Investigations on SI engine to study the Influence of Waste Plastic Pyrolysis Oil blends with and without Distillation and Additives

A Dissertation work
Submitted in partial fulfilment of the

Requirements for the award of the degree of

Doctor of Philosophy

in

Mechanical Engineering
by

KAREDDULA VIJAYA KUMAR

Roll No: 701414

Under the Supervision of

Prof. Ravi Kumar Puli
Mechanical Engineering Department

National Institute of Technology

Warangal - 506004

Department of Mechanical Engineering
NATIONAL INSTITUTE OF TECHNOLOGY
WARANGAL – 506004
Telangana State, INDIA.
June, 2018

Investigations on SI engine to study the Influence of Waste Plastic Pyrolysis Oil blends with and without Distillation and Additives

A Dissertation work
Submitted in partial fulfilment of the

Requirements for the award of the degree of

Doctor of Philosophy

In

Mechanical Engineering

by

KAREDDULA VIJAYA KUMAR

Roll No: 701414

Under the Supervision of

Prof. Ravi Kumar Puli
Mechanical Engineering Department
National Institute of Technology
Warangal - 506004

Department of Mechanical Engineering
NATIONAL INSTITUTE OF TECHNOLOGY
WARANGAL – 506004
Telangana State, INDIA.

June - 2018

THESIS APPROVAL FOR Ph.D.

This thesis entitled **"Investigations on SI engine to study the influence of waste plastic pyrolysis oil blends with and without distillation and additives"** by **Mr. Kareddula Vijaya Kumar** is approved for the degree of Doctor of Philosophy.

____

____

____

Examiner

Dr. Ravi Kumar Puli
Professor, Department of Mechanical Engineering, NIT Warangal
Supervisor

Prof. P. Bangaru Babu
Head, Department of Mechanical Engineering, NIT Warangal
Chairman

NATIONAL INSTITUTE OF TECHNOLOGY

WARANGAL – 506 004, Telangana State, INDIA

CERTIFICATE

This is to certify the thesis entitled **"Investigations on SI engine to study the influence of waste plastic pyrolysis oil blends with and without distillation and additives"** submitted by **Mr. Kareddula Vijaya Kumar** for, Roll No. 701414, to **National Institute of Technology, Warangal** in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Mechanical Engineering** is a record of bonafide research work carried out by him under our supervision and guidance. This work has not been submitted elsewhere for the award of any degree.

Place: Warangal.

Date:

Supervisor

Dr. Ravi Kumar Puli
Professor,
Department of Mechanical Engineering,
National Institute of Technology,
Warangal, Telangana State.

NATIONAL INSTITUTE OF TECHNOLOGY

WARANGAL – 506 004, Telangana State, INDIA

DECLARATION

This is to certify that the work presented in the thesis entitled **"Investigations on SI engine to study the influence of waste plastic pyrolysis oil blends with and without distillation and additives"**, is a bonafide work done by me under the supervision of **Dr. Ravi Kumar Puli**, Professor, Department of Mechanical Engineering, NIT Warangal, India and has not been submitted for the award of any degree to any other University or Institute.

I declare that this written submission represents my ideas in my own words and where ever others ideas or words are included have been adequately cited and referenced with the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Place: Warangal.

Date:

Kareddula Vijaya Kumar

Roll No. 701414

Dedicated To

My Supervisor

&

My Family Members

ACKNOWLEDGMENTS

I am most grateful to my supervisor **Prof. Ravi Kumar Puli**, for all the expert guidance, keen insight and valuable professional and personal advice he has given throughout my research. It has been a challenge, a unique learning experience and a pleasure to work under his prominent guidance.

I would like to express my deep sense of gratitude for the motivational urge, review and critical suggestions offered by the Doctoral Scrutiny Committee (DSC), comprising of **Prof. P Bangaru Babu**, the Chairman and Members **Prof. K V Sai Srinadh**, Dept. of Mechanical Engineering and **Dr. A. Veeresh Babu**, Associate Professor, Dept. of Mechanical Engineering and **Prof. P Nageswara Rao**, Dept. of Chemistry, during various review meetings, which instilled in me an immense confidence to continue my research and accomplish my goal. I also thank **Prof. C.S.P. Rao, Prof. S. Srinivasa Rao** and **Prof. L. Krishnanand** (former Chairmen, DSC) for their encouragement.

I would like to express my sincere gratitude to **Prof. K V Sai Srinadh, Prof. G. Amba Prasad Rao** (MED) for their invaluable help, personal advice and concern for my research.

I am extremely grateful to the Director of the institute **Prof. N.V. Ramana Rao**, Head of the Department **Prof. P Bangaru Babu**, for extending the required facilities for carrying out the experiments. I also thank the office staff of Department of Mechanical Engineering.

My special thanks to **Mr. Y. Ramachander, Mr. M. Narasimha, Mr. K. Ramesh, Mr. A. Satish Kumar, Mr. G. Ravinder, Mr. B. Ramulu,** technicians of the Mechanical Engineering Lab for their help in conducting the experiments.

I express my sincere thanks to my co-scholars **J. Amala Ranga Babu** and **D. Ravichandra** for their help to carry out experiments, endless hours of discussions and arguments for the completion of the thesis.

My very special thanks go to my family members without whose encouragement and understanding it would have been impossible for me to complete this thesis.

Finally yet importantly, I convey my thanks to everyone who have contributed to the realization of this thesis.

Kareddula Vijaya Kumar

ABSTRACT

Technological development makes the world as global village and energy are becoming an integral part of it. However, the existing sources to generate the energy are non-replenishable in nature and also finite in availability. The replenishing period of the fossil sources is not balancing with the energy demands of the world and causes for the energy crunch. Among all fossil energy consuming sectors, the transportation sector occupies the second place. However, the transportation sector causes for releasing massive pollutants. On the other hand, modernizing life styles and rising of human comforts leads to raising another kind of pollution called plastic waste. Even though, the scientific community warns the mankind regarding the problems associated with the plastic utility, use of plastic and its accumulation become inevitable. Usage of the plastic at the domestic level becomes the major culprit of this plastic waste.

A common solution to the above two problems is converting the plastic waste into usable fuel form. The process of converting this waste plastic into the fuel is called pyrolysis. Though the experimental works on the suitability of plastic oil in IC engines has been carrying out from a decade, no considerable outcomes exist. Most of the research work is run around the diesel grade fuel but very minimal on petrol grade fuel. Therefore, the main objective of this research is studying and analyzing the feasibility of Plastic Pyrolysis Oil (PPO) in SI engine. This research work aims to analyses the SI engine performance and emission characteristics fueled with waste plastic oil blends with and without distillation and additives.

The experiments are conducted using at 10%, 20%, and 25% of crude plastic pyrolysis oil blends to run the engine by varying the load at a constant speed of 1500 rpm. From the experimental studies, it is noticed that when SI engine operated beyond 25 percent crude plastic pyrolysis oil causes for misfiring and abnormal engine vibrations. Therefore, experiments are carried out up to 25PPO blend percentage. Thereby, strong sparks are initiated to ignite the fuel iridium spark plugs are replaced instead of normal spark plugs. Performance of the engine is marginally improved and emissions are controlled to the extent but the blend proportion cannot be raised beyond the 25 % of PPO.

The performance and emissions of the engine are not at the considerable level, and also blend percentage is limited. Therefore, in order to control the emission rates and to improve the performance of the engine 5% alcohol additives are added to the same PPO

blends. Methanol and ethanol are chosen as additives to control the emissions and also to enhance the performance of engine. It is observed from the results, the BTE of 25PPO5E blend is 10.68% increases compared to PF and 20% increases than 25PPO. The BTE of methanol additive blend is 8.01% increases compared to PF and 21.74% increases than without additive blend. The HC emissions of 25PPO5M blend are 34% decrease compared to PF and 25% decreased than 25PPO. Whereas HC emissions of 25PPO5E blend is 41% increase compared to PF and 79% increase than 25PPO. The NO_x emissions of 25PPO5M blend are 31.89% decrease compared to 25PPO and 2% decreased than PF. Whereas NO_x emissions of 25PPO5E blend is 52.63% decrease compared to 25PPO and 6% decrease than PF. It is note to worthy from the experimental results that, by adding the alcohol additive in plastic oil blend the performance improved and control the NOx emissions. However, addition of ethanol is unable to control the HC emissions, while methanol additive augments the thermal performance and also able to control the CO, HC and NO_x emissions. Therefore, methanol additive is best-suited additive for the plastic oil blended with petrol. Though, the performance and emissions are refined but unable to increase the blend proportion beyond the 25 % of PPO.

A noteworthy alternative to increase the blend proportions and to control the rate of emissions is altering the properties like viscosity, density and calorific value and octane number of crude PPO is distillation. Experiments are conducted with blends at 10%, 20%, and 25% of distilled plastic pyrolysis oil and compared with crude PPO blends. The BTE increases with DPPO-PF fuel blends compared to PPO-PF blends but less than PF. Nearly 9.4% increment in the BTE is observed for 25DPPO operation when compared to 25PPO but 2.9% decrement compared to PF. The NO_x emissions of 25DPPO blend are 10.75% decreased compared to 25PPO and 23.8% increase compared to PF. From the results, it is clear that the engine can run beyond 25% of distilled plastic oil blends without any modifications.

Further, tests are conducted even up to 50% DPPO and pure DPPO. From the results, the BTE increases with increase in DPPO blend up to 30% DPPO, proportions but less than PF. Nearly 4.3% decrement in the BTE is observed at full load for 50DPPO operation when compared to PF. The NO_x emissions increases with increase in DPPO blend, proportions compared to PF. The NO_x emissions of 50DPPO blend are 44.3% increase at full load condition compared to PF. Engine fuelled with pure DPPO, nearly 5.7% decrement in the brake thermal efficiency and 73% of NO_x emissions is observed. From the experimental studies, it is noticed that the engine can run even beyond the 50 % blend i.e. pure DPPO, but further increasing the blend percentage beyond 50% causes for higher NO_x emissions and lower thermal performance. Therefore, the experiment is restricted to 50 % DPPO alone.

