. The compression ratios for both LHR and LHR (EEE) engines are varied and compared with the conventional engine. The cumulative work done and thermal efficiency are high for conventional engines at lower compression ratios. As the increase in compression ratios for LHR and LHR (EEE) engines, it shows a better improvement in thermal efficiency.

3.1 COMBUSTION PARAMETERS

3.1.1 Cylinder Pressures

The cylinder pressures as a function of crank angle are shown in Fig 2 and Fig 3. Simulated and experimental values are compared in Fig 4. It is learnt that the cylinder peak pressures for conventional engine with a compression ratio of 15 is higher by about 6.32% and 4.07% than LHR engine with compression ratios 14 and 15. It is also observed that the cylinder peak pressure of LHR engine with compression ratios 17, 19 and 21 are higher by about 6.85%, 20.45% and 29.87% respectively than conventional engine of compression ratio 15.

It is observed that the conventional engine of compression ratio 15 is giving higher cylinder peak pressures about 7.92% and 6.42% than LHR (EEE) engine with compression ratios 14 and 15 respectively. It is also learnt that the cylinder peak pressures of LHR (EEE) engine with compression ratios 17, 19 and 21 are higher by about 4.92%, 16.49% and 23.34% respectively than conventional engine of compression ratio 15.

The decrease in the cylinder pressure of LHR and LHR (EEE) engine at compression ratios of 14 and 15 than conventional engine with the same compression ratios is mainly due to decrease in effective compression ratio.

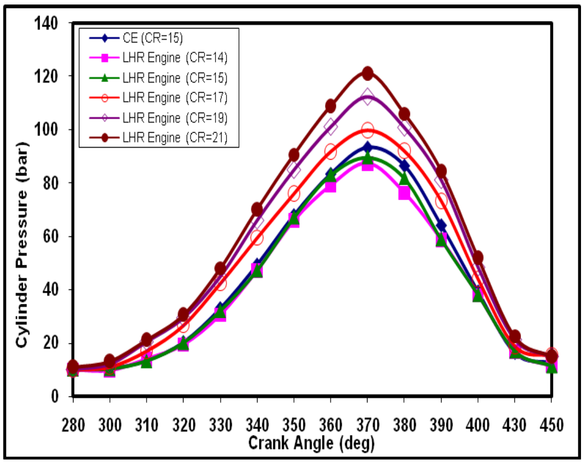

Fig.2. Comparison of Cylinder Pressure for Conventional and LHR engines for different compression ratios.

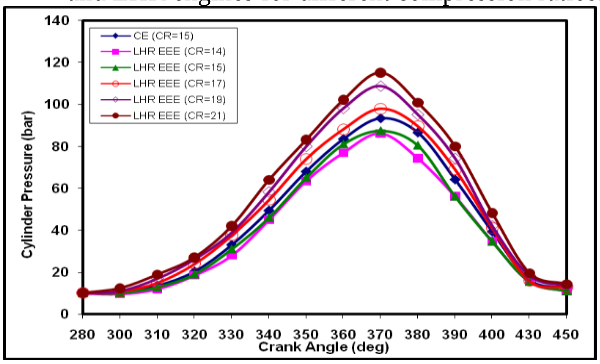

Fig.3. Comparison of Cylinder Pressure for Conventional and LHR (EEE) for different compression ratios.

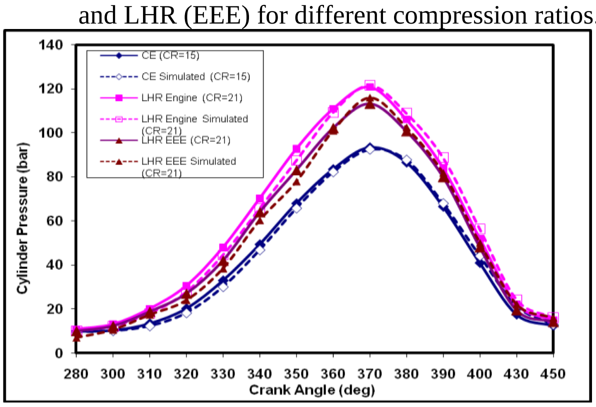

Fig.4. Comparison of Cylinder Pressure for Conventional (CR=15), LHR(CR=21) and LHR (EEE) (CR=21) with Simulated engines.

