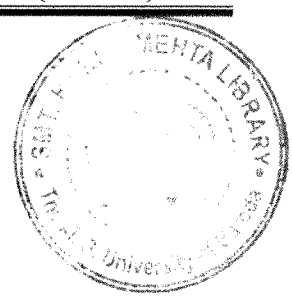

Chapter 1

Introduction

Energy is an essential and vital input for economic activity. It is also the lifeline of modern societies. Building a strong base of energy resources is a pre requisite for sustainable economic and social development of a country. Environmental concerns are also a need of the present times. With increasing trend of motorization & industrialization, the world's energy demand is growing at a faster rate.

World's energy consumption has only increased continuously since decades except for a brief period like the oil crisis in 1970's in which the growth slowed down. Energy consumption has increased by more than 5% in 2010, after a slight decrease in 2009. This strong increase is the result of two converging trends. On one hand, industrialized countries, which experienced sharp decreases in energy demand in 2009, recovered firmly in 2010. Oil, gas, coal, and electricity markets followed the same trend. On the other hand, China and India, which showed no signs of slowing down in 2009, continued their intense demand for all forms of energy.

Energy consumption is not expected to decrease in this century, because the world population is increasing and the economies of developing countries are expanding rapidly. In contrast, the source and supply of primary energy sources like coal, oil and natural gas seem to decrease to a critical point. Although the exact date is debatable, most investigators agree that production peak of oil and natural gas is near. The point of maximum production of oil is called Hubbert Peak. At that point, half of all the recoverable oil that ever existed on our planet has been used. There is still oil left but it is much more difficult and expensive to recover it. Reaching the Hubbert Peak means that production will decrease in future and demand will continue to increase.

In 2008, the energy supply by fossil fuels was nearly 81% of the total world's energy demand. This constitutes 33.5% by oil, 26.8% by coal and 20.8% by gas. The renewable energy sources like hydropower, solar power, wind power, geothermal power and biofuels contributed to about 13% of the world's energy supply and nuclear power contributed to 5.8%. The facts show that oil is the most popular energy fuel. Since their

exploration, the petroleum fuels continued as a major conventional energy source. On the other hand, they are limited in reserves and highly concentrated in certain parts of the globe. Those countries not having these resources are facing energy / foreign exchange crisis due to heavy import bill on crude petroleum. Increased extraction and consumption of fossil fuels have led to a fast depletion in the underground based petroleum derived fuels. These factors have contributed to a sharp increase in petroleum prices.

Also, the petroleum fuels are currently the dominant global source of CO_2 emissions, green house gases & global warming. Their combustion is posing a stronger threat to clean environment. The global warming emissions are the most serious environmental problem. Therefore many nations have signed the UN agreement to prevent a dangerous imbalance in the climate system. The extent of dangerous pollutant concentration in the environment is a subject of debate. The global temperature rise by 2% by 2050 is considered as a high risk level by Stockholm Environmental Institute. This means a global temperature rise of more than 2% is harmful to the environment. In order to limit this temperature rise, the carbon emissions should be declined by 75% in the industrial countries by 2050. A 75% decrease in carbon emissions in the next 40 years implies about 2% decrease every year. As of 2011, the warming emissions of energy production continued rising regardless of the consensus on the basic problem. There is a 25–30 years lag in the complete warming effect of emissions. According to Robert Engelman (World Watch Institute) for security of civilization, one has to stop increase of emissions within a decade regardless of economy and population of the state.

Sharp hike in petroleum prices and increase in environmental pollution jointly have necessitated exploring some renewable indigenous alternatives to conventional petroleum fuels. Also, depletion of fossil fuels, vehicular population, increasing industrialisation, extra burden on home economy, growing energy demand, explosion of population, environmental pollution, stringent emission norms (Euro I, II, III, IV), etc emphasize on the need for alternative fuels. The alternative fuels must be technically feasible, environmentally acceptable, readily available and economically competitive. The possible options we have are renewable energies solar power, Compressed Natural Gas (CNG), producer gas, alcohols, hydrogen, bio alcohol such as methanol, ethanol, butanol, chemically stored electricity such as batteries and fuel cells, propane, non fossil methanol, non fossil natural gas, emulsified fuels, biofuels mostly from non edible seed oils, biodiesels i.e. transesterified form of seed based oils and other biomass sources.