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

Abbreviations	Description
IC	: Internal Combustion
DF	: Diesel Fuel
DI	: Direct Injection
IDI	: Indirect Injection
CI	: Compression Ignition
SI	: Spark Ignition
BSFC	: Brake Specific Fuel Consumption
BTE	: Brake Thermal Efficiency
CO	: Carbon Monoxide
HC	: Hydrocarbons
UBHC	: Unburned Hydrocarbons
NO_x	: Oxides of Nitrogen
O_2	: Oxygen
CO_2	: Carbon Dioxide
BP	: Brake Power
SP	: Spark Plug
PF	: Petrol Fuel
PPO	: Plastic Pyrolysis Oil
DWPO	: Distilled Waste Plastic Oil
DPPO	: Distilled Plastic Pyrolysis Oil
10PPO	: Blend of 10% Plastic Pyrolysis Oil and 90% Petrol (vol/vol)

10PPOSP	: 10% of PPO blend operated by using Iridium Spark Plugs
10PPO5E	: Blend of 10% Plastic Pyrolysis Oil, 5% Ethanol and 90% Petrol (vol/vol)
10PPO5M	: Blend of 10% Plastic Pyrolysis Oil, 5% Methanol and 90% Petrol (vol/vol)
10DPPO	: Blend of 10% Distilled Plastic Pyrolysis Oil and 90% Petrol (vol/vol)
20PPO	: Blend of 20% Plastic Pyrolysis Oil and 80% Petrol (vol/vol)
20PPOSP	: 20% of PPO blend operated by using Iridium Spark Plugs
20PPO5E	: Blend of 20% Plastic Pyrolysis Oil, 5% Ethanol and 75% Petrol (vol/vol)
20PPO5M	: Blend of 20% Plastic Pyrolysis Oil, 5% Methanol and 75% Petrol (vol/vol)
20DPPO	: Blend of 20% Distilled Plastic Pyrolysis Oil and 80% Petrol (vol/vol)
30DPPO	: Blend of 30% Distilled Plastic Pyrolysis Oil and 70% Petrol (vol/vol)
40DPPO	: Blend of 40% Distilled Plastic Pyrolysis Oil and 60% Petrol (vol/vol)
50DPPO	: Blend of 50% Distilled Plastic Pyrolysis Oil and 50% Petrol (vol/vol)
M85	: Blend of 85% Methanol and 15% Petrol (vol/vol)
CA	: Crank Angle
BTDC	: Before Top Dead Centre
TDC	: Top Dead Centre
WPO	: Waste Plastic Oil
WPD	: Waste Plastics Disposal
MSW	: Municipal Solid Waste
PSW	: Plastic Solid Waste

PP	: Polypropylene
PS	: Polystyrene
PE	: Polyethylene
PET	: Polyethylene Terephthalate
CPCB	: Central Pollution Control Board
HDPE	: High Density Polyethylene
LDPE	: Low Density Polyethylene
GC-MS	: Gas Chromatography and Mass Spectrometry
FTIR	: Fourier Transform Infrared Spectroscopy
NZ	: Natural Zeolite
SZ	: Synthetic Zeolite
ULSD	: Ultra Low Sulfur Diesel
PPEH	: Pyrolysed Polyethylene Hydrocarbons
PM	: Particulate Matter
DS	: Dry Soot
SOF	: Soluble Organic Fraction
DEE	: Diethyl Ether
MEA	: Methoxy Ethyl Acetate
EGT	: Exhaust Gas Temperature
EGR	: Exhaust Gas Recirculation
OEM	: Original Equipment Manufacturer
TWC	: Three-Way Catalytic
BTEX	: Benzene, Toluene, Ethylbenzene, p-xylene, m-xylene, o-xylene

VOC	: Volatile Organic Compounds
OEM	: Original Equipment Manufacture
HDC	: Hydrodynamic Cavitation

Chapter 1

Introduction

1.1. General Aspects of Alternate Fuel Demands

In the present scenario, there is a vast demand and potential in the automobile sector. Day by day increasing demand of automobile sector causes to raise the dependence on various conventional energy sources. The non-renewable nature, which is declined with time, in addition to increasing the pollution of fossil fuels causes to search for an alternative energy source. The increasing population density of automobile leads to demands more fuel consumption that leads to reducing the availability and also raises the cost. Therefore, it is necessary to search for an alternate fuel, which can replace effectively, the conventional fuel without much affecting the engine design and operation. The advanced technology being utilized in automotive technology and enhanced utilization of automobiles allows running the engine with various kinds of alternative fuels. In addition, fossil sources utilization in various engineering applications would contaminate the environment with their burning products. However, different control devices were utilized to decrease the emission rate, which leads to diminishing the vehicle mileage by around 15%. It is worthwhile to look into the suitability of using 'clean' burning fuels to use in spark-ignition engines. Moreover, environmental protection issues have been emphasized all over the world in recent years, so it is high time to find some clean and renewable sources to internal combustion engines. Among many alternative fuels, plastic oil is having its own significance as it is produced from the waste plastics. Pyrolysis process is a waste plastic recycling process in which the petroleum grade plastic oil is the critical by-product. The huge amount of plastic waste is being accumulated at geometric progression every year, which are creating serious environmental problems. While analyzing the energy needs in the light of plastic waste disposal together with the energy needs, advances the creation of plastic oil as an improved alternative. In plastic pyrolysis, handling and processing of waste plastic are much more flexible and easier than the common recycling technique. It needn't any intense sorting procedure, hence it is less labour intensive. In the current research, plastic waste is used to generate plastic oil and to run a petrol engine. Experiments are conducted on three-cylinder petrol engine using standard petrol blended with crude and distilled plastic pyrolysis oil, with and without adding the additives. Performance and emission characteristics are evaluated and compared with baseline fuel.

1.2. Fuels for SI Engines

Petrol is multiple mixtures of hydrocarbons which are derived from raw petroleum processing and distillation, they consist of different biological compounds acquired from other energy sources. In the present situation petrol is a vigorously processed product that can also contain different manufactured components, which adds to meet the demands and to enhance its performance of today's advanced engine innovation.

1.2.1. History of Petrol

Since 1850's to 1900's, petrol was able for burning and was deliberated a pointless by-product of kerosene producing. Be that as it may, with the innovation and the attractiveness of the transportation sector, the demand for petrol has increased suddenly between 1900 and 1920. Thermal cracking is a procedure for separating heavier hydrocarbons in petrol range hydrocarbons came into utilization by around 1913 to meet with the expanding demand for petrol. In the late 1930s, higher octane products were produced from the Houdry catalytic cracking process, which replaced thermal cracking. In the next years, a lot of advancement and new techniques being implemented in the catalytic process. In the late 1940s, platinum catalysts were utilized in the catalytic pyrolysis process. Superior petrol, numerous containing restrictive added additives, started to show up in the mid of 1950s. The demand of petrol sustained increase until the mid of 1970s and the demand leveled to at approximately 1.5 billion m^3 per year. The essential factors in the adjustment of command were a change in the fuel economy in cars and the fuel deficiencies of the 1970s which have created from that point onwards.

1.2.2. Alcohol fuels as additives in SI Engines

Alcohols are by nature automatically formed or either synthesized carbon-based linkages. They can be generated either from the agricultural feedstock, local crops or even from the agricultural waste. Since these are the form of a renewable source, they can be used in versatile applications including in IC engines as either as fuel or as an additive. Using alcohols as fuels or adding new carbon group elements to existing fuels as additives is not a new idea. In alcohols, a hydroxyl group is polymerized to the carbon atoms. Therefore, by using these additives to conventional fuels, their C-H chain is changed, which may generate new polymerized chains. Among various types of alcoholic fluids, methanol and ethanol are the most commonly used fuel/additives in IC engines.

Few of the popular companies are encouraging research on the use of alcoholic substances as fuels from long back. For example: Henry Ford Model T car is designed to run the car with ethanol derived from corn alcohol in the year 1908. However, research on alternatives is accelerated from 1970s’ due to the oil crisis. From that time onwards, ethanol has become an established alternative fuel or an additive in IC engines. Though ethanol exists from days back, it is not commercialized because of the rate of production. As the ethanol is a biomass derivative, biotechnology people are still focusing on raising the yield and also reduce the cost of production. The generation of ethanol even from starch is considered an advancement in a bio-science. However, the current technologies being used for the generation of ethanol from corn starch is not economically feasible. A potential source to produce ethanol at the feasible range is to utilize lignocellulosic materials such as wood chips, gasses, solid animal waste, sawdust, crop residues and industrial wastes.

Another alternative alcoholic fuel is methanol. The prime reason to use methanol in IC engines is it can produce from urban refuse and biomass. The research on methanol generation and utilization is still going in view of improving the performance of the engine and to control the emissions. By using the methanol derived from various forms of urban waste and biomass reasonable amount of energy is produced, which is responsible to minimize or no consumption of fossil energy. Methanol is usually used in race cars from the years together due to its high octane rating. The increased octane rating will promote to run the engine at higher compression ratios and consequently the performance of the engine is enhanced. Considerable research is carried out on testing the methanol as a fuel in both compression ignition and spark ignition engines. It is noticed that there is a substantial enhancement in engine performance with absolutely without any accomplishment in engine modifications.

The lack of availability of methanol to the owners of the vehicles is a large impediment to its widespread use as an automotive fuel. Manufacturers have already provided multi fuelled vehicles capable of burning petrol, methanol, or mixtures of petrol and methanol in the State of California. There is a growing infrastructure of fuel stations in California that provide M85. Further availability will certainly develop if additional methanol fuelled vehicles are old. Most of the manufacturers will produce methanol fuelled vehicles because methanol properties are playing a vital role to improve engine performance and control the exhaust gas emissions.

However, conventional fuels have been the predominant transportation fuel for the development period of automotive engines due to alleviate of operation for the engine and availability of supply. But compared to alcohol fuels, conventional fuels have a lower octane number and emit much more toxic emissions. Therefore, alcohol fuels are attracting awareness worldwide as supplementary and additive fuel in SI engine.

1.3. Disposal of Waste Plastics – A major problem

Plastics have opened the route for a plenty of new creations and gadgets yet it has likewise wound up stopping up the channels and turning into a health hazard [1]. Waste plastic disposal is an ever-increasing menace for the global environment. Utilization of plastic is becoming a part and parcel of common man's life because of its economic feasibility, durability and flexibility. All around the world, investigate on plastic waste management is being done as reported by [2]. Besides paper waste, plastic waste and food waste is the major constituent of industrial and municipal waste in urban communities. Indeed, even the urban areas with low economic development have begun delivering more waste plastic because of plastic shopping bags, PET bottles, plastic packaging and other appliances which utilizes plastic as the major constituent [3]. In the current scenario, the management, recovery, recycling of the solid waste plastic is a substance of concern. Industries are getting more attracted to the manufacturing of plastic field, so factory-made a large number of products from plastics. Plastics have turned into a vital piece of a way of life, and the worldwide production of plastic has increased enormously from last 50 years [4]. This expansion has transformed into a noteworthy task for local specialists, in charge of strong waste administration and sanitation. Because of the absence of solid waste administration, the vast majority of the plastic waste is neither gathered legitimately nor discarded in a suitable way to maintain a strategic distance from its negative effects on public health, environment and waste plastics are causing choking and littering of sewerage framework [5].

Disposal of waste plastic is being one of the prime sources for various kinds of environmental issues and methods to control the waste disposal are accelerating in a progressive way. In developed nations, a few waste plastics disposal / conversion procedures are being adopted, however, those are not economically feasible and efficient. In excess of 100 metric huge amounts of plastics are delivered worldwide consistently. Across the country review, directed in the year 2003, in excess of 10,000 tons of waste plastic are being created every day in India, and just 40 % of them are reused and then adjust 60 % is simply dumped. Plastic waste contributes to the solid waste streams by around 8% to 15% by weight and twice that by volume. It is anticipated that the yearly 3.6 million tons of post-consumer plastic waste was achieved by the year 2007 - 2008. At these alarming levels of waste generation, India is getting ready for a great deal in disposing and reusing of the plastic waste. A few procedures and means have endeavoured to fight against the disturbing levels of waste age. However, each procedure had its downsides and a few operatives, monetary and money related restrictions for viable usage.

1.4. Alarming Aspects of Waste Plastics

Due to exponential growth in population, the need of plastic products has progressively expanded throughout the most recent couple of decades. Since plastics are non-biodegradable, they can't have effectively come back to the normal carbon cycle; consequently, the life cycle of plastic materials ends at waste disposal offices. Plastic pollution, dumping plastic products into the environment affects adversely the wildlife, wildlife habitat, or humans. It adversely affects lands, waterways and oceans.

- Littering of waste plastics causes obstructing of regions sewage frameworks prompts spreading of waterborne sicknesses and expanding the cost of sewage support frameworks.
- Soil fertility is influenced because of plastic material as it frames a piece of fertilizer staying on the dirt for quite a long time without normal degradation.
- Animal that eats the plastic food bags disposed improperly dies because of suffocation, stomach and intestine related diseases.
- Plastic waste is discovering its way into the streams, seas, and oceans of the world because of which the rich marine life is confronting genuine wellbeing risks.
- The plastic materials manufacturers are polluting the environment by disposing of the plastic waste and chemicals used in the process of manufacturing plastic material into nearby water channels and open spaces, thereby causing health hazards as well as environmental pollution in a vast area.

