Chapter - 1

Introduction

Since the invention of the internal combustion engine over a hundred years ago its impact on the life of human beings has been immense. The application of the engine as a source of motive power covered a large number of systems ranging from handheld power tools driven by small engines, such as chain saws, up to large power requirements for static installations or marine applications. The compression ignition (CI) engine, also known as the Diesel engine, was developed from the efforts of Akroyd Stuart and Rudolf Diesel. Stuart's engine first developed in 1892 ran on a compression ratio of around three, which was too low to ignite the fuel by compression alone. An external heat source was required to start the engine, but could be removed once in operation. Diesel's compression ratio was such that the fuel spontaneously ignited after injection into cylinder. This concept was finally achieved in 1893, and the prototype ran with a thermal efficiency of 26%. This was roughly double the efficiency of any contemporary power plant, and most research and development in the first place concentrated on improving the efficiency and performance of the engine. The traditional fossil fuel was used to run this engine. Since then, a lot of innovations have been introduced by various investigators during the earlier period of development till the world war. A large number of war related applications pushed the interest of further development during the pre war and earlier part of post war period. In the process, the consumption of conventional fossil fuel increased leap and bound all over the world. The "oil shock" of 1970s gave a renewed soul searching to conserve the "oil" and find alternative sources of energy more vigorously.

The trio of conventional fossil fuels, viz., petroleum, natural gas and coal which meet most of the world's energy demand today, are being depleted rapidly. Also, their combustion products are causing global problems, such as the greenhouse and, ozone [illegible] depletion, acid rains and pollution, which are posing great danger for our environment , and eventually, for the total life on our planet. However, it has become apparent over the three decades that the harmful effects of exhaust gas emissions constituents, both in terms of the damage to the environment and human health, is such that worldwide legislation has been put in place. This has therefore meant that the development on diesel engines have been driven by the need to improve the exhaust gas emissions.

To solve the green house and depletion crisis simultaneously, all researchers and decision makers looked for new source of energy or renewable energy. They found different types of alternative fuels to substitute the traditional fossil fuel with clean new source of non-fossil based energy. Alternative fuels, known as non-conventional or advanced fuels, are any materials or substances that can be used as fuels, other than conventional fuels. Some well known alternative fuels include biodiesel, bio alcohol such as methanol, ethanol, butanol, chemically stored electricity such as batteries and fuel cells, hydrogen, non-fossil methane, non-fossil natural gas, vegetable oil and other biomass sources. And also, there are alternative fossil fuels such as compressed natural gas (CNG).

Hydrogen is the most abundant element in the Universe, and it is expected that the Earth's early atmosphere was a reducing one, in which hydrogen predominated. Now, over four billion years later, the atmosphere is an oxidizing one, and over most of the Earth's surface oxygen predominates. The gradual conversion from a hydrogen-rich environment to an oxygen-rich one was the result of a global redox cycle. Water was split into oxygen and hydrogen, and the hydrogen atoms escaped into Space. Biology played an important part in this process, which still continues.

Hydrogen is one of the promising future fuels as renewable and alternative fuel for internal combustion engines. Hydrogen is a versatile energy carrier that can be used to power nearly every end-use energy need. There are a number of unique features associated with hydrogen that make it remarkably well suited in principle, to engine applications. Some of these most notable features are the following: Hydrogen, over wide temperature and pressure ranges, has very high flame propagation rates within the engine cylinder in comparison to other fuels. These rates remain sufficiently high even for very lean mixtures that are well away from the stoichiometric mixture region. Preferably during combustion, the engines are operated under stiochiometric mixture, but mostly the internal combustion engines are operated under lean mixture condition to reduce the fuel consumption rate. Certainly, such lean mixture operation leads to a lower power output for any engine size. This drawback of lean mixture operation with hydrocarbon fuels is solved by using hydrogen. Whereas, the operation on lean mixtures, in combination with the fast combustion energy release rates around top dead center with short combustion duration associated with the very rapid burning of hydrogen–air mixtures results in high-output efficiency values and high rates of pressure rise following the ignition. This permits stable lean mixture operation and control in hydrogen fueled engines.

