INVESTIGATION OF MIXTURE FORMATION PROCESS IN VARIOUS CYLINDER AND INJECTION CONFIGURATIONS OF DI-SI ENGINES THROUGH MULTIDIMENSIONAL MODELLING

by

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submitted

in fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

NEW DELHI, INDIA

MAY - 2006

1. Fuel injection devices
2. DI-SI engines

CERTIFICATE

The thesis entitled **"Investigation of Mixture Formation Process in Various Cylinder and Injection Configurations of DI-SI Engines through Multi-dimensional Modelling"** being submitted by Mr. **Abhijeet Mohan Vaidya** to the Indian Institute of Technology Delhi for award of the degree of **Doctor of Philosophy**, is a record of original bonafide research work carried out by him. He has worked under our guidance and supervision, and has fulfilled the requirements for the submission of this thesis, which has attained the standard required for a Ph.D. degree of this Institute.

The results represented in this thesis have not been submitted elsewhere for the award of any degree or diploma.

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ACKNOWLEDGEMENTS

At this moment, I would like to fully utilize this opportunity to express my heart-felt thanks to a few people who have helped me much and brought me and my ambitious project to this level.

First of all, I would like to thank my supervisor Dr. P. M. V. Subbarao. His presence in the form of my supervisor was itself the biggest psychological support for me. He not only supported my various ideas but also refined them and corrected me whenever required. His many hints have been very useful in overcoming many blockages that have come my way. He was also very prompt in providing me with the required resources.

Further, I express my thanks to Prof. R. R. Gaur, who, always lend an ear to my demands and complaints and was always ready to give me time inspite of his busy schedule. He very enthusiastically and sincerely organized and lead many brain storming meetings and has provided me with many valuable suggestions throughout the tenure of this project.

My many thanks to Dr. D. S. Khatri for his support. He always very enthusiastically drove to IIT a distance of more than an hour to discuss his many ideas with me and rest two supervisors. I am specially thankful to my supervisors for their support and patience during the pessimistic periods of this project.

My many thanks to Dr. M. R. Ravi, who directly and indirectly helped me in more than one way. I have learned a lot from him through his lecture classes, his published articles and thesis and many informal discussions some of which were held in different places of the department including corridors, staircases, computer labs etc. My words are not enough able to express my feelings about him.

My extended stay in IIT has become much pleasurable because of company of many friends and Keshav (ME) owns a lion's share of the credit. The help received from Mr. Rajesh Gupta is highly appreciable. It was because of him that my long hours in the lab used to be more fruitful and enjoyable. Mr. Subhash Chander (PP) has left an era of unforgettable moments out of his association of the last two years.

The association with my beloved juniors, Hemant Punekar, Ratna Kishore Velamati and my junior friends, Anand Krishnan and Rupesh Kumar was too very joyous.

I express my thanks to librarians of IIT-K and IIT-B for allowing me to use the libraries. Many thanks to all those people who are the unknown makers of Linux, LaTeX, Gnuplot, GIMP and GSVIEW etc.

I would like to thank my parents who allowed me to pursue this degree inspite of adverse conditions. The love and support of my brother, Mr. Shailesh Vaidya and sister, Mrs. Rashmi Saraf, is also highly appreciated.

I thank the Almighty to give me the opportunity of pursuing this higher study.

A. M. Vaidya

May 8, 2006

ABSTRACT

Direct injection of gasoline in cylinder has emerged as the most promising concept for simultaneously achieving high fuel economy as well as high power. The actual benefits of these engines can be realized only if the in-cylinder flow phenomenon is properly governed. Spray formation, mixing with surrounding flow and formation of combustible mixture should happen properly. The in-cylinder flow phenomenon is more complex and has more significant impact on overall performance of the engine.

Over last two decades, multidimensional flow simulation (CFD) has emerged as an important technique capable of computing flow in thermal systems. Hence CFD can be employed to understand the in-cylinder flow processes of DISI engines. This work deals with development and application of a flow simulation tool for understanding and improving the mixture formation processes in various geometries of DISI engines.