1.5. Plastic Waste to Liquid Fuel

Reusing of plastic wastes can give a chance to gather and waste plastic disposed in the most ecologically friendly way and it can be changed over into an asset. Waste plastics are manufactured from petroleum products and are made primarily of hydrocarbons, then also contain additives such as colorants, antioxidants and other stabilizers by Williams et al. [6]. In the majority of the circumstances, plastic waste reusing might be economically viable, which are in high demand and as it creates assets. Plastic waste reusing additionally has an extraordinary potential for asset preservation and greenhouse gas emissions decrease, for example, producing petroleum fuels like diesel and petrol fuel from waste plastics in the pyrolysis process [7].

It can be evidenced from earlier research observed that the production and consumption of polymer provoke some enormous gap and the use of virgin material is getting high to fill these gaps. Utilization of plastic product must be decreased up to a specific degree yet the utilization of innovative material for industrialized can be decreased by utilizing management and recycling methods. Most of the investigators have investigated and reported on the waste plastic recovery and recycling. Moreover, the eco-friendly issues with landfilling are the huge waste of energy and resources from the disposal of huge amounts of remnant material [8].

The production procedure for the transformation of fluid fuel from plastic wastes depends on the pyrolysis of the plastics and the build-up of the subsequent hydrocarbons. Pyrolysis is generally characterized as the controlled heating or burning of a material in the absence of oxygen. In the plastic pyrolysis process, the macromolecular structures of polymers are cut into smaller oligomers or molecules and here and there monomeric units. The advance degradation of these resulting molecules depends upon various distinctive conditions including (and not constrained to) residence time, temperature, and the presence of catalysts and different process conditions [9]. The pyrolysis reaction can be done with or without the presence of a catalyst. Therefore, the reaction will be catalytic pyrolysis and thermal pyrolysis.

In catalytic pyrolysis technique a suitable catalyst is utilized to do the cracking reaction. The presences of catalyst reduce the reaction time and temperatures. Also, catalytic degradation yields a much narrower product distribution of carbon atom number with a peak at lighter hydrocarbons and occurs at considerably lower temperatures. From a financial viewpoint, decreasing the cost significantly further will make this procedure a considerably more appealing alternative. This alternative can be streamlined by reuse of catalysts and the utilization of effective catalysts in lesser amounts. This technique appears to be the most encouraging to be created in a cost-effective commercial polymer reusing process to take care of the intense ecological issue of waste plastic disposal.

Thermal pyrolysis includes degradation of the polymeric materials by heating without oxygen. The procedure is typically directed at temperatures between 400^{o}C to 500^{o}C and results in the formation of a carbonized char (solid residues) and a volatile fraction that may be separated into condensable hydrocarbon oil consisting of aromatics, iso-paraffin's, paraffin's, and olefins etc. The segment of each portion and their exact structure depends essentially on the nature of the waste plastic yet in addition to process conditions. The nature and the extent of these reactions depend on both the reaction temperature and furthermore at the residence of the products in the reaction zone, a perspective that is basically influenced by the reactor design.

1.6. Objectives and Research Approach

The main objective of this research is to investigate the performance and emission characteristics of waste plastic pyrolysis oil with and without distillation and additives fuelled in SI engine.

- To study the method of converting of waste plastics into the valuable fuel oil.
- To study the process involved in transforming the properties of crude state to useful plastic fuel.

The areas of the investigations include:

- To study the influence of plastic pyrolysis oil blends of 10%, 20%, and 25% on the performance and emission characteristics of SI engine.
- To improve the combustion quality, test runs are conducted with the iridium spark plugs by using 0%, 10%, 20% and 25% of PPO blends in SI engine.
- To study the effect of 5% of alcohol additives addition to plastic pyrolysis oil blends of 10%, 20%, and 25% fuelled in SI engine.
- To study the performance and emission characteristics of SI engine by using 10%, 20%, and 25% of distilled plastic pyrolysis oil and compared with crude PPO blends.
- To study the influence of distilled plastic pyrolysis oil blends of 0%, 10%, 20%, 30%, 40%, 50% and pure DPPO on the performance and emission characteristics of SI engine.

1.7. Organization of Thesis

The thesis has been organized into six chapters and the essence of each chapter is given below.

Chapter 1 consists introduction to plastic oil.

Chapter 2 consist a literature survey on energy recovery from plastic waste, waste plastic disposal issues, Waste plastic oil fuelled in diesel engines, Alcohol additives in spark ignition engine.

Chapter 3 presents the details of materials and methodology for the experiment.

Chapter 4 presents the details of experimental set-up.

Chapter 5 Results and Discussion

5.1. Presents the influence of waste plastic oil blends at 0%, 10%, 20% and 25% were fuelled in SI engine.

5.2. Presents the test results for performance and emission characteristics of petrol engine running on waste plastic oil blends by changing iridium spark plugs.

5.3. Presents the influence of plastic oil with the addition of 5% ethanol additive blends fuelled in SI engine.

5.4. Presents the petrol engine performance and emission analysis by using crude plastic oil blends with and without the addition of 5% methanol additive.

5.5. Presents the experimental analysis on SI engine by using distilled plastic pyrolysis oil-petrol blends.

5.6. Presents the performance and emission characteristics of SI engine by using distilled plastic oil petrol blends. (0-50% of DPPO blends with 10% step size and pure DPPO).

Chapter 6 presents the concluding part and scope for the future study and uncertainty analysis for use instrument.

1.8. Summary

This chapter concise the energy demands across the world and need of alternative fuel for the automotive sector. It consolidates the negative impact of plastic waste on environment and utilization of this plastic waste to derive the petroleum grade fuel. It also an emphasis on pollutants liberated from the fossil fuels. It also plays a special focus on enhancement of SI engine performance and control over emissions by using alcohol additives.

Chapter 2

Literature Review

2.1. Introduction

The rapid industrialization and rushing of the automobile sector have led to a steep rise in demand for petroleum-based fuels. Which results, the fossil fuel reserves are rapidly exhausting. Scientist estimated that, known petroleum reserves to be depleted in less than 50 years with the present rate of consumption. It forewarns the research community regarding the shortage of energy by the shortage of finite fossil fuel reserves. Besides designing the efficient engines, it needs to search for the substitute of the current using fuels to fulfill future demands. For any country, economic growth critically depends on the availability of energy sources in the long-term at the affordable, economical and accessible range. As the mankind is awakening towards the pollution and global warming, the energy sources are choosing based on environmental friendly. As India is a tropical country, it is enriched with the plenty of renewable energy resources. However, the technology is also upgrading towards the effective utilization of these renewable sources. The advancement in technology also promotes the conversion of unavailable energy even from waste into a useful form of energy. Among many alternative fuels, plastic oil is having its own significance as it is produced from the waste plastics, which is the critical by-product of waste plastic recycling by pyrolysis process. This chapter consists three different sections, the first section describes the energy recovery from waste plastics, the successive section covers waste plastic oil is the alternate fuel for diesel engine and the last session emphasizes on alcohol additives in SI engine.

2.2. Energy recovery from plastic waste

Oil accounts for approximately one-third of all the energy used in the world. The Energy Information Administration (EIA, 2007) projects that world oil consumption of petroleum products will grow to 118 million barrels per day by 2030, as oil continues to be a major source of energy. Most of the studies estimate that oil production will peak by 2040 (GAO, 2007). Peak in production means half of the oil is removed and to remove the remaining half, more financial support is needed as compared with the cost of oil. According to the international energy agency, oil used for transport grew from 500 million tonnes of oil equivalent in 1970 to nearly 900 tonnes in 1990. Experts claim that about 21.3 millions of barrels per day or over one third of the world's oil production is in decline. The total number of vehicles in 1950 was 50 million, which grew to

151 million in 1965, 369 million in 1985, and 479 million in 1996. It is estimated that the possible expansion of the automobile fleet will range up to 3 billion vehicles in 2050. Thus, the nations that depend on oil-producing countries will spend more money on buying oil.

Waste plastic is a non-biodegradable hydrocarbon material that, which consists of toxic and harmful chemicals, which may cause for many ecological problems. According to the Central Pollution Control Board (CPCB), India produces 5.6 million tons of plastic waste per annum and solitary 60% of this waste is recycled for the energy generation. Nevertheless, the usage of plastic becomes inevitable in daily life in one or other form. However, awareness among the people is increasing on reducing the plastic utilization rate. As a part of technological advancement, researchers introduced some effective ways to recycle the waste plastic. The process of converting waste plastic into useful petroleum grade fuel is methodically depicted in Fig. 2.1.

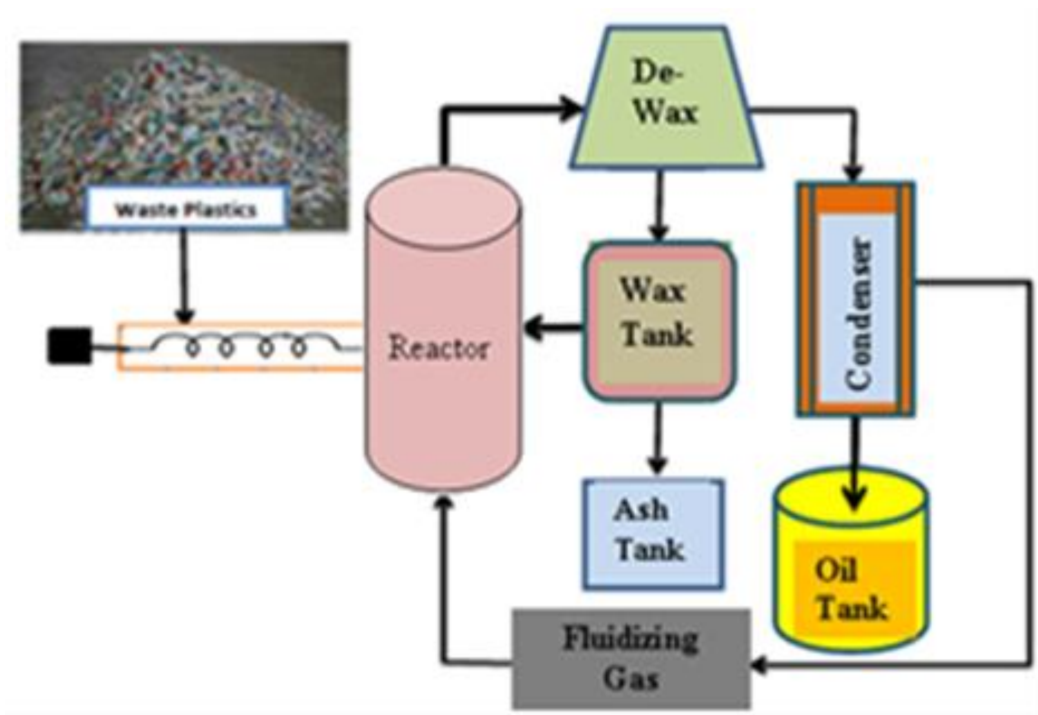


Fig. 2.1. Process of Pyrolysis of Waste Plastics Technology

In this pyrolysis process, waste thermoplastic is converted into chips and pellets separately and these chips are fed through a surge hopper to hot screw conveyor. Since, the hot screw is maintained at high temperature, plastic chips are reaching molten temperature. The hot plastic liquid is passed to reactor, which is at 450-500^{o}C and atmospheric pressure. In the reactor, the molten waste plastic is converted into hydrocarbons by the cocking phenomenon in the absence of oxygen and the reaction accelerates at the presence catalyst. A periodic maintenance is carried out, to remove the solid residue from the bottom of the reactor. The vapors coming from the reactor are entered into the condenser where these vapors are getting condensed into liquid hydrocarbon fuels. The uncondensed charge is recirculating to the reactor through fluidized gas.