One of the most important features of engine operation using hydrogen is that it is associated with less undesirable exhaust emissions from engine as compared with that of other fuels. There are no contribution of the hydrogen fuel to the formation of additional constituents of gas emissions such as unburnt hydrocarbons, carbon monoxide, carbon dioxide, oxides of sulfur, and smoke. The contribution of the lubricating oil to such emissions in well-maintained engines tends to be rather negligible. Only oxides of nitrogen and water vapor are the main products of combustion emitted. Also, with lean operation, the level of NOx tends to be significantly smaller than those encountered with operation using other fuels.

The fast burning characteristics of hydrogen permit much more satisfactory high speed engine operation. This would allow an increase in power output with a reduced penalty for lean mixture operation. Also, the extremely low boiling temperature of hydrogen leads to fewer problems encountered with cold weather operation. The heat transfer characteristics of hydrogen combustion in engines are significantly different from those in engines operating on other fuels. The radiation component of heat transfer tends to be small yet the convective component can be higher especially for lean mixture operation. The sensitivity of the oxidation reactions of hydrogen to catalytic action with proper control can be made to serve positively towards enhancing engine performance.

Hydrogen can have a high effective octane number mainly because of its high burning rates and its slow pre-ignition reactivity. A number of different solutions have been implemented to achieve lower emissions and many engineers and scientists agree that the solution to all of these global problems would be to replace the existing fossil fuel system with the clean hydrogen energy system. Hydrogen is a very efficient and clean fuel. Its combustion will produce no greenhouse gases, no ozone layer depleting chemicals, and little or no acid rain ingredients and pollution. Hydrogen, produced from renewable energy (solar, wind, etc.) sources, would result in a permanent energy system which would never have to be changed.

The implementation of duel fuelling of hydrogen-diesel is one of the many methods investigated to control the emissions and enhance the diesel engine efficiency. Fossil fuels possess very useful properties not shared by non – conventional energy sources that made them popular during the last century. Unfortunately, fossil fuels are not renewable. In addition, the pollutants emitted by fossil energy systems, viz., CO, CO_2, C_nH_m, SO_X, NO_X, radioactivity, heavy metals, ashes, etc. are greater and more damaging than those that might be produced by renewable based hydrogen system. However, the diesel as a conventional fossil fuel is still essential requirement to ignite the clean hydrogen fuel in the combustion chamber. The supplementing of hydrogen in compression ignition engine serves to reduce the greenhouse emission, reduce the conventional fossil diesel fuel consumption and enhance the engine performance.

The oil crisis of 1973 ignited the spark of hydrogen fuel research. Since then, a considerable progress has been made in the search of hydrogen as alternative energy source. A long term goal of energy research has been to seek for a method to produce the hydrogen fuel economically by splitting water using sunlight as primary energy source. Lowering of worldwide CO_2 emission to reduce the risk of climate change (greenhouse effect) requires a major restructuring of the energy system. The use of hydrogen as an energy carrier is a long term options to reduce CO_2 emissions. Global utilization of fossil fuels for energy needs is rapidly resulting in critical environment problems throughout the world. Energy, economic and political crises, as well as the health of humans, animals and plant life, are all critical concerns. A worldwide conversion from fossil fuels to hydrogen would eliminate many of the problems and their consequences.

Supplementing of hydrogen totally as fuel in compression ignition engine is still in the investigation stage and therefore, the hydrogen- diesel dual fuel option is the simple and widely applicable option. Various induction/injection options are investigated in the recent past which includes supplementing of hydrogen partially. Hydrogen induction or injection in the intake air manifold and direct hydrogen injection are the techniques one can employ to control the combustion process in a compression ignition engine using diesel oil as fuel. Hydrogen induction or injection in the intake manifold employs inducing hydrogen into air passage to mix, diffuse and enter the combustion chamber homogenously along with air. Then this mixture is compressed and ignited by the injection of diesel when it comes with suitable pressure inside combustion chamber to explode this mixture at the end of compression stroke and starts the power stroke. The main advantages expected of the techniques are increase in brake thermal efficiency, elimination of the flash back and pre ignition. The modifications needed in the CI engine to homogenize air-hydrogen mixture are simple. The main drawback expected is the reduction in the intake air. Few options to take care of this deficiency are to introduce turbo charger to enhance intake air, use of recirculation of exhaust gases partly through the air intake port, and use of oxygenated fuel as a blend with the diesel.