Solar powered panels are very costly and solar energy is not available at all times of the day. Solar energy is not evenly distributed at all locations and problems associated with their maintenance do exist. Compressed natural gas is mostly petroleum based and is available only at refinery locations. Alcohols do have lower cetane numbers and high latent heat of vaporization. Emulsified fuels like Ethanol have lower cetane numbers and lower calorific values which are a disadvantage. Hydrogen as a fuel is considered (highly) explosive and its production is expensive and difficult to store and transport.

More so, for developing countries, fuels of bio-origin, such as alcohol, vegetable oils, biomass, biogas, biodiesels, etc. are becoming important because of their renewable and environmental friendly nature. Some of these fuels can be used directly, while others need some sort of modification before they are used as substitute to conventional fuels.

From the point of view of protecting the global environment and the concern for long term supplies of conventional diesel fuels, it becomes necessary to develop alternative fuels comparable to conventional fuels. Diesel fuel is largely utilized in the transport, agriculture, commercial, domestic, and industrial sectors for the generation of power/ mechanical energy, and the substitution of even a small fraction of total consumption by indigenous alternative fuels particularly of bio-origin will have a significant impact on economy, the environment, the development of agro based industries of the region. Of the alternative fuels, biodiesel obtained from vegetable oils holds good promises as an eco-friendly alternative to petroleum diesel fuels.

Bio-diesel which can be used as an alternative diesel fuel is made from renewable biological sources such as vegetable oils and animal fats. It is bio-degradable, non-toxic and possesses low emission profiles. Also, the use of bio-fuels is environment friendly. Biodiesel production increased by 85% making it the fastest growing renewable energy source in 2006. Over 50% of the world's biodiesel is produced in Germany.

The name bio-diesel was introduced in the United States in the year 1992 by the National Bio-diesel Board which has pioneered the commercialization of bio-diesel. Chemically, bio-diesels are methyl/ethyl esters of vegetable oils. Studies indicate that it can be used in compression ignition engines with little or no (engine) hardware modifications.

One hundred years ago, Rudolf diesel first tested vegetable (Peanut) oil as fuel for his engine. With the advent of cheap petroleum, appropriate crude oil fractions were

refined to serve as fuels and diesel fuels and diesel engines started evolving together. Later in the 1940s, vegetable oils were used again as fuel in emergency situations during the period of World War II. Because of the increase in crude oil prices, limited resources of fossil fuels and the environmental concerns these days, there has been renewed focus on vegetable oils for the production of bio-diesel fuels. Bio-diesel is an oxygenated fuel and has the potential to reduce the level of pollution and the level of global warming. Biofuels provided 2.7% of the world's transport fuel, as of 2010. According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050.

Biodiesels have recently been recognized as a potential substitute to Diesel oil. It is produced from oils or fats using a process called transesterification, in which oils are reacted with alcohols in order to form the esters which are called biodiesels. Feedstock for biodiesel include animal fats, vegetable oils like Soy, Rapeseed, Jatropha, Mahua, Sunflower, Palm, Hemp, Pongamia Pinnata (Karanja), Cotton seed, Neem, Rubber seed, Linseed, Corn, Sesame, Cotton seed and Algae. Biodiesel is a liquid closely similar in properties to fossil/mineral diesel. Chemically, it consists mostly of Fatty Acid Methyl (or Ethyl) Esters (FAME). Most of the biodiesels meet the American Society for Testing and Materials (ASTM) biodiesel standards. Several developed countries have introduced policies encouraging the use of bio diesels made from vegetable oils, bio mass etc. in transport, agriculture and other sectors with the idea of achieving the following goals.