Moreover, environmental protection issues have been emphasized all over the world in recent years, so it is urgent to find some clean and renewable sources to internal combustion engines. Among several alternative fuels, plastic oil is having its own importance as it is derived from the plastic wastes, which is the critical by-product of plastic wastes recycling by pyrolysis process. Pyrolysis is the process of thermally degrading long-chain polymer molecules into smaller, less complex molecules through heat and pressure. The process requires intense heat with a shorter duration in the absence of oxygen. The three major products that are produced during pyrolysis are oil, gas and char which are valuable for industries, especially production and refineries (Shafferina et al. [10] and Shafferina et al. [11]).

Kiran et al. [12] have discussed the recycling of waste plastics by pyrolysis is one of the conventional approaches to dispose the waste plastic and that can convert solid plastics into high-quality liquid fuel. The thermo-gravimetric examination of plastic wastes shows that the critical temperatures, which should be effective for pyrolysis. From this pyrolysis, higher gaseous products yielded from polyethylene waste and higher liquid yielded from polystyrene waste. The dominant liquid product of polyethylene waste was prophenyl-benzene whereas for waste polystyrene was styrene is the dominant pyrolysis product.

Kim et al. [13] discussed the probability of source of secondary fuel from plastic wastes to fuel in a blast furnace. The accomplishment of this procedure, furthermore, was critically dependent upon the optimization of operating systems. It was noticed that the blast furnace energy efficiency improved by enhancement of the combustibility by utilizing plastic wastes. The observations made from these tests were an increase of both the level of oxygen enrichment and blast temperature, and with a decrease in particle size, the combustibility of polyethylene waste might be enhanced at a given distance from the tuyeres. It was also originated that the addition of waste plastics, the efficiency of coal combustion reduced at a longer distance from the tuyeres.

Jerzy Walendziewski [14] has developed a new recycling system and apparatus to liquefy these plastics disposals into fuel oils. These discarded plastics are melted and evaporated first, and their vapors are condensed and extracted after passing through various metal catalysts for decomposition. These cycled oils are a different one by one according to the kind of raw plastic, and generally, have high heating values with rather higher density and their total yield is about 60 - 80% of raw plastics. The recycled oils are fed to diesel engines of several factories as a 30 - 40% blended fuel with gas-oil. Recycle of plastics by the above method will be a very good contribution to energy and environments of the earth. The new cycle system is showed use of the Cracked PE (Polyethylene) blending oil for engine performance.

Miskolczi et al. [15] have studied the influence of cracking parameters (residence time and temperature on the product structures, properties of products and yields. The investigation was carryout on the mixture of different municipal waste plastics containing polyurethane rubber, polystyrene, polyamide, ethylene propylene copolymer, polypropylene and polyethylene in a horizontal tube reactor. The liquid and gas products formed were studied by gas chromatography and reported. It was noticed that the polymers chemical structure significantly affected the quantitative and qualitative properties of volatile products and liquids contains around 50% olefin content.

Ayhan Demirbas [16] has discussed the recovery of petrol-range hydrocarbons from municipal waste plastics by non-catalytic pyrolysis. In this research three types of plastic wastes were considered such as polypropylene, polyethylene and polystyrene. During the pyrolysis process, waste plastics can be decomposed into three segments such as liquid, gas and solid residue. Fractional distillation is chosen for achieving suitable petrol-range hydrocarbons from the pyrolytic oil. From the results observed that the higher gaseous products are yielded from polypropylene and Polyethylene wastes, whereas higher liquid products are yielded from polystyrene waste.

Ali et al. [17] have carried out a single-stage and two-stage reaction process of pyrolysis and also has studied the behaviour of PVC mixed waste plastic with petroleum residue during thermal and catalytic decomposition. In the individual pyrolysis process, both the high-density and low-density polyethylene wastes were yielded lower conversion products, whereas more than 90% conversion to gaseous and liquid products from waste polystyrene and petroleum residue.

Adil et al. [18] have studied LDPE was decomposed thermally and catalytically in a reactor at the temperature range at 400^{o}C to 500°C with a raw material. The Increase in temperature and air flow rate increased the yield of products and also affected the peroxide number and the acid number. Many modifications were noticed between the composition of products and yields which reduces with temperature increasing. Thermal and catalytic oxidative decomposition is a capable technique to degrade LDPE waste.

Vicente et al. [19] discussed wide scope of waste plastics use in wrapping and building materials, garbage and shopping bags, industrial and household products, toys, clothing, fluid containers, and packaging films. In addition, only 2 to 3 times can possibly to reutilizing of a virgin plastic materials, in light of the fact that, after each reusing, the plastic material strength decreases may be due to the thermal degradation. Especially, the solvents including a hydrogen contributor have the capacity to participate in the thermal degradation of polymers influencing the hydrocarbon conveyance and yield.

Panda et al. [20] explained the production of liquid oil from waste plastics would be a better alternative since the heating value of the plastic fuel is around 40,000 kJ/kg compared with petroleum fuels. This helps in conservation of natural resources. Mechanical recycling of waste plastics has become a widely adopted method in different countries. Pyrolysis using a catalyst, a method to convert waste plastic into a fuel is gaining gradual momentum and is being adopted in different countries recently due to its efficiency over other processes.

Jasmine Shah et al. [21] have used low density polyethylene were catalytically pyrolyzed, with a wide range of acidic and basic catalysts like alumina, zinc oxide, silica, calcium carbide, homogeneous mixture of silica-alumina and magnesium oxide in batch reactor under atmospheric pressure. Though CaC_2 is better on the basis of reaction time, however the efficiency of conversion into liquid for SiO_2 was found to be high at optimum conditions. The understanding of FTIR analysis shows that, catalytic pyrolysis of low-density polyethylene leads to the formation of a complex mixture of carbonyl group containing like ketones, alkenes, phenols, aromatic and aldehyde compounds.

Ayhan Demirbas [22] has discussed waste management systems, waste management methods, waste classification, waste management concept, bio-waste and biomass resources. The waste management system consists of the entire span of activities related to treating, handling, recycling or disposing the waste materials. General classification of the most general sources of wastes is construction waste, commercial waste, biomedical waste, domestic waste, biodegradable waste, non-biodegradable waste, hazardous waste, animal waste, industrial solid waste and ashes.

Singh R P et al. [23] have studied that the environmental degradation and energy crisis are currently two vital issues for global sustainable development. Speedy population and industrialization blast in India has led to the relocation of peoples to the cities from the villages, which generates thousands of tons of municipal solid waste (MSW) daily. The management of MSW requires proper infrastructure, maintenance and promote for all activities if not it causes hazards to the inhabitants. The MSW management system comprises with collection, processing, storage, transfer, generation and dumping of solid wastes.

Velghe et al. [24] have studied the potential of thermal conversion of municipal solid waste into oil through the pyrolysis process. It was performed slow and fast pyrolysis under different temperatures and heating rate. The oil found by slow pyrolysis segregates spontaneously in an oily product and a water rich product. Composition analyses by Gas Chromatography and Mass Spectrometry (GC/MS) of the oil products showed aliphatic hydrocarbons as the major compounds. The pyrolysis oils have a low weight % of water and high heating value. Heating rate, residence time and temperature has an effect on the yield of liquid products and composition during pyrolysis of municipal solid waste. Smaller residence times and high heating rates induce the presence of waxy material in the liquid produces from fast pyrolysis.

Moinuddin et al. [25] have carried out a heavy hydrocarbon fuel production of polystyrene waste plastic under thermal degradation process in the temperature range of 200-450°C without using a catalyst. They suggested two different techniques to produce plastic oil from waste thermoplastics. The experimental results unveiled that muffle furnace liquefaction system is a most suited technique for thermoplastics than direct liquefaction system. In addition, the liquid oil produced can be used in multiple applications such as boilers, furnaces, turbines and diesel engines without the requirements for treatment or upgrading. It was analysed the produced hydrocarbon oil by GC-MS test is found that can range C_6 to C_{25} and Fourier Transform Infrared Spectroscopy (FTIR) analysis results showed band energy which is reflected with calorific value. Also, it stated that fuel was used for feedstock refinery or heavy equipment because of this hydrocarbon range.

Patni et al. [26] have done development and upgrading about a vast increase in the invention of all kinds of commodities which generate waste indirectly. Plastic materials are the wide range of applications because of the flexibility and relatively close to the ground cost. Recycling methods are subdivided into primary, secondary, tertiary, and quaternary. As the heating value of the plastic wastes is comparable to that production of fuel would be an enhanced alternate. In this research discussed the methods of conversion of waste plastic into useful fuel, particularly pyrolysis and catalytic degradation.

Achyut et al. [27] have cracked waste polypropylene (PP) by catalytically and thermally in a batch reactor in the presence of kaolin clay and maintain the temperature range at 400^{o}C to 550°C in order to achieve appropriate liquid fuels. Emphasis has been on the study of the performance of kaolin on the yield of liquid product and total reaction time with an assessment to optimizing the liquid fraction of the yield in the reaction.

Christine et al. [28] have studied different fuel samples produced from plastic wastes under different reaction conditions by using different catalysts. The produced fuel samples are exposed to a parametric study based on the yield of fuel sample, selecting of the fuel, reaction temperature, and fuel properties. Catalytic pyrolysis involves degradation of the polymeric materials by heating them in the absence of oxygen and in the presence of a catalyst. The pyrolysis process reactions were carried out on polymer to catalyst in the ratio of 10:1 and maintain temperature ranges in between 400^{o}C - 550°C. The atmospheres for the pyrolysis process were provided by using nitrogen as a carrier gas and to determine the chemical composition of sample GC-MS was performed. In a diesel engine, a blend of plastic oil and diesel was used as a fuel and found that the performance improvement and reduction of emissions such as CO and an increase in NOx. The cost of production can be reduced if we change the catalyst because 65% of production cost is due to the catalyst.

Sarker et al. [29] have studied the conversion of polypropylene waste into needful oil without the presence of a catalyst by using thermal degradation. From the analysis results noticed that produced oil mainly consists of alkenes and alkanes. Be that as it may, on account of waste PP of heavy fuel oil conversion cost bring down when the business plant will be begun and this fuel could be used in substantial feedstock refinery and heavy equipment for further alteration. By building up the pilot plant group and individual countries would be able to gain outside money by trading the fuel oil and the countries will transform into independent fuel oil achieve nations and can move down fuel oil interest for its own particular household different purposes.

Sonawane et al. [30] carried out experiments on HDPE waste in form of carry bags using an in house invented glass reactor with one litre capacity. For reaction, approximately 200 to 300 grams of waste material is used. By purging nitrogen gas in the reactor an inert atmosphere was created. The reactor temperature was maintained around 550^{o}C and the reaction was handled with and without the use of alumina and natural zeolites (NZ) as catalysts. They reported that time taken to complete the reaction is around 2.5 hrs with the catalyst. The reaction was delayed by an hour without catalyst. However, alumina catalyst produces more yield than natural zeolite. i.e. by adding both the catalyst by 5 % by volume, alumina catalyst gives 70 to 71% that is 65 to 67% of yield with natural zeolite.

Syamsiro et al. [31] have recovered liquid fuel from three kinds of municipal waste by catalytic pyrolysis process in the presence of naturel zeolite and commercial Y zeolite catalysts. From the results, the highest liquid fraction noticed with HDPE waste. The presence of catalyst increased the gaseous fraction and liquid fraction reduced. Pyrolysis with commercial Y zeolite produced less yield than natural zeolite catalyst presence in this process.