Some work on multidimensional modelling of DISI engines is reported in the past in the literature. Some study has been done to understand the effect of operating parameters on engine performance. However complete studies are not presented. A complete study of DISI engines would involve investigation of various possible geometries. Also each geometry should be studied under varying operating conditions. This will give information regarding suitability of different configurations to operate as a complete DISI engine. Such a complete study would lead to establishing most optimum geometry and corresponding optimized parameters.

The objective of the present work is to perform such a comprehensive study through CFD simulation.

Towards this end, a computer simulation program has been developed indigenously to compute the flow inside DISI engines. The flow in DISI engines is turbulent, compressible, multiphase and multi-specie. Further the physical domain is complex and deforming. Considering these factors, the required formulation is developed and a computer code is written.

The code has following features.

(a) Standard k - ε turbulence model to account for turbulent flow

(b) Use of curvilinear non-orthogonal coordinates to compute the flow in realistic complex geometries

(c) Standard wall functions implemented for non-orthogonal grid

(d) Capability to handle moving boundary i.e. piston and solution of flow over a deforming computational domain

(e) Multi-block grid for handling piston with arbitrary shaped cavity

(f) Discrete droplet model (DDM) for solving evaporating fuel spray including spray wall interaction

(g) A novel and efficient droplet tracking and advancing algorithm applicable over a deforming and non-orthogonal curvilinear grid

(h) Complete two-way coupling between the gas and liquid phases

(i) Compressible, multi-component, multi-phase formulation applicable to flow inside DISI engine

(j) Finite volume technique for solving the gas phase equations

(k) Tri-Diagonal matrix algorithm for solving the set of non-linear equations

The code is validated with respect to available experimental, analytical and computational data.

The geometries studied in the present work, using above mentioned code, are listed below.

(a) DISC chamber geometry

(b) Pent roof chamber geometry with centrally located injector

(c) Pent roof chamber geometry with side located injector

(d) GDI geometry

(e) GDI - Top geometry

(f) GDI - opposed geometry

For each geometry, a detailed parametric study is performed whereby the effect of following parameters is studied.

(a) Start of injection (SOI) timing

(b) Injector orientation

(c) Droplet diameter

(d) Spray cone angle

(e) Tumble ratio

The study is done of stratification as well as homogenization processes. Obtaining best possible state of the air-fuel charge at the time of spark discharge is the criterion for optimizing the parameters. Best possible mixture formation is decided for each geometry and then all the geometries are compared to give the most optimum one.

The performance of the engine has to be judged from global mixture formation phenomenon. In full load, it is important to calculate the level of overall homogeneity of air fuel mixture achieved. In part load conditions, it is necessary to understand the distribution of flammable air-fuel mixture in cylinder. Proper pattern of stratification of mixture with flammable charge around spark plug and lean charge away from it should be obtained.

It is not possible to visually inspect and compare mixture formation under different conditions. Hence it is necessary to *quantify* the mixture formation process. This is done by using two newly defined parameters called homogeneity index and stratification index. These parameters properly represent the mixture formation phenomenon and are calculated from detailed data of spatial and temporal variation of primitive flow variables generated from a simulation. The scope of the work is limited to computation of mixture formation process and subsequent combustion process is excluded.

Based on the repeatability with which the required level of homogeneity and stratification is obtained in different injection conditions, the reliability of each configuration is checked. It is found that DISC chamber geometry offers tight constraints in producing stratified mixture but shows acceptable performance for producing homogeneous mixture but requires high tumble level and fine droplets. The central injector pent roof configuration offers very favourable homogenization as well as stratification characteristics if high tumble level and wide spray cone angles are employed. The side injector pent roof configuration is not suitable for stratification and also creates homogeneous mixture only if tumble level is high. Thus, it is not very favourable geometry. GDI-top geometry is suitable for creating stratified as well as homogeneous mixtures. GDI geometry shows best performance amongst all considered geometries as it is possible to create stratified as well as homogenous mixture with ease. GDI - opposed geometry shows similar characteristics as DISC chamber geometry. It has poor performance in stratification mode and requires high tumble level to create homogeneous charge.

In brief, GDI geometry, pent roof geometry with central injector and GDI - Top geometry perform satisfactorily as DISI engines and other geometries are not recommended.

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