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3.1.2 Flame Temperatures

The flame temperatures as a function of crank angle are shown in Fig 5 and Fig 6. Simulated and experimental values are compared in Fig7. It is observed that the flame temperature for conventional engine with a compression ratio of 15 is lower by about 1.66%, 7.86%, 16.25%, 22.94% and 27.94% than LHR engine with compression ratios 14, 15, 17, 19 and 21 respectively.

It is noted that the flame temperature for conventional engine with a compression ratio of 15 is lower by about 0.62%, 5.28%, 9.82%, 15.00% and 23.66% than LHR (EEE) engine with compression ratios 14, 15, 17, 19 and 21 respectively.

The increase in flame temperature is mainly due to insulation coatings applied to the walls of the combustion chamber and increase in compression ratios.

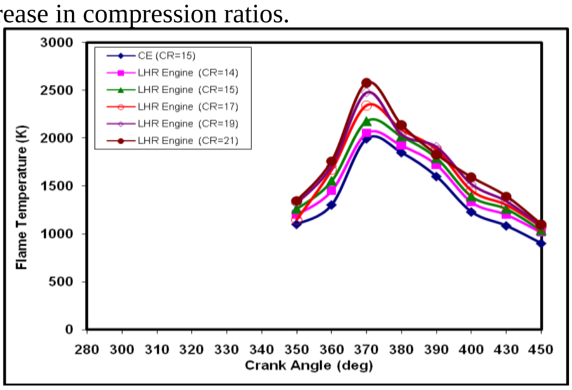

Fig.5. Comparison of Flame Temperature for Conventional and LHR engines for different compression ratios.

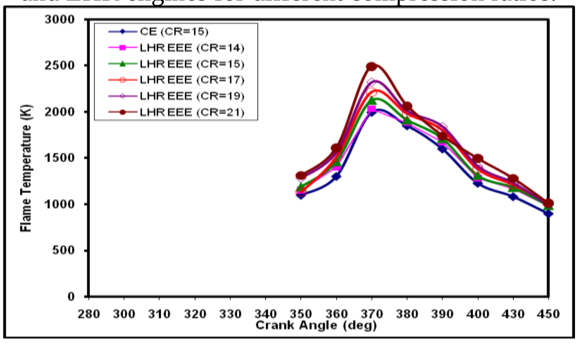

Fig.6. Comparison of Flame Temperature for Conventional and LHR (EEE) for different compression ratios.

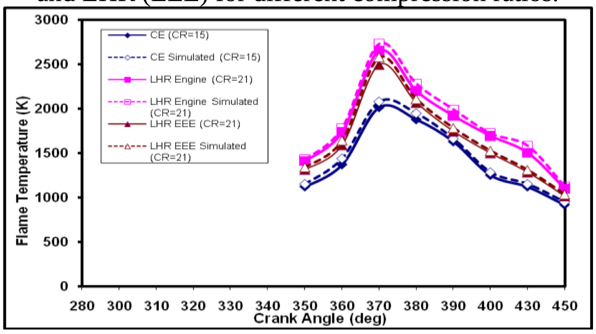

Fig.7. Comparison of Flame Temperature for Conventional (CR=15), LHR(CR=21) and LHR (EEE) (CR=21) with Simulated engines.

3.1.3 Heat Release Rate

The heat release rates as a function of crank angle are shown in Fig 8 and Fig 9. Simulated and experimental values are compared in Fig10. For simulating of heat release in which WIEEBE'S heat release model is used. It is observed that the heat release rates for conventional engine with a compression ratio of 15 is lower by about 2.44%, 10.46%, 11.95%, 19.42% and 25.13% than LHR engine with compression ratios 14, 15, 17, 19 and 21 respectively.