Brajendra et al. [32] have studied the production of an alternative fuel for diesel from the HDPE waste grocery bags produced by pyrolysis. They compared the results of pyrolysed polyethylene hydrocarbons (PPEH) with conventional petroleum-derived ultra-low sulphur diesel (ULSD). Blends of ULSD and PPEH with diesel were prepared and the subsequent fuel properties measured. It is predicted that these results will further an understanding of the applicability and disadvantages of HDPE as a feedstock for the invention of the alternate fuel for internal combustion engines.

Rohan et al. [33] have studied the production of hydrocarbon fuel from polypropylene waste. The fuel production from waste has been accomplished 99% with around 52% of gas yield and 47% of liquid yield. A GC-MS unit analysed the gases and liquids produced by this process. The analysis result shows that it consists of mainly aromatic compounds in the range of C_5 to C_{10}.

Miandad et al. [34] conducted the review on conversion of energy from waste plastic oil by catalytic pyrolysis oil. They explained in detail the usage of catalyst was evaluated to improve the catalytic pyrolysis process and the factors affecting the process of catalytic pyrolysis such as feedstock composition, retention time and temperature. The production of liquid fuel from the plastic waste by catalytic pyrolysis process gives higher quality than the oil produced by thermal process.

Miandad et al. [35] studied the conversion of pyrolysis liquid fuel from polystyrene waste and investigation carryout the effect of reaction time and temperature on the quality and pyrolysis yield. It is observed that char production reduced, increased gas production and liquid oil yield with the reaction temperature maintained at 450^oC compared to the reaction temperature maintained at 400^oC. The GC-MS analysis data revealed that pyrolysis oil produced from polystyrene waste, mainly contains 21% of ethyl-benzene, 26% of toluene and 48% of styrene compounds.

Tekin et al. [36] have discussed the production of liquid fuel from waste polypropylene by considering different additives in pyrolysis process. The temperature was maintained around 500^oC in the fixed bed reactor. The composition of fuels from both the runs with additives and the thermal runs was found to be comparable. The most of the compounds were identified mostly alkanes, dienes and alkene.

Khan et al. [37] have discussed the waste plastic pyrolytic fuel characteristics are comparable to conventional diesel fuel. In this pyrolysis process, a stainless steel reactor is used to achieve needful fuel products from high density polyethylene waste. The reaction temperature maintained at 330^oC to 490^oC for 2 to 3 hours to obtain flammable gaseous hydrocarbon, solid residue and liquid hydrocarbon products. They reported that the pyrolytic oil properties were more are less similar with conservative diesel fuel.

Al-Salem et al. [38] have reported recent progress in the recycling and recovery of plastic solid waste. Special prominence is made on waste generated from polyolefin basis, which creates a huge percentage of our daily lives. The routes of treatment the PSW is discussed in detail chemical, mechanical, re-extrusion and energy recovery arrangements. Re-extrusion, which entails the re-introduction of clean scrap of single polymer to the extrusion cycle in order to produce products of the like material is generally applied in the processing line itself but not often applied among recyclers as recycling materials rarely possess the required quality. The advantage of pyrolysis oil from plastic solid waste have dual benefit of recovering energy from waste materials and reducing the environmental problems caused by waste plastic.

Songchai et al. [39] studied the distillation of plastic oil produced from fast pyrolysis of waste plastics. For the distillation process temperatures maintained initially 180^{o}C for one hour and latter 150^{o}C and 180^{o}C for one hour thirty minutes. They reported that, the both distilled oils have less viscosity and density than the pyrolysis oil and the properties are more or less similar to the petrol. The distilled oil formed from fast pyrolysis of waste plastics is an alternate source of energy for SI engines.

Miandad et al. [40] studied the production of an alternative fuel for diesel from the catalytic pyrolysis of PP, PS and PE in the presence of SZ and NZ catalysts. The temperature was maintained around 450^{o}C in the reactor and process duration is 75 min. They reported that, less liquid oil yield produced by the mixing of PS with other waste plastics and high liquid oil yield produced by the mixing of PE and polypropylene by using both synthetic and natural zeolite catalysts than individual pyrolysis process. The GC-MS analysis and FTIR data revealed that pyrolysis oil produced from these waste plastics mostly contained aromatic compounds with a less aliphatic compounds. This pyrolysis oil has potential to use in IC engines instead of petroleum fuels.

Biddinika et al. [41] considered the energy recovery from municipal waste plastics. The innovation is an incorporated arrangement of shredding machine and pyrolysis machine. The technology is anticipated to reveal the advantage of alternative energy produced from waste plastics is flammable fuel for household.

Sogancioglu et al. [42] have discussed the thermal processing is an important application for both feedstock recovery and energy recovery from plastic wastes. Polystyrene, polypropylene, polyethylene, polyethylene terephthalate, low and high density polyethylene thermoplastics were used in this study. They reported the influence of the type of plastic, waste plastic rewashing and process temperature on pyrolysis liquid oil fraction. From the analysis C10-C40 HC contents of pyrolysis fuels were intensely pretentious from the prewashing process and pyrolysis temperatures under identical pyrolysis conditions.

Sing et al. [43] reviewed the influence of recycled Nylon//LDPE/HDPE plastic solid waste with different reinforcements such as hemp fibre, sand, metal powder, natural fibre etc. They reported that the different research work done by many scientists in this field of progress and recycling in the management and recovery of plastic solid waste by different techniques such as quaternary, tertiary, primary and secondary.

Prosper et al. [44] have discussed the recycling process of waste plastics into needful fuel products obtain with both batch and continuous pyrolysis reactors by using a suitable technology and behaviour of pyrolytic oil with the addition of silica alumina catalyst on the quality and yield. The liquid yield of HDPE waste is 80% that of polypropylene waste is 82.6% and for waste polystyrene is 80% found by mass. From the results it is clears that the characteristics of pyrolytic sample are obtained from both polypropylene and HDPE waste are comparable to conventional transport fuel.

2.3. Waste plastic oil fuelled in diesel engines

Diesel engines are the most contemporary power plants in automobile sector due to their outstanding higher brake thermal efficiency and driveability. Despite their advantages, they emit high levels of smoke and nitrogen oxide emissions that will have an effect on human health. The stringent emission norm has been obligatory to control these pollutants. In addition, due to the rapid growth of automotive vehicles in the transportation sector, the consumption of oil keeps increasing. All the above factors results in the depletion of petroleum fuels have necessitated the search for alternate fuels for diesel engines as reported by many researchers. Waste disposal has been a major problem in most of the countries. The research work focuses on the utilisation of waste plastic oil in diesel engines. Most of the research work has been done by mixing oil developed from waste plastics disposal with heavy oil for marine application.

Furthermore, Osami Nishida et al. [45] blended pyrolytic oil (or Waste Plastics disposal) from household and an industrial plastic waste with Marine Heavy Fuel Oil to reduce the viscosity of the heavy oil significantly. Their experimental results indicated that, the WPD mixing ratio of 20 vol. % reduces the viscosity of the experimental heavy fuel oil by 90 % from 177 cSt to 20 cSt at 50^{o}C. The blended oil has been applied to a small size high-speed single-acting 4 stroke diesel engine (16 hp, 2200 rpm) without preheating the oil. The experiment on the engine with non-preheated blended oil has shown a stable performance of the engine and also gives a significant reduction in fuel heating cost. Although NO_x emission increases marginally the emission of PM, DS and SOF are decreased by half of the mixing ratio of 30 vol. %.

Mani et al. [46] have conducted an experimental study on a DI diesel engine operating with WPO and used as an alternate fuel in a diesel engine without altering the engine design. Engine fuelled with WPO, The performance, combustion and emission characteristics showed a stable performance with brake thermal efficiency, similar to that of diesel and showed higher thermal efficiency up to 75% of the rated power. CO_2 and HC emissions were marginally higher than that of the baseline operation. The toxic gas carbon monoxide emission of WPO was higher than diesel. From the results it is noted that the engine was able to run with pure WPO and smoke reduced by around 40% to 50% at all loads.

Mani et al. [47] investigated the influence of WPO as a fuel in a single cylinder CI engine by varying injection timing. From the results it is clears that the engine can able to run at the retarded injection timing by using 100% plastic oil. Tests were performed at (23^o, 20^o, 17^o and 14^o BTDC) four injection timings. The retarded injection timing of 14 BTDC results compared to 23 BTDC at the standard injection timing resulted in increased thermal efficiency, smoke and carbon dioxide emissions while the carbon monoxide, hydrocarbons and nitrogen oxides are decreased at all the test conditions. The maximum brake thermal efficiency and lower cylinder peak pressure were founded with retarded injection timing compared to all other injection timings. The engine operated by using waste plastic oil 35% of smoke intensity increased with retarded injection timing compared to standard injection timing.

Mani et al. [48] did experiment on WPO as an alternate fuel in a compression ignition engine and its performance characteristics were analysed comparing with diesel. From the investigation it is clear that the CI engine can able to run with pure WPO. The increment of oxides of nitrogen emissions by about 25%, hydrocarbon emissions by about 15%, Smoke increased by 40% and 5% of carbon monoxide emissions increased for WPO operation at full load were noted when compared to diesel fuel operation. Engine fuelled with WPO showed higher exhaust gas temperature at all loads and the thermal efficiency was higher up to 80% of the full load compared to diesel.

Jane Pratoomyod et al. [49] was studied the effect of plastic pyrolysis oil in a CI engine without any engine alteration. The engine fuelled with blends of diesel fuel with plastic oil in the different proportions of diesel to waste plastic oil, the parameters are measured and compared with that of diesel fuel. The results showed that, the specific fuel consumption of waste plastic pyrolysis oil blends was higher and the BTE of waste plastic pyrolysis oil blends were lower than diesel fuel. They also reported that, the engine NO_x emissions from waste plastic pyrolysis oil were higher than diesel operation.

Chumsunti et al. [50] experimental investigations are carried out on CI engine fuelled with DWPO and different nozzle pressures. They reported that the engine can operate fuelled with DWPO and also observed that the physico-chemical properties of DWPO are more or less similar to diesel fuel. Experiments are conducted on four stroke single cylinder DI diesel engine operating with pure distilled waste plastic pyrolysis oil by varying nozzle pressures. It is observed that by setting three different nozzle pressure engine performance improved and controls the emissions compared to engine operated in standard nozzle pressure.

Kumar et al. [51] have investigated the performance and emission analysis of blends at 0% to 75% with 25% step size of WPO obtained by catalytic pyrolysis of waste high density polyethylene with diesel in a CI engine with varying loads. The results showed that the BSFC was found to be increasing with the addition of waste plastic oil concentration and BTE of mixed blended fuel as lower as compared with diesel. EGT increases with an increase in engine load. The NO_x and CO emission increases with increase in percentage of WPO in blends. UBHC decreases with an increase in the engine load and increases with increase in percentage of the WPO in blends.

Naima K et al. [52] reviewed experimental results on diesel engine with different kind of oils such as plastic oil, engine oil and cooking oils. They reported that, the 100% waste plastic oil can able to run diesel engine and ignition delay was longer by around 2.5^{o} CA compared to diesel. From the results shows that, the waste plastic oil gave 75% higher thermal efficiency at rated power compared with diesel. The engine NO_x emissions were increased 25% for plastic oil compared to diesel fuel operation.

Shanmuga et al. [53] have experimentally investigate the functioning of Nano engine and operated with plastic oil with gasoline blends also addressed the emission characteristics of the engine. Their results show that brake thermal efficiency was enhanced at the blend proportions compared to that of gasoline fuel.

