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Mathematical Modeling of Thermal Flow in CI Engine: A Review of the Recent Literature

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ABSTRACT

Mathematical Modeling of the combustion chamber of a CI engine has been formulated and validated by a number of investigators. The basic focus of the studies has been in the following areas: 1. Development of thermal stresses in the combustion chamber with a view to effecting a robust design and 2. Optimum thickness of heat protective coating meant for improving the thermal efficiency of the compression ignition engine and the distortion of cylinder liner due to the thermal load. A review of the recent literature has been carried out in these aspects of CI engine.

KEYWORDS

Literature Review:
A number of authors have reported on mathematical modeling of thermal flow in the combustion chamber of I. C. Engine including C. I. Engine.

Chigrinova et al [1] have analyzed the thermal stresses in the Combustion Chamber of an I. C. Engine with a view to determining the optimum thickness of a heat protective coating on the absorbing surface of the piston and the cylinder. Their experience suggests that the ultimate temperature of the piston top positioned above the first packing ring is 180^0C-200^0C for high speed engine. For forced marine engine, having an increased service life, the indicated temperature does not exceed 150^0C. For modern, reliable engines, the temperature on the piston-top side cooled by the oil is 200^0-220^0C. Thus, for deciding the material of heat-resistance and heat-protective coating, it is necessary to consider the temperature at different sites of the combustion chamber subjected to thermal stresses. The temperature may differ from the mean temperature by no more than +-100^0C. In deciding on the material of the coating, it is necessary to estimate the heat flow through the cylinder head and on the piston top. The thickness of the heat-resistance and heat-protective coating should be determined considering the temperature of the surface under the coating. This temperature should not exceed 250^0C-350^0C for Al alloys, 400^0C-500^0C for Cast Iron, 450^0C-500^0C for steel and 600^0C-650^0C for high temperature steel. The stress developed depends on entropy, enthalpy and the temperature of the coating material. On the basis of analysis of the heat exchange in the cylinder of an I. C. Engine and on investigation of the heat stress of the combustion chamber parts, they have developed a new method for calculating the optimum thickness of a heat protective coating on the heat-absorbing surface of the piston and the cylinder. This accounts for the varying stress arising in the combustion chamber during the operation of the Engine.

The performance of a nano ceramic Al_2O_3 as a coating material in the low heat rejection engine has been reported by Musthafa et al [2]. The fuel used was rice bran methyl ester or diesel fuel mixture. An increase in Engine Power and decrease in specific fuel consumption, as well as significant reduction in exhaust gas emission (except NO_x) and smoke density were observed in the Ceramic-coated engine as compared to those of the uncoated engine.

Lowrence et al [3] have presented the effect of coating on piston, cylinder head and valves on the performance of a modified 4-stoke Diesel engine using wet ethanol (5% water) on the emission characteristics of exhaust gas. Zirconia, which has low thermal conductivity, high temperature resistance to erosion, corrosion and high strength was selected as a coating material for engine components. Ethanol was sprayed in inlet manifold and spark plug was erected on engine head to facilitate ignition. Engine performance was studied for both wet ethanol and diesel with and without Zirconia coating.

Wang H. Sun et al [4] have studied the factors contributing to the roundness of cylinder liner. The analysis considered both mechanical and thermal load and the cooling effect as obtained from simulation study. Results have indicated that thermal factors have very significant influence on the distortion of cylinder liner. The preload of joint bolt also plays a significant role. The other two factors viz., the gas pressure and piston thrust force only lead to deformation of a part of cylinder liner. The comprehensive analyses, considering these factors give detailed description to cylinder liner distortion under realistic condition.

Micklow et al [5] have investigated the in-take and in-cylinder flow field of a four valve direct injection C. I. engine using a 3-D unsteady turbulent compressible Navier- Stoke solver KIVA 3V. Complex flow structures are developed during compression stroke. The homogeneity of the in-cylinder flow characteristics and temperature field has also been studied. These simulation studies have improved the understanding of the intake process and its influence on direct injection compression engine.

Toh et al [6] have carried out numerical simulation to investigate the inlet port geometry on the in-cylinder flow of 4-stroke I. C. Engine during the intake and compression stroke. Through the numerical simulation, it is found that inlet port with elliptical cross section is more conducive to tumble motion. The studies have also been validated by experimental distribution of U-velocity and V-velocity along X and Y axis of the two crank angle (CA=179^0 and CA=240^0) in the symmetry plane of the engine cylinder.

Due to its superior durability, drivability and fuel efficiency, the Compression Ignition (CI) engine has found broad applications in both heavy-duty off-highway vehicles and equipment in a comprehensive parametric study, Shi et al [7] demonstrated that a CI Engine fuelled with gasoline-like fuels has great potential to meet more stringent emission standards while maintaining fuel economy.

Li and Song [8] have formulated heat transfer for multi-dimensional engine. The formulations have been validated against analytical solution. The model is able to predict unsteady and non-uniform temperature distribution on the chamber surface. A finite volume approach has been adopted for fluid flow calculations. The formulation was used to predict the transient heat condition, in-cylinder combustion process and heat conduction in the piston and cylinder head in diesel engine. The model predicts that the combustion chamber surface temperature fluctuates by 100K within an engine cycle due to transient diesel-spray combustion. The highest surface temperature on the piston surface occurs at the edge of the piston bowl along the spray axis. Results also show that the conjugate of heat transfer model does not significantly alter the prediction of the global engine combustion and emission parameters.