It is also observed that the heat release rates for conventional engine with a compression ratio of 15 is lower by about 1.76%, 7.20%, 6.66%, 7.60% and 10.73% than LHR (EEE) engine with compression ratios 14, 15, 17, 19 and 21 respectively.

The increase in heat release rates in LHR and LHR (EEE) engines is mainly due to high operating temperatures. As the compression ratio increases, the temperature attained also increases.

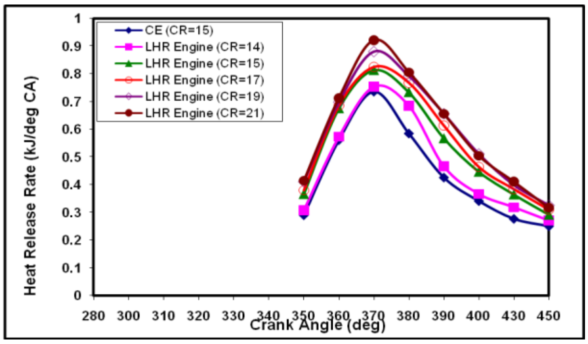

Fig.8. Comparison of Heat Release Rate for Conventional and LHR engines for different compression ratios.

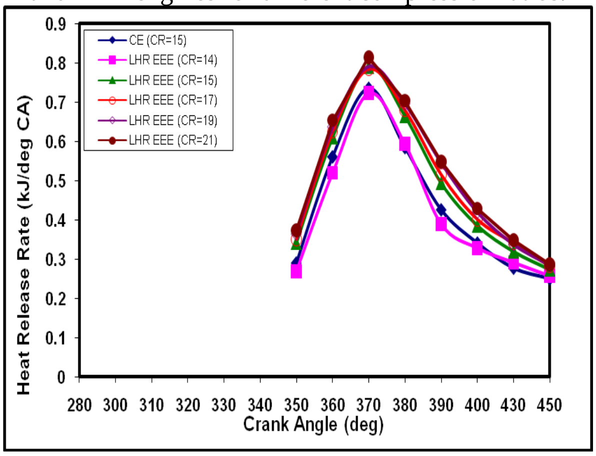

Fig.9. Comparison of Heat Release Rate for Conventional and LHR (EEE) for different compression ratios.

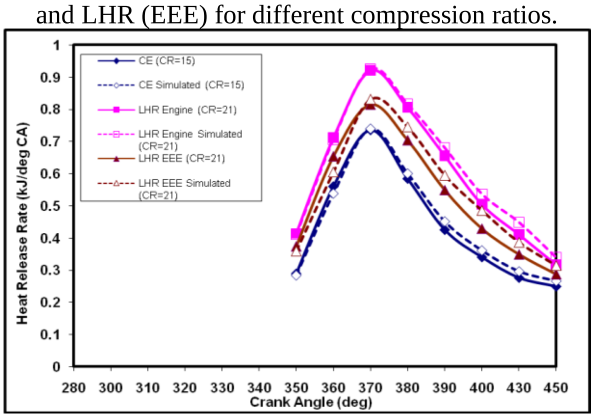

Fig.10. Comparison of Heat Release Rate for Conventional (CR=15), LHR(CR=21) and LHR (EEE) (CR=21) with Simulated engines.

3.1.4 Cumulative Heat Release

The cumulative heat release as a function of crank angle is shown in Fig 11 and Fig12. Simulated and experimental values are compared in Fig13. For simulating of heat release in which WIEEBE'S heat release model is used.

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It is learnt that the cumulative heat release for conventional engine with a compression ratio of 15 is lower by about 9.44%, 25%, 35.14%, 43.36% and 49.47% than LHR engine with compression ratios 14, 15, 17, 19 and 21 respectively.
It is also noted that the cumulative heat release for conventional engine with a compression ratio of 15 is lower by about 2.36%, 9.26%, 20.63%, 28.49% and 28.49% than LHR (EEE) engine with compression ratios 14, 15, 17, 19 and 21 respectively.
The high values of cumulative heat release in LHR and LHR (EEE) engines are mainly attributed to high combustion chamber temperatures.