Kaimal et al. [54] have carried experimental study on a DI diesel engine combustion characteristics by operating with waste plastic oil blends of 0%, 25%, 50%, 75% and 100% on volume basis. All the experimental tests were carried out under varying loading conditions at constant speed of 1500 rpm and an injection timing of 23^{o} BTDC at 180 bar injection pressure. From the experimental outcomes indicates that the engine thermal efficiency lower compared to diesel operation for pure plastic fuel and its blends at all load conditions. The combustion duration, heat release, ignition delay and peak cylinder pressure of all blends and pure plastic fuel were higher compared to diesel.

Rinaldini et al. [55] have investigated the IDI engine combustion, performance and emission characteristics by using pyrolysis oil obtained from waste plastics. The pyrolysis process has become the centre of attention because of its dual benefit of recovering energy from waste materials and reducing the environmental problems caused by waste plastics produced by both industrial and domestic activities. The experimental outcomes clear that the engine can able to run with pure plastic oil, but the slight reduction of performance was noticed compared to diesel operation.

Janyalertadun et al. [56] have studied the fuel production from landfill plastic wastes and conducted the experiments on single cylinder diesel engine by using plastic oil without altering the engine design. The thermo-physical properties of fuel produced from landfill plastic wastes are more similar to the diesel. The engine exhaust CO, HC emissions were diminished compared to diesel operation at full load for oil produced from landfill plastic wastes.

Kalargaris et al. [57] have studied the multi cylinder DI diesel engine at different pyrolysis temperatures by operation of fuels recovery from waste plastics. They suggested that the recycling of plastic waste by pyrolysis is one of the conventional approaches to dispose the plastic waste and that can transform solid plastics into high quality liquid fuel. From the results, it is noticed that the engine was found shorter ignition delay period and higher thermal efficiency at all loads by operating fuel produced from pyrolysis process at lower temperatures. The engine exhausts CO, CO_2, HC and NO_x emissions are less compared to fuel produced from higher pyrolysis temperature.

Kalargaris et al. [58] have carried experimental study on a multi cylinder DI diesel engine operating with waste plastic oil blends of 0%, 25%, 50%, 75%, 90% and 100% by various engine loads of 25%, 50%, 75% and 100%. The engine performance, combustion and exhaust emission characteristics were analysed and compared with the baseline fuel operation. From the results, they reported that a diesel engine can operate with the pure PPO at higher loads. The performance of the engine is comparable to baseline fuel while at lower loads and the longer ignition delay period causes stability issues. From the experimental outcomes, it is noticed that the brake thermal efficiency of the engine is diminished and NO_x emissions are increased compared to diesel fuel operation.

Kalargaris et al. [59] investigations carried out on diesel engine operated with plastic oil produced from pyrolysis of ethylene-vinyl acetate and low density polyethylene plastics. The temperature was maintained at 700^{o}C for low density polyethylene plastics and 900^{o}C for ethylene-vinyl acetate plastics in the reactor during the pyrolysis process. The both pyrolysis oils without the addition of diesel were investigated in a diesel engine and results are compared with diesel operation. They reported that the pyrolysis oil produced at low density polyethylene plastics exhibited the thermal efficiency, combustion characteristics are nearly identical with the diesel operation and exhaust emissions CO, CO_2, NO_x is diminished but unable to control HC emissions. Whereas, engine operated with ethylene-vinyl acetate plastic oil presented HC, NO_x emissions are higher and lower efficiency compared to diesel.

Kalargaris et al. [60] have investigated on long-term effects of plastic oil fuelled in a compression ignition engine. Conducted the engine longevity test in 4, 20 and 36 hours by using, a blend of 75% plastic oil blended with 25% diesel and reported the engine condition. From the results it is noticed that the engine was failing after 36 hours by using 75% of the plastic oil blend when a piston was cracked. The engine was opened after the engine failure and investigated the engine parts. Additionally, the investigation of the exhaust temperatures throughout the failure moment recommended that the underpinning purpose behind the piston cracked may be due to the injector failure was conformed and analysed the excessive wear due to the elevated pollution. At long last, the deposits from the cylinder heads were gathered and investigated uncovering that imperfect combustion was occurring.

Hariram et al. [61] investigation deals with the DI diesel engine performance and combustion parameters by using waste plastic oil blends at 0-30% with 15% step size in volume ratio. From the experimental outcome noticed that the rate of pressure rise, peak pressure, rate of heat release and in-cylinder pressure were higher for 30% blend compared to diesel operation.

The brake specific fuel consumption for plastic oil blends was obtained to be higher compared to diesel results. The engine exhausts NO_x emissions and smoke opacity is increasing with the increase in blend proportions.

Hariram et al. [62] have studied the performance and combustion characteristics of single cylinder DI diesel engine operating with plastic oil blends at 0%, 15% and 30% on volume basis conducted at no load and full load condition. At full load the peak pressure, rate of pressure rise, in-cylinder pressure and rate of heat release rate were more for plastic oil 30% blend than diesel. The maximum smoke opacity and NO_x emissions were noticed with 30% blend compared to diesel operation.

Kaimal et al. [63] have examined the diesel engine combustion characteristics by operating two different oils such as rice bran methyl ester produced by methanolysis of rice bran oil and plastic oil produced by pyrolysis of plastic waste. All the experiments were carried out at constant speed of 1500 rpm and an injection timing of 23^o BTDC at 180 bar injection pressure. The experimental outcome clears that the engine can able to run with both rice bran methyl ester and pure plastic oil. The combustion was delayed and lower thermal efficiency observed for both fuels compared to diesel operation.

2.4. Controlling exhaust emissions from diesel engines

Mani et al. [64] have studied the effect of cooled exhaust gas recirculation (EGR) on DI diesel engine using 100% WPO. It was observed that the engine fuelled with plastic oil by using without EGR higher NOx emissions. Whereas, the engine operated with cool EGR NO_x emissions were reduced compared to without EGR. Based on the noteworthy decrease in the exhaust CO, HC emissions, minimum possible smoke, NO_x emissions, and comparable BTE was noticed when the engine operated with 20% of EGR level was optimized. The engine BTE reduces with increase in the EGR flow rate at full load, the possible reason may be due to larger replacement of air happen with high EGR percentages. The NO_x emission decreases with diminished the peak combustion temperature by an increase in EGR percentage, due to the higher heat capacity with a presence of gases.

Devaraj et al. [65] have carried an experimental investigation on single cylinder water cooled, DI diesel engine using WPO mixed with 5% and 10% di ethyl ether used as an alternate fuel. From the experimental results, it is observed that minimized smoke levels compared to diesel and WPO. The thermal efficiency enhanced with addition of di ethyl ether compared to diesel and WPO. By increasing the di ethyl ether blended percentage with WPO, the heat release rate and peak pressure diminished compared to without additive WPO. It has been reported that the addition of oxygenates, enhanced combustion process and emissions are controlled and increases the Cetane rating which is superior to neat diesel by blending of di ethyl ether with WPO.

Senthilkumar et al. [66] have studied the combustion, performance and emission characteristics of DI diesel engine operating with pure plastic oil blended with and without 10%, 20% of jatropha methyl ester as an additive on volume basis. The experimental outcomes observed that the specific fuel consumption decreased and thermal efficiency increased with increase in additive blend percentage at full load condition compared to pure plastic oil operation. The engine exhausts HC and CO emissions are controlled with an increase in additive blend percentage in plastic oil but unable to control NO_x emissions. Nearly 11.4% of smoke emissions were diminished in the case of 20% of the additive plastic oil blend compared to without additive plastic oil blend.

Bridjesh et al. [67] have investigated the influence of plastic oil with and without two different additive blends operated on diesel engine by varying different loads. Experiments are conducted at 100% of plastic oil, 10% of MEA and 40% of plastic oil blended with 50% of diesel fuel, 10% of DEE and 40% of plastic oil blended with 50% of diesel, 50% of plastic oil blended with 50% of diesel were prepared on a volume basis and results are compared with diesel. The engine thermal efficiency increased and exhaust emissions are controlled with 10% of MEA additive plastic oil blend compared to without additive plastic oil blend. The minimum NO_x emissions were noticed with 10% of DEE additive plastic oil blend compared to other operated fuels.

Damodharan et al. [68] have studied the influence of waste plastic oil produced by catalytic pyrolysis from waste plastics on the combustion, performance and emission characteristics of DI diesel engine. Experiments were conducted at different EGR rates from 0% to 30% with 10% step size by changing three injection timings on the engine rated speed and power. Heat release rate and peak pressure for pure plastic oil decreased progressively with increasing EGR rates. The engine exhausts NO_x emissions reduced by increasing the percentage of EGR at all injection timings. The minimum NO_x emissions noticed with 30% EGR rates at 21°CA BTDC compared to other injection timings and EGR rates.

2.5. Alcohol additives in Spark Ignition engine

Liu et al. [69] have investigated the effect of methanol-petrol blends on spark ignition engine by considering different operating conditions. From results shows that, the engine can able to run without any altering engine design by using low fraction petrol-methanol blend. Furthermore, the percentage of methanol increases the methanol emissions and formaldehyde emissions increases with load increases by varying engine speeds. Both the non-regulated and regulated emissions should be effectively converted from conventional three-way catalytic converters. The engines exhaust emissions of CO and HC decreases with the addition of methanol in petrol and enhances the engine cold start.

Yanju et al. [70] have studied the performance and emission characteristics of SI engine operated with three methanol-petrol blends. From the results shows that the combustion duration and ignition delay are shortened and higher peak combustion pressure develops about the TDC with increasing methanol ratio. The engine brake thermal efficiency improved to increase in the methanol blend percentage. The engine operated with 85% methanol blend, nearly 25% of CO emissions and 80% of NO_x emissions are decreased compared to petrol operation.

Srinivasan et al. [71] have investigated with and without ethanol and oxygenated additives on multi cylinder spark ignition engine. Their study showed that the addition of ethanol is additive in gasoline, the blended fuel calorific value was reduced and increased the octane number of the blended fuel. This increased octane number is cause for higher brake thermal efficiencies and addition of ethanol additive can control the environmental pollution. From the results it is clear that the addition of ethanol, the engine performance improved and engine exhaust emissions of CO, NO_x reduced but HC emissions are increased compared to petrol operation.

Hong Zhao et al. [72] have investigated the emission characteristics of four passenger cars by using methanol-petrol blends at different mixing ratios at 15%, 20%, 30%, 50%, 85% and 100% on volume basis. Emissions of thirteen carbonyl compounds and eight volatile organic compounds were quantified and identified. They studied the OEM TWC and the new TWC converters on exhaust pollutions of unregulated and regulated carbonyl and volatile organic compounds by using different blend ratios. For all additive blends, the total emissions of BTEX and VOCs are decreased compared to emissions of petrol operated cars. The maximum BTEX emissions were decreased with engine operated with 85% of additive blend and lowest emissions decreased with 15% blend. From the results shows that the passenger cars operated with lower mixing ratios of methanol blends have lesser effects on the environment compared to passenger cars operated with petrol fuel.

Al-Hasan [73] has investigated the influence of ethanol-petrol blends operated on four stroke multi cylinder SI engine by varying engine speed from 1000 to 4000 rpm. Experiments are conducted at three-fourth throttle opening position by using with different fuel percentages from 0% to 30% of ethanol blended with petrol on volume basis. From the results clears that the addition of ethanol improves the engine brake thermal efficiency, torque and brake power, while it reduces the equivalence air fuel ratio and specific fuel consumption. The engine exhaust CO_2 concentration increases, whereas HC and CO emissions were reduced compared to petrol operation. He reported that the engine operated with 20% of ethanol blend given the enhanced results compared to other operated fuels at all engine speeds.