Oxygenated fuels are chemical compounds containing oxygen as a part of their chemical structure. The extent of oxygenated fuel as diesel blends and its effect on emissions and performance of diesel engine is a subject of investigation. It has been shown that formation of the air pollutants can significantly be reduced by blending oxygenates into diesel oil. Many types of oxygenated fuel are available and they are divided in alcohols and ethers. Methanol, Ethanol, Isopropyl alcohol, *n*-butanol, and *t*-butanol are few alcohols, while, Methyl tetra-butyl ether, Tertiary amyl methyl ether, Tertiary hexyl methyl ether, Ethyl tertiary butyl ether, Tertiary amyl ethyl ether, and Diisopropyl ether are examples of esters used for oxygenation.

Development of more efficient compression ignition engines is almost completely based on experimental investigation. Alongside experimental investigations, with the advancement in computing techniques, the theoretical, simulation, modeling and optimization studies applied to engine performance are attempted by few investigators. Simulation, modeling and programming for performance, fuel consumption, exhaust temperature, toxic emissions and other factors are built. Today, many techniques, packages and codes are used for diesel-hydrogen mixtures or blends.

Artificial neural networks (ANNs) are a modeling technique that can be very useful when experimental data bank is available. ANNs are being successfully applied across an extraordinary range of practical problems, in areas as diverse as finance, medicine, engineering, geology and physics. Indeed, anywhere that there are problems of prediction, classification or control, artificial neural networks are being successfully implemented. Their success is due to three unique attributes: universal approximation ability (input-output mapping), the ability to learn from and adapt to their environment, and the ability to invoke weak assumptions about the underlying physical phenomenon.

The two most useful properties include nonlinearity on Input-Output mapping and ability to learn by example. Artificial neural networks are very sophisticated modeling techniques capable of modeling complex functions and processes. The true power and advantage of ANN lies in their ability to represent both linear and nonlinear relationships. Since they are generic nonlinear function approximators, they offer a different way to analyze and to recognize patterns within the data. Traditional linear models are simply inadequate when it comes to modeling data that contains non-linear characteristics. Furthermore, ANN keep in check the curse of dimensionality problem that affects traditional attempts to model nonlinear functions with large numbers of variables – as is the case with traditional engine mapping models.

Artificial neural networks learn by example. The model developer collects representative data, and then uses training algorithms to automatically learn the structure of the data. Use of real data with an appropriate training algorithm is supervised or active learning using an external teacher. In conceptual terms, the teacher may be thought of as having knowledge of the external environment that is represented by a set of input-output examples. The teacher, by virtue of built-in knowledge, is able to provide the neural network with a desired or target response to its inputs. During training, the network, to which the environment is unknown, generates a response to the inputs. The network response is compared to the desired response, thereby generating an error which is used to adjust the network parameters. The aim of the parameter adjustment is to eventually have the network emulate the teacher.

In essence, a neural network is a collection of basic units, neurons, computing a nonlinear function of their input. Every input has an assigned weight that determines the impact this input has on the output of the neuron. By interconnecting the correct number of neurons in a suitable way and setting the weights to appropriate values, a neural network can approximate any function, linear or nonlinear. This structure of neurons and connections, known as the network's topology, together with the weights of the connections, determines the network's final behavior.

ANNs have been developed for number of years and now widely used in various application areas. ANN offers a way to simulate nonlinear, or uncertain, or unknown complex system without requiring any explicit knowledge about input/output relationship. It can approximate any continuous or nonlinear function by using certain network configuration. It can be used to learn complex nonlinear relationship from a set of associated input/output vectors. Recently, ANNs have been used in internal combustion engines for engine performance, exhaust temperature, fuel consumption analysis and prediction.

The use of statistics in engineering has increased rapidly. As internal combustion systems become more complex, the problems faced by researchers also increase in complexity. For some design problems, no physical model exists and empirical studies must be developed and executed in order to optimize engineering systems for performance and compliance to regulations. This holds particularly in the field of diesel combustion design, where typically, the engine is controlled by a great number of parameters, in order to meet multiple performance objectives. To find the optimum solution one of the famous techniques for this purpose is the Genetic Algorithm (GA). GA is the first evolutionary optimization technique introduced by Holand J. in 1975, which is based on Darwinian principle of the 'survival of fittest' and the natural process of evolution through reproduction. GAs are a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome like data structure and apply recombination operators to these structures, so as to preserve critical information. They are often viewed as function optimizers although the range of problems to which they have been applied in quite board. An implementation of a genetic algorithm begins with a population of typically random chromosomes. Then, it evaluates these structures and allocates reproductive opportunities in such a way reproduce, than those chromosomes which are poorer solutions. It depends on steps such as selection, crossover, and mutation. Also, in the genetic algorithms a lot of algorithms are used. Non-dominated sorting genetic algorithm (NSGA), Differential evolution (DE), Memetic algorithm (MA), Particle swarm optimization (PSO), etc. Fig. 1-1 shows a classification of optimization techniques with the main divisions for each technique. GAs is prompted the researchers to find a non dominated sorting genetic algorithm. In non-dominated sorting genetic algorithm (NSGA), the crossover and mutation operators remain as usual, but selection operator works differently from simple genetic algorithm.