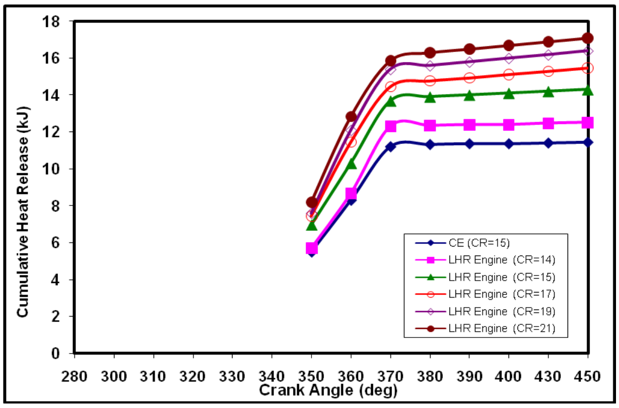

Fig.11. Comparison of f Cumulative Heat Release for Conventional and LHR engines for different compression ratios.

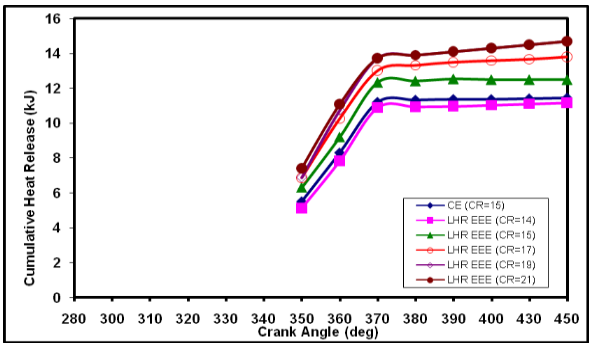

Fig.12. Comparison of Cumulative Heat Release for Conventional and LHR (EEE) for different compression ratios.

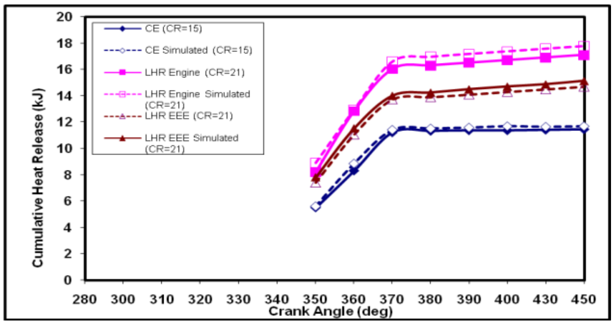

Fig.13. Comparison of Cumulative Heat Release for Conventional (CR=15), LHR(CR=21) and LHR (EEE) (CR=21) with Simulated engines.

3.1.5 Total Heat Transfer

The total heat transfer as a function of crank angle is shown in Fig 14 and Fig15. Simulated and experimental values are compared in Fig16. For simulating of heat transfer in which ANNAD'S heat transfer model is used. It is noted that the heat transfer for conventional engine with a compression ratio of 15 is higher by about 32.97%, 26.36%, 14.62%, 7.97%, and 3.72% than LHR engine with compression ratios 14, 15, 17, 19 and 21 respectively.
It is also observed that the heat transfer for conventional engine with a compression ratio of 15 is higher by about 39.68%, 39.36%, 21.54%, 15.42% and 9.84% than LHR (EEE) engine with compression ratios 14, 15, 17, 19 and 21 respectively.
The total heat transfer mainly comprises of two terms. One is due to convective heat transfer which is higher for conventional engine than a LHR and LHR (EEE) engine. The radiative heat transfer is high for LHR and LHR (EEE) engines due to high operating temperatures than that of conventional engine. Overall, the heat transfer to the cylinder walls is reduced in a LHR and LHR (EEE) engine when compared with the conventional engine.