Fikret et al. [74] have discussed the effect of 60% ethanol blend on SI engine performance and exhaust emission characteristics by little modification in carburettor design and results are compared with pure petrol operation. The engine operated with blend fuel, the engine torque reduces and brake specific fuel consumption increases and output power measurements were noticed. While engine efficiency increased and exhaust emissions decreased drastically using with an additive blend compared to pure petrol. The ethanol has more octane number compared to petrol. The addition of ethanol in petrol, the blended fuel heating value was decreased and augmented the octane number of the additive fuel. Because this BTE increment majorly depends on the octane number of additive, this leads to higher BTE of additive petrol blend compared to petrol.

Basavaraju et al. [75] have investigated on a single-cylinder petrol engine by using the methanol-gasoline blends to increase performance and control the exhaust emissions. Primarily, the engine was operated by petrol with compression ratio is 7.5:1 at full load and different speeds. This technique is utilized for expanding the fuel competence of an engine and to reduce the emissions produced during the combustion process by adding the different percentage of methanol to the gasoline on a volume basis. The result shows that, the engine performance improved and the exhaust emissions controlled by operating with methanol gasoline blends.

Jose et al. [76] have investigated the effect of methanol-gasoline blends to improve the power output and to control the exhaust emission level of an engine. It has been noticed that as the percentage of alcohol increases, drastically reduces the exhaust emission levels of hydrocarbons and carbon monoxide. By advancing the ignition timing and increasing the engine compression ratios, almost 12.5% improved in the power output has been accomplished in his investigation.

Ahmadi [77] has conducted a review on the influence of different alcohol percentage blends fueled in both spark ignition and compression ignition engines with various operating conditions. From the results it clears that, even the addition of alcohol additives reduces the environmental pollution of the blended fuel and it improves the brake thermal efficiencies compared to both petrol and diesel fuel operations.

Francesco et al. [78] have investigated the combustion behaviour and air-fuel mixing on turbocharged GDI wall-guided multi-cylinder optical engine by conventional and optical diagnostics with using ethanol-petrol blends at 10%, 50% and 85% on volume basis. Combustion characteristics such as combustion duration, heat release rate and mass fraction burned were measured based on in cylinder pressure curve data. The propagation speed, flame structure, and spray penetration were analysed by optical data. Finally, they reported that the oxygen presence in the ethanol allows a more and faster effective combustion with respect to fuels characterized by high petrol fraction causes to enhanced engine efficiency, stability and improved combustion initiation.

2.6. Summary

In this chapter, the effort has been made to review the related literature on various methods of disposal of waste plastics and the effect of environmental factors. From the literature survey, it is noticed that it is possible to convert solid plastic waste into liquid plastic waste oil, which could be used as a conventional petroleum fuel. But no effort has been made to use plastic waste oil as a complete alternate fuel in a petrol engine.

- First section deals with plastic oil obtained from the pyrolysis process. From the literature, it is observed that it was an operative way to produce a valuable energy extract by pyrolysis of different solid waste plastics. The pyrolysis of plastic oil is much easier and flexible than the common recycling method since it does not need an intense sorting process, thus less labour intensive.
- Second section deals with the crude PPO as an alternate fuel in diesel engines. Many researchers are carrying investigations to use the pyrolysis oil as recourse to petroleum grade fuel. While analysing the energy needs in the light of waste plastic disposal promotes the production of plastic pyrolysis oil as a better alternative fuel in IC engines. Furthermost investigations were carried out with PPO as an operating fuel in diesel engines and minimal research was reported on petrol grade engines.
- Third section deals with the control of emissions in diesel engines. Many researchers investigated on controlling of emissions using different techniques like EGR and adding different additives.
- Fourth section deals with the control of emissions in SI engines. Most of earlier investigation that is cleared, using methanol or ethanol as an additive in spark ignition engines can offer an increased thermal efficiency and increased power output due to its high octane rating and high heat of vaporization.

Chapter 3

Materials and Methodology

3.1. Introduction

Though the research on run the IC engines with different alternative bio-diesels is existing from last two decades, in recent past, usage of fuel derived from the waste plastic is attracting the research community. The monomers of the plastic materials are differently cross polymerized, thus the plastic waste does not dissolve in the ground. However, they are also has non-biodegradability nature as well. Hence, the plastic waste is dissolved by the pyrolysis process to convert the inhibited chemical energy of waste plastic into useful petrol grade fuel. Pyrolysis is the process of transforming the waste plastic into petroleum grade fuel to use in IC engines. Few of the earlier researchers analyses the PPO in diesel engine, but no considerable investigations with consolidated outcomes are carried out on petrol engine.

For the present work, pyrolysis plastic oil is purchased from GK industries Hyderabad, India. The thermos-physical and chemical properties of raw fuel are within the ASTM standards. Therefore, at the initial runs no further treatment is carried out, and experiments are run at 0% to 25% of PPO blends in petrol engine. From the experimental outcomes, it is noticed that thermal efficiency of engine is diminished and emissions are increased compared to petrol fuel. As an alternative technique to improve the combustion quality, test runs are conducted with the iridium spark plugs by using 0%, 10%, 20%, 25% and 30% of PPO blends in SI engine. Even then, the blend proportions cannot be increased beyond 25% of crude PPO.

From the critical analysis of earlier researchers, it is noticed that, even the addition of alcohol additives reduces the net heating value of the blended fuel and it improves the octane number. This increased octane number causes for higher brake thermal efficiencies and the addition of alcohol additives can control the environmental pollution. Therefore, in order to control the emission rates and to improve the performance of the engine 5% of alcohol additives are added to PPO blends. Though, the performance and emissions are refined but the blend proportion cannot be raised beyond the 25 % of PPO. Thereby, distillation is carried out on crude plastic oil to further refine the properties of fuel. Experiments are conducted with blends at 10%, 20%, and 25% of distilled plastic pyrolysis oil and compared with crude PPO blends. From the results it is clear that, the engine can run beyond 25% of distilled plastic oil blends without any modifications. Further, tests are conducted even up to 50% DPPO and pure DPPO.

3.2. Distillation of PPO

The plastic pyrolysis oil had some disadvantages such as high carbon residue, low volatility and high viscosity. Therefore, before using the PPO as fuel the viscosity had to be reduced. Distillation is one of the interesting methods to reduce the viscosity of the plastic oil and also to improve the atomization of the fuel to use them in the spark ignition engines. This process applied for petrol and diesel grade fuel production process. (Fig. 3.1.) Batch distillation process was carried out to remove the impurities from plastic pyrolysis oil and increase the volatility of PPO. The sample was externally heated in a closed vessel. The vapour leaving the vessel was condensed in a water condenser and the distilled plastic pyrolysis oil was collected separately. Non condensable volatile vapours were left to the atmosphere. The distillation process was carried out between 90°C to 160°C. 42 percent of PPO was distilled in the batch distillation while 6 percent of PPO was left out as pyro gas and rest of all other fractional fuel percentage was 52% including diesel grade fuel and light gas also. As the derived plastic fuel from the waste plastic after pyrolysis and distillation catches fire in room temperature itself, so flash and fire point is not valid for the arrived fuel as same like as petrol.

Fig. 3.1. Batch distillation apparatus

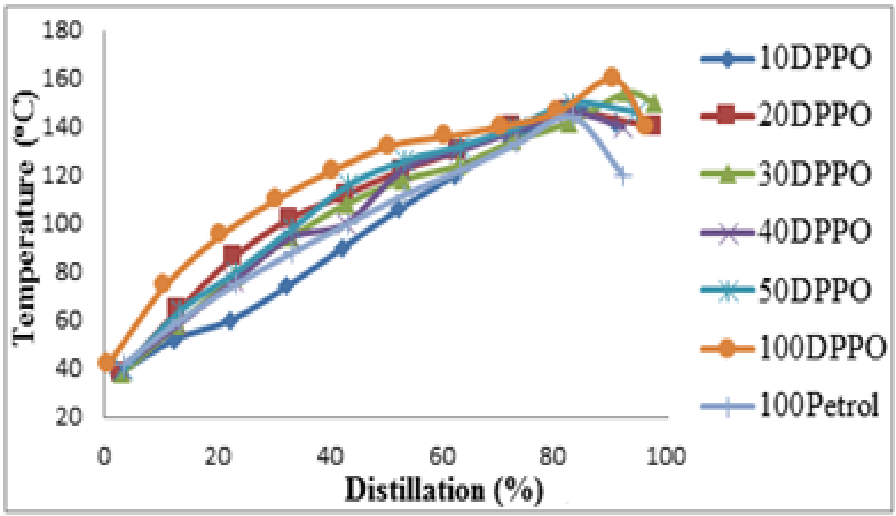


Fig. 3.2. Volatility variation in pure petrol and distilled plastic oil blends

Fig. 3.3. Pure DPPO after distillation

And the extraction from the distillation i.e. plastic fuel slightly having more calorific value and higher carbon content compare to that of petrol fuel, and also having density more than that of the gasoline. Some of the properties of the petrol, plastic pyrolysis oil, distilled plastic pyrolysis oil and alcohol additives are compared in appendix-B. The tendency of a fuel to vaporize is also characterized by determining a series of temperatures at which various percentages of the fuel have evaporated (boiling temperatures), as described in ASTM D86, Test Method for Distillation of Petroleum Products. The temperatures at which 10 percent, 50 percent, and 90 percent evaporation occurs are often used to characterize the volatility of gasoline. The distillation characteristics curves of the petrol and plastic fuel as well as the different blends are shown in Fig. 3.2. From Fig. 3.2 it can be observed that the volatility property is more in the plastic pyrolysis distilled oil blends compared to the pure petrol. By carry out the distillation on DPPO, it exhibits the similar characteristics that of petrol. From the total tested fuel, 95 % of DPPO is vaporised and 3% is collected as residue and rest is liberated to atmosphere as pyro gas. The photographic view of distilled DPPO and residue is as shown in Fig. 3.3.

3.3. Emulsifier Apparatus

The emulsifier is a blending apparatus which is used to prepare homogeneous mixture of PPO (i.e. with and without 5% alcohol additives) and DPPO in gasoline blends at desired proportions. The apparatus was supplied by Ormeroo Engineers Limited, England as shown in Fig. 3.4. The ingredients of blends at predetermined proportions are stirred in two stages to assure homogenous mixing. The prepared PPO and DPPO blends for investigating the performance and nature of emissions of a petrol engine.

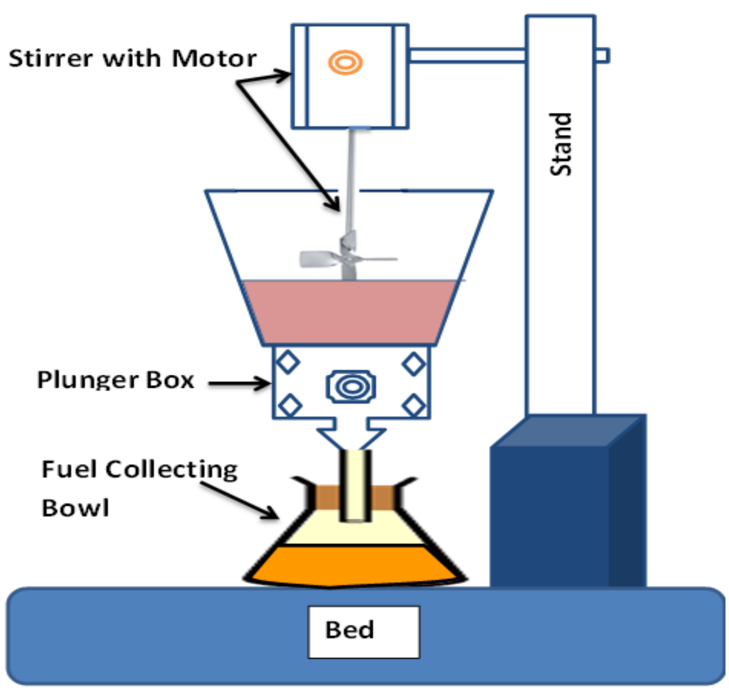


Fig. 3.4. Schematic diagram of Emulsifier Apparatus

3.3.1. Preparation of plastic oil blends

The basic properties of PPO-PF with and without additive blends were measured and compared with petrol fuel. PPO fuel C-H-N-S analysis was carried out at IICT Hyderabad, India. Testing reports explicate that the carbon content in a PPO is nearer to that of petrol fuel and nitrogen content is more than petrol fuel. As the derived plastic fuel from the waste plastic after pyrolysis flash and fire point are 40^{o}C and 44^{o}C respectively.