Computer-aided conversion of a direct injection diesel engine into CNG dedicated or dual fuel combustion has been presented by Donateo et al [9]. The procedure had been applied to determine the best fuel economy chamber configuration that is also prompt to detonation. The application to a dual-fuel engine showed that the combustion process is only weakly influenced by the bowl profile (in fact the emission can't be improved more than 5% for a given operating condition). However the procedure is successful in defining the best shape of the profile in order to achieve the goals of conversion process and a reduction of NO_x emission upto 20%. Further work is required to optimize the chamber by setting a variable compression ratio for the dual-fuel case.

Jemni et al [10] have attempted to convert a Diesel Engine into a dual-fuel (gasoline-diesel) spark ignition engine. This also facilitates the LPG and CNG. A three dimensional numerical modeling of the turbulent in-cylinder flow through the two manifolds was undertaken. They have reported improved performance of a number of key parameters. Brake power (BP), Brake Torque (BT), and Brake Thermal Efficiency (BTE) are increased by 16%, 13.9% and 12.5% respectively using optimal manifold. The Brake Specific Fuel Consumption (BSFC) is reduced by 28%. Simulation and experimental result confirmed the benefits of the optimized manifold geometry on the in-cylinder flow and engine performance. Figure (i), below shows two distinct zones for performance divided at 1200 rpm. Optimized IM offers better advantage (9.6%) at rpm below 1200. Beyond 1200 rpm the efficiency advantage reduces to 6.25%.

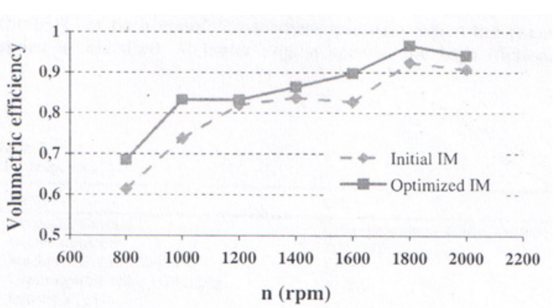

Fig. (i) Volumetric efficiency vs Engine rpm for two manifolds

Xia et al [11] have attempted to improve the engine performance by controlling piston motion by an eccentric shaft of properly designed shape turns the optimal motion of the piston into a constant angular rotation. They find out the following results-

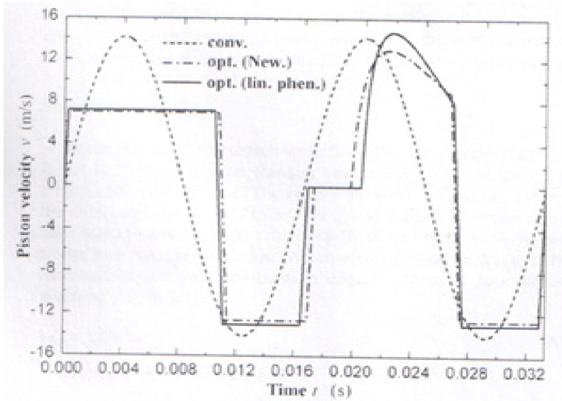

Fig. (ii) The profile of the piston velocity versus the time for the full life cycle

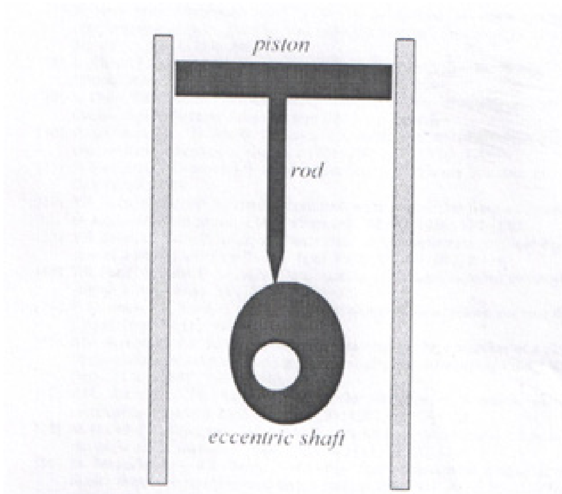

Fig. (iii) The mechanical transfer, an eccentric shaft of properly designed shape turns the optimal motion of the piston into a constant angular rotation

The heat transfer between the working fluid and the environment obeys the linear heat transfer law. The optimal piston motion trajectories for maximizing the work output per cycle are derived on each stroke by applying optimal distribution of total cycle time among the stroke is also obtained. The piston motion along the optimal power stroke with constant acceleration consists of 3 segments- (i) initial motion delay, (ii) the middle motion and (iii) the final maximum deceleration segment. The obtained results have been compared with the conventional cycle result. The results show that the optimizing the piston can improve both the net work output per cycle and the net efficiency of the standard engine by more than 12%, which is mainly due to increase in the average temperature of the working fluid during the initial segment of the power stroke .

Tanner et al [12] have developed a CFD based optimization of fuel injection using an adaptive gradient method. The engine simulations have been performed with a CFD code KIVA-3 which is equipped with well established spray combustion and emission models. It has been demonstrated that the optimal injection method has a large potential for reducing emission while maintaining low fuel consumption. The optimization method uses adaptive step size mechanism which depends on the gradient of the search direction.

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