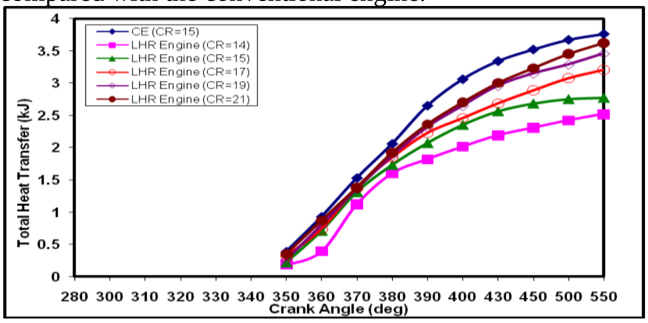

Fig.14. Comparison of Total Heat Transfer for Conventional and LHR engines for different compression ratios.

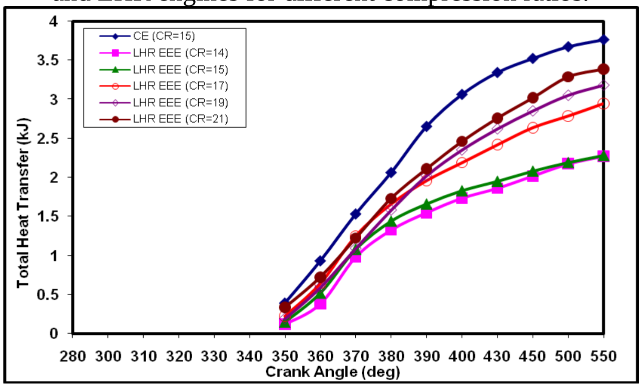

Fig.15. Comparison of Total Heat Transfer for Conventional and LHR (EEE) for different compression ratios.

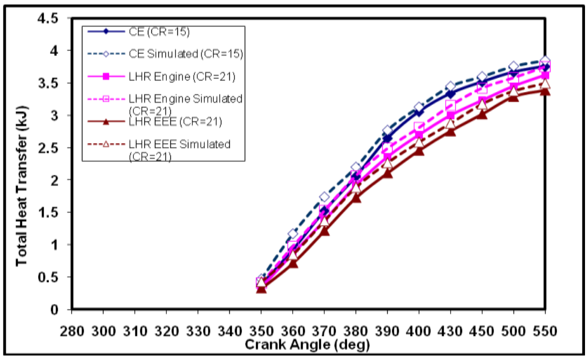

Fig.16. Comparison of Total Heat Transfer for Conventional (CR=15), LHR(CR=21) and LHR (EEE) (CR=21) with Simulated engines.

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3.1.6 Cumulative Work done

The cumulative work done as a function of crank angle is shown in Fig 17 and Fig18. Simulated and experimental values are compared in Fig19. It is learnt that the cumulative work done in conventional engine with a compression ratio of 15 is greater by about 9.05%, 4.06% and 2.66% than LHR engine with compression ratios 14, 15 and 17 respectively. It is also learnt that the cumulative work done in conventional engine with compression ratio of 15 is lower by about 11.37% and 11.56% than LHR engine with compression ratios 19 and 21 respectively.

It is observed that the cumulative work done in conventional engine with compression ratio of 15 is greater by about 12.54%, 12.54% and 7.83% than LHR (EEE) engine with compression ratios 14, 15 and 17 respectively. It is also learnt that the work done in conventional engine with compression ratio of 15 is lower by about 8.42% and 9.16% than LHR (EEE) engine with compression ratios 19 and 21 respectively.

The increase in work done is mainly due to high pressures attained due to increase in compression ratios.