Fig. 3.5. PPO blends preparation by using Emulsifier Apparatus.

In the present work different plastic oil petrol blends was prepared with and without distillation and alcohols as additives at 5% on a volume basis. 25% of PPO blend is indicated as 25PPO. For example, 25% of pure PPO blended with 75% of PF is denoted as 25PPO. 25% PPO blend with ethanol is indicated as 25PPO5E. For example, 25% of PPO and 5% of ethanol blended with 70% of PF is denoted as 25PPO5E. 25% PPO blend with methanol is indicated as 25PPO5M. For example, 25% of PPO fuel and 5% of methanol blended with 70% PF is denoted as 25PPO5M. Similarly 25% of DPPO blend is indicated as 25DPPO. For example, 25% of pure

DPPO blended with 75% of PF is denoted as 25DPPO. The prepared blend sample for investigation is as shown in Fig. 3.5.

3.4. Improvement of Distillation Yield

3.4.1. Filtration Process

While carryout the distillation process high quantity of residue is observed and sedimentations are also prevent in the waste plastic pyrolysis oil. Therefore, in order to minimize these residues, filtration process was carried out. After carryout the primary filtration with cloth filter most of the sludge are sieved. Again this filtered oil was poured in secondary (coil) filter and observed very little amount of sediments are filtered as shown in Fig. 3.6.

3.4.1.1. Filtered fuel samples distillation process

Fig. 3.6. Primary (cloth) and secondary (coil) filtration process

Both Primary (cloth) filter and Primary (cloth) & secondary (coil) filtered waste plastic pyrolysis oil converted to fuel was use for further distillation process and making petrol grade fuel. Distillation column was use for distillation process as shown in Fig. 3.7. Distillation process set up different columns with different temperature profile like low boiling point fuel to high boiling point fuel. Petrol grade fuel collected from fractional column and temperature range was 60°C to 160°C. This fuel hydrocarbon compound also heavier and this fuel are not igniting.

Collected petrol grade fuel percentage was about 30% and rest of all other fractional fuel percentage was 70% including diesel grade fuel and light gas also. Fractional distillation process was also generating some light gases. Light gas cleaning procedure also same above procedure. Plastic pyrolysis fuel to different fuel by using fractional distillation column used for heat applied with different column temperature wise and fuel break down into shorter into longer chain wise and come out into different fraction column then collected into separate container.

Fig. 3.7. Distillation Apparatus

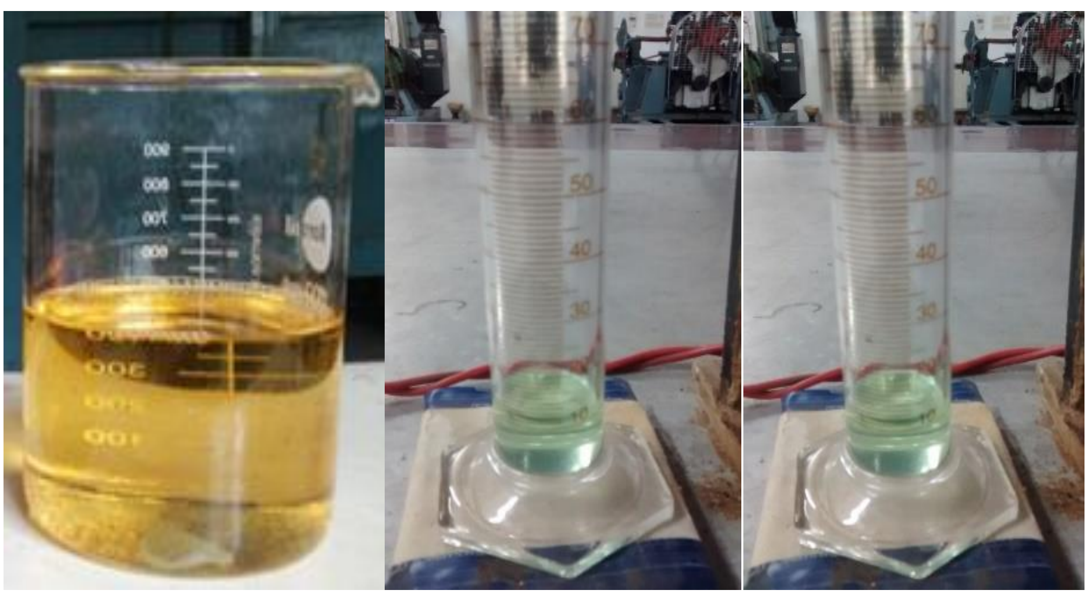


Fig. 3.8. Color variation of Crude DPPO without filtration, cloth filtered DPPO, cloth and coil filtered DPPO samples after distillation process

In the present study distilled waste plastic pyrolysis oil is obtained in the boiling range of 60^{o}C-160^{o}C. The oil obtained by distillation is as shown in Fig. 3.8. There is no marginal improvement in collected petrol grade fuel percentage from distillation compared to the crude distilled plastic pyrolysis oil. Which leads to attempt for another effort to improvement in collected petrol grade fuel percentage, hydrodynamic cavitation gave the best outcome with substantial increment in the quantity of petrol grade fuel during distillation.

3.4.2. Hydrodynamic Cavitation

Hydrodynamic cavitation setup is produced to generate fluid mechanically an efficient and homogeneous cavitation. The design of the cavitation setup realizes a temporal long use of energy transfer generated by transient cavitation. The cavitation generated hydro-dynamically covers spatial as well as temporal for the whole product stream, where this is not seen in any other apparatus. The generation and intensity of the cavitation could be controlled by process parameters like pressure and flow rate. Applications would be found in all field of mechanical and chemical processing of fluids streams. Fields of application would range from mixing or disintegration of particles and colloidal suspensions or homogenization to the increase of chemical reaction and synthesis. In all fields it has to process fluid mass flows by mechanical or chemical means like mixing, changing product matrix or chemo-physical properties of the ingredients.

The following observations are made during the cavitation process.

- Hydrodynamic cavitation experiment was carried out in chemical engineering department at NIT Warangal, but I was unable to prevent the schematic as they are going to apply for patent on that design.
- The efficiency of the chemical reactions and processes can enhance by particle disintegration.
- Hydrodynamic cavitation (HDC) is a process of vaporisation, bubble generation and bubble implosion in a flowing liquid which results increase in local pressure.
- In this HDC, the chain structure of hydro carbons are broke by sudden variation in local pressures.
- On continuous breaking of this chemical chain leads to increase the yield in distillation.
- There are only a few well established mechanical methods are available to perform this

hydrodynamic cavitation.

- In hydrodynamic cavitation along with hydrocarbon chains, suspended impurities are also broken as shown in Fig. 3.9.

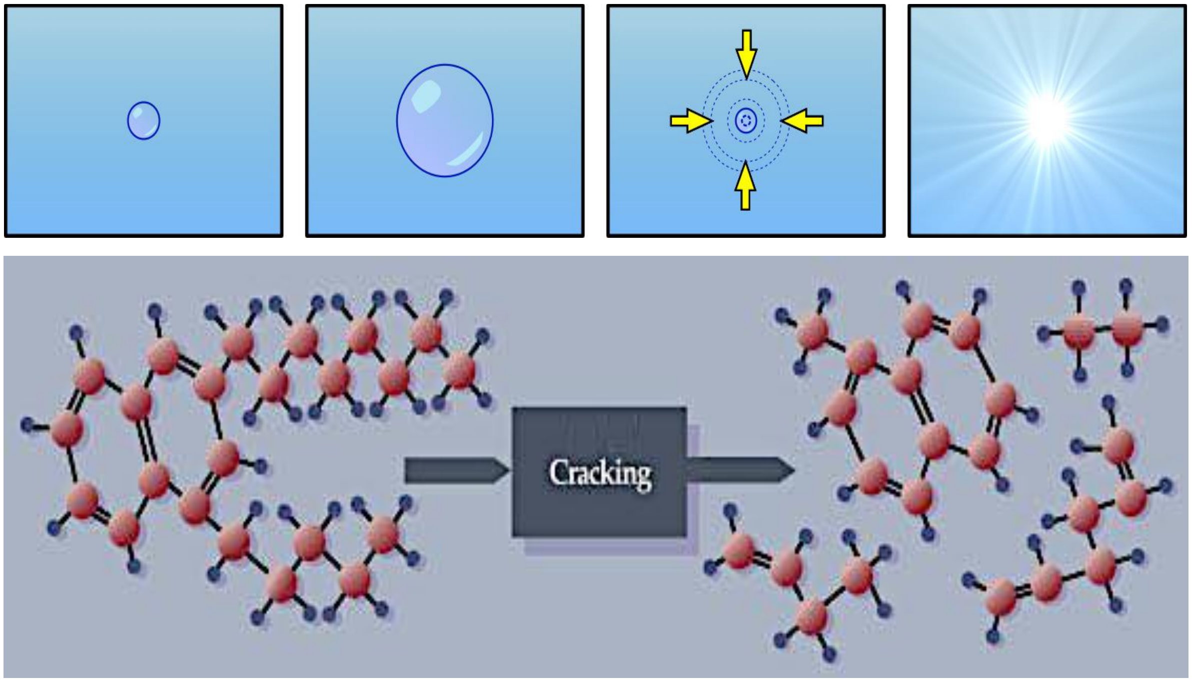


Fig. 3.9. Hydrocarbon cracking during cavitation bubble collapse

Fig. 3.10. Nano and Micro filtration process of crude PPO after cavitation

After Hydrodynamic Cavitation, the refined oil was again filtered with Micron filter and Nano filter as shown in Fig. 3.10.

- Distillation was performed on both filtered and unfiltered oil by using distillation apertures.
- Nano filtration taking much time, so initiated the distillation with micro filtered oil, but the collected petrol grade fuel percentage results are not encouraging which makes to proceed without filtration.
- Surprisingly unfiltered oil gave more percentage of petrol grade fuel in distillation compared to crude plastic pyrolysis oil as shown in Fig. 3.11.
- The increment in fuel percentage is 7% then the crude.

Properties of Plastic Pyrolysis Oil before and after hydrodynamic Cavitation Process are shown in appendix-G.

Fig. 3.11. After HDC collected DPPO

3.5. Summary

- Detailed description on various blend proportions were considered in current research.
- Plastic pyrolysis oil obtained from the waste plastic is carried out distillation processes to use in petrol engine.
- Different methods were carried out to improve distillation yield.
- There is no substantial increment in percentage of petrol grade fuel from primary (cloth) filtered oil and primary & secondary (cloth & coil) filtered oil by the distillation process. But purity of oil was improved by removing the sediments from the oil.

Hydrodynamic Cavitation gave marginal enhancement in the petrol grade fuel percentage from distillation. The kinematic viscosity of plastic pyrolysis oil was reduced by 21.2% compared to without cavitation plastic pyrolysis oil.

Chapter 4

Experimental Setup

4.1. Introduction

In this chapter, the experimental details and procedure to evaluate the performance and emission parameters of a multi cylinder SI engine by using waste plastic oil with and without distillation, additives.

4.2. Experimental Setup