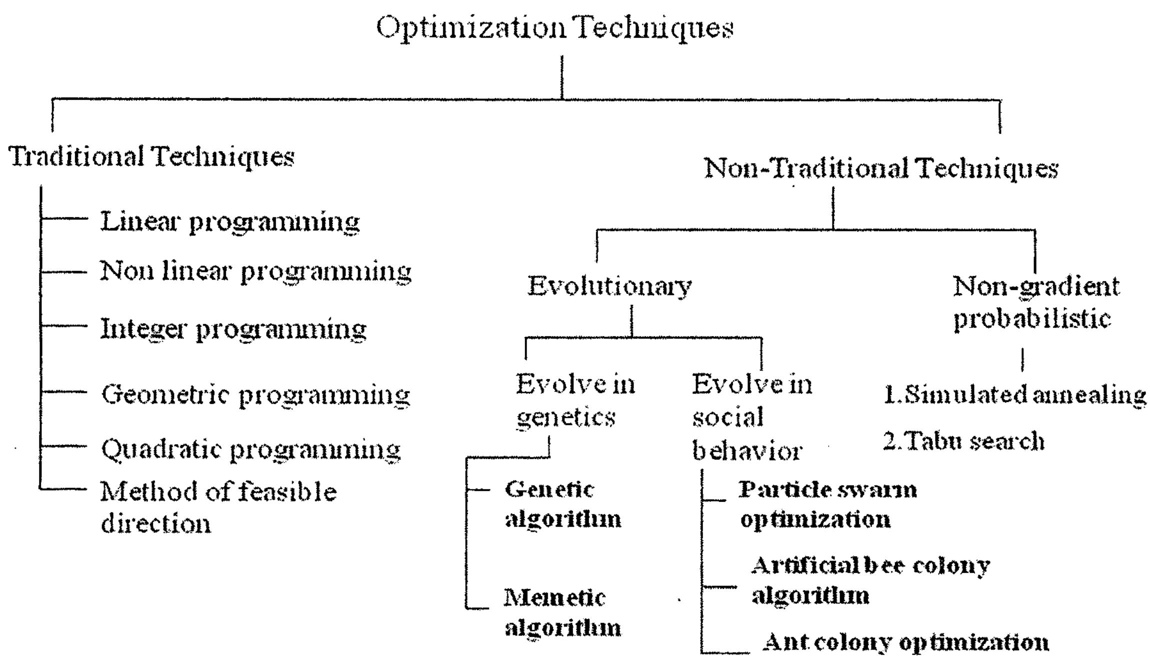

Fig. 1-1 Classifications of Optimization Techniques

The above few paragraphs narrate the various experimental and theoretical / simulation / optimization options available to evaluate the thermal performance and exhaust gas emissions of a compression ignition engine using various improvising techniques. From a systematic review of the earlier investigations, (details are given in Chapter 2) the scope of the present research study is identified.

1.1 Organization of Thesis

The Thesis is organized in the following manner: An introduction covering the experimental investigations during the development of the compression ignition engine and the relevance and importance of modeling and optimization for the evaluation of the thermal performance and the exhaust gas constituents is presented in this chapter. Chapter 2 gives a systematic and comprehensive review of the literature on the various developmental options and based on the review, the research problem is identified. The experimental study carried out on the multi cylinder compression ignition engine with various options of hydrogen induction in the intake manifold together with diesel and oxygenation of diesel with chosen blend are presented in Chapter 3. Chapter 4 gives modeling through ANN and optimization using GA for the thermal performance and exhaust gas emission. The conclusions derived from the studies reported in Chapters 3 and 4 are summarized in Chapter 5. References and Appendices are presented at the end of the report.