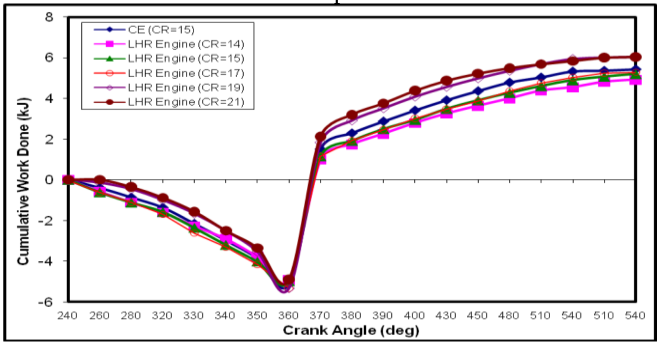

Fig.17. Comparison of Cumulative Work Done for Conventional and LHR engines for different compression ratios.

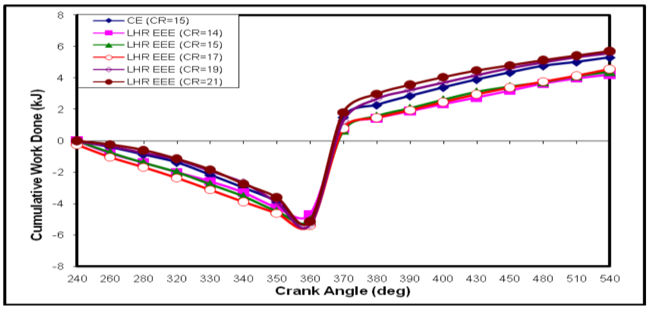

Fig.18. Comparison of Cumulative Work Done for Conventional and LHR (EEE) for different compression ratios.

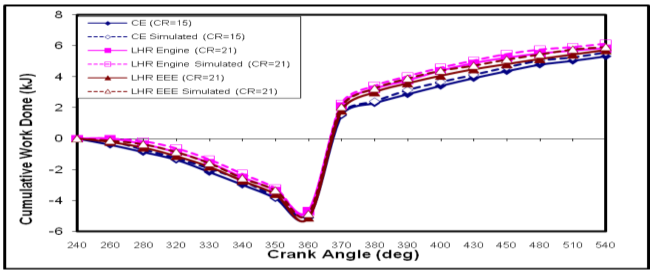

Fig.19. Comparison of Cumulative Work Done for Conventional (CR=15), LHR(CR=21) and LHR (EEE) (CR=21) with Simulated engines..

IV. CONCLUSION

The experiments are conducted on conventional diesel engine, later which is converted into LHR engine. The experimentation procedure is repeated on LHR engine. Then LHR engine is operated on Extended Expansion cycle by modifying the inlet cam. In comparison of experimental and simulated combustion parameters such as cylinder pressure, cylinder mean temperature, rate of heat release, and cumulative heat release for different compression ratios for all stages of engine taken for investigation are concluded as follows.

- The cylinder peak pressure of conventional engine is higher for compression ratios 14 and 15 when compared with LHR and LHR (EEE) engine, and it is higher in LHR and LHR (EEE) for compression ratios 17, 19 and 21.
- The flame temperature is found to be higher for LHR and LHR (EEE) engines than conventional engine due to insulation coatings applied on the combustion chamber walls and as the compression ratio increases there is hike in temperatures attained in the combustion chamber.
- The heat release rate and cumulative heat release are found to be high for LHR and LHR (EEE) engines with higher compression ratios compared to conventional engines.
- The total heat transfer in LHR and LHR (EEE) engines is lower than that of conventional engine due to insulation coatings applied on the combustion chamber walls to minimize heat transfer. And this leads to high exhaust gas temperatures.
- The cumulative work done in LHR and LHR (EEE) engines is lower for compression ratios 14,15 and 17 may be due to decrease in effective compression ratios. And it is higher for compression ratios 19 and 21 when compared with conventional engine.

The simulated values of the combustion parameters discussed above are well comparable with the experimental values. WIEBE'S heat release model is used to estimate the amount of heat released. ANNAND'S heat transfer model is used to estimate the heat transfer.

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