- Prevent environmental degradation by using cleaner fuels to reduce the burden on foreign exchange.
- Reduce the dependence on imported finite fossil fuel resources by replacing them with renewable domestic sources and to provide new demand for crops.
- Support the agriculture and thereby uplift the rural economy.
- Utilization of waste lands, promotion of Agro based industries.

The major advantages of biodiesels are

1. Biodiesels are greener to the environment, biodegradable, renewable, indigenous and have properties closer to that of conventional Diesel oils. Hence it can act as a potential diesel fuel supplement in the near future.

2. They help a country to attain energy self sufficiency in transport, power, agriculture & other related sectors and also boosts rural economy by generating employment. The employment is generated as more labour is required to maintain and cultivate trees whose seeds are feedstock for production of biodiesel.

3. In a predominantly vast agricultural country like India, utilization of waste lands for growing non edible seed bearing trees gives a major thrust to agriculture, rural economy & agro based allied industries.

4. Biodiesel does not need exclusively a separate storage infrastructure. Safe storage time would be up to 6 months beyond which it undergoes oxidation forming a gel like substance.

5. The most important advantage of biodiesels is that its mass scale production & implementation on a large scale requires less expenditure in terms of cost and time compared to all other possible alternative energy sources. It is mentioned in the literature that biodiesels are successfully used in the form of blends with diesel in the existing diesels engines with no modifications.

Due to these advantages of biodiesels over other energy sources, it is a thrust area in energy sector, for power production, transport etc.

In a country like India having a huge agricultural potential, vegetable oil proves a promising alternate for petroleum (diesel) fuel. Today, India has 17% of the world's population, and just 0.8% of the world's known fossil fuel and natural gas resources. India's annual requirement of oil is 120 million metric tonnes. Significant part of this is consumed in the transportation sector. India produces only about 25% of its total requirement. The import cost today of oil and natural gas is over Rs. 2, 00,000 crores. Oil and gas prices are escalating; the cost of a barrel of oil has doubled within a year. We have nearly 60 million hectares of wasteland, of which 30 million hectares are available for energy plantations like Jatropha, Honge (Karanja/pongamia pinnata) etc. Once grown, the crop has a life of 50 years. Each acre will produce about 2 tonnes of bio-diesel at about Rs. 20 per litre. Biodiesel is carbon neutral and many valuable by-products flow from this agro-industry. Carbon neutral is a term used to describe fuels that neither increase nor reduce the amount of carbon in the atmosphere. India has a potential to produce nearly 60 million tonnes of bio-fuel annually, thus making a

significant and important contribution to the goal of "Energy Independence" of India, boosting agriculture based industries and uplifting our rural economy and thereby GDP of the country.

India being predominantly an agricultural country requires major attention for the fulfillment of energy demands of a farmer. Irrigation is the bottleneck of Indian agriculture, it has to be developed on a large scale, but at the same time Diesel fuel consumption for these sectors must be kept at a minimum level because of the price of Diesel oil and its scarcity due to fast depletion. Finding an alternative fuel for petroleum diesel fuel is critically important for our nation's economy and security. The complete substitution of oil imports by indigenous alternatives for the transportation and agricultural sectors is the biggest and toughest challenge for India.

In recent years systematic efforts have been made by several investigators to use biodiesels made from vegetable oils like Sunflower, Peanut, Soybean, Rapeseed, Palm , Cotton Seed, Linseed, Jatropha, Corn, Sesame, Karanja (Pongamia Pinnata), Rubber seed oils etc as alternate fuel to Diesel oil. The vegetable oils used to produce biodiesels are made from renewable sources that are potentially inexhaustible, environment friendly, biodegradable, non aromatic & practically have zero sulphur content in them. Many of the vegetable oils are edible in nature, but their use as fuel has limited applications due to higher domestic food requirement. Only few non edible seed oils have been tried on a diesel engine, leaving a lot of scope in this area. The potential non edible seed oils important from Indian perspective are the oils extracted from the seeds of Karanja plant (Pongamia Pinnata), Mahua, Jatropha Carcus (Ratanjyot), Nagachampa and Rubber (Hevca Brasiliensin).

Almost all non edible oils are being used in soap and pharmaceutical industries, but due to dark colour and odour, Karanja oil is less preferable compared to other non edible oil species for these purposes. Hence Karanja oil can be obtained easily for engine applications after transesterifiation. Esterified oil of Karanja is also referred to as Karanja biodiesel throughout in the present study. Karanja oil is easily available in many parts of India and is relatively cheap compared to other non-edible oils. Hence government agencies and non government organisations should be encouraged to take up cultivation of Karanja at a faster pace as compared to other species available in India as a commercial & potential diesel fuel substitute from the future point of view. This point

emphasises the selection of Karanja species for the present study. However, details of Karaja species are discussed in Appendix I.

With the use of fuels like Karanja oil and its ester as alternative to diesel, a country can become self-sufficient in its energy requirements and thereby the dependence of the nation on other countries for oil imports will get reduced. Moreover, the farmers of the nation would also be contributing towards a healthier environment. Bio fuel used alone or in blended form with diesel has the advantage of contributing to cleaner exhaust and reduced requirement of fossil fuel resources of petroleum derivatives.

Of all the investigations conducted, Karanja (Pongamia Pinnata) holds promise for further studies since this oil is not much explored as an alternative biofuel for engine applications. Also its production potential in India is about 1,35,000 million metric tonnes and its present utilization being around 200 million metric tonnes per annum, indicating clearly under utilisation of its present potential. The tress can be grown in humid as well as subtropical climates, need no maintenance and yields an oil content of 33%. It is easily available in many parts of India, cost is low and meets all biodiesel standards. Taking into consideration the utility of Karanja oil for all the applications in totality, it is found from the literature that 94% of the oil potential from this species is still underutilised in our country. Also, studies on Karanja biodiesel on a diesel engine at constant preset CR & IP are reported. However, open literature appears to indicate very less details into the studies of thermal performance, emission characteristics and combustion analysis with esterified oil of Karanja (Karanja biodiesel) on a diesel engine particularly at different compression ratios and fuel injection pressures.

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 to conduct computational studies.

The use of statistics in engineering has increased rapidly. As internal combustion systems become more complex, the problems faced by investigators 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 designs, 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.

Engine application engineers usually want to know the performance of a CI engine for various proportions of blends, for various compression ratios and at different injection pressures. This requirement can be met either by conducting comprehensive tests or by simulation i.e., modeling the engine operation. Testing the engine under all possible operating conditions and fuel cases are both time consuming and expensive. On the other hand developing an accurate model for the operation of a CI engine fuelled with blends of biodiesel is too difficult due to the complex nature of the processes involved. As an alternative, engine performance and exhaust emissions can be modeled by using artificial neural networks (ANN). ANNs are inspired by the early models of sensory processing by the brain. An ANN can be created by simulating a network of model neurons in a computer. By applying algorithms that mimic the processes of real neurons, we can make the network 'learn' to solve many types of problems.

1.1 Organisation of Thesis

The thesis begins with an introduction giving a brief insight into the importance of biodiesels as an alternative fuel in compression ignition (CI) engine, the application of GA in case of multi-objective optimization problems and modeling using ANN. Chapter 2 gives a systematic and comprehensive review of the literature on use of various vegetable oils and their biodiesels as alternate fuels in CI engines. The review also comprises of few available studies related to multi-objective optimization and ANN. The experimental test rig used to conduct the study is explained in Chapter 3. Chapter 4 deals with the results of the experimental study carried out on the engine using pure Diesel oil, blends of Karanja biodiesel with diesel, Karanja biodiesel as fuels. It also includes a

comparison between the results of the present study with the results of similar nature available in the open literature with the same as well as other biodiesels, followed by a summary of the experimental study. The multi-objective optimization through GA and further modeling through ANN for thermal performance and exhaust gas emissions are explained in Chapter 5. Chapter 6 presents the concluding remarks of the study which is followed by appendices and references at the end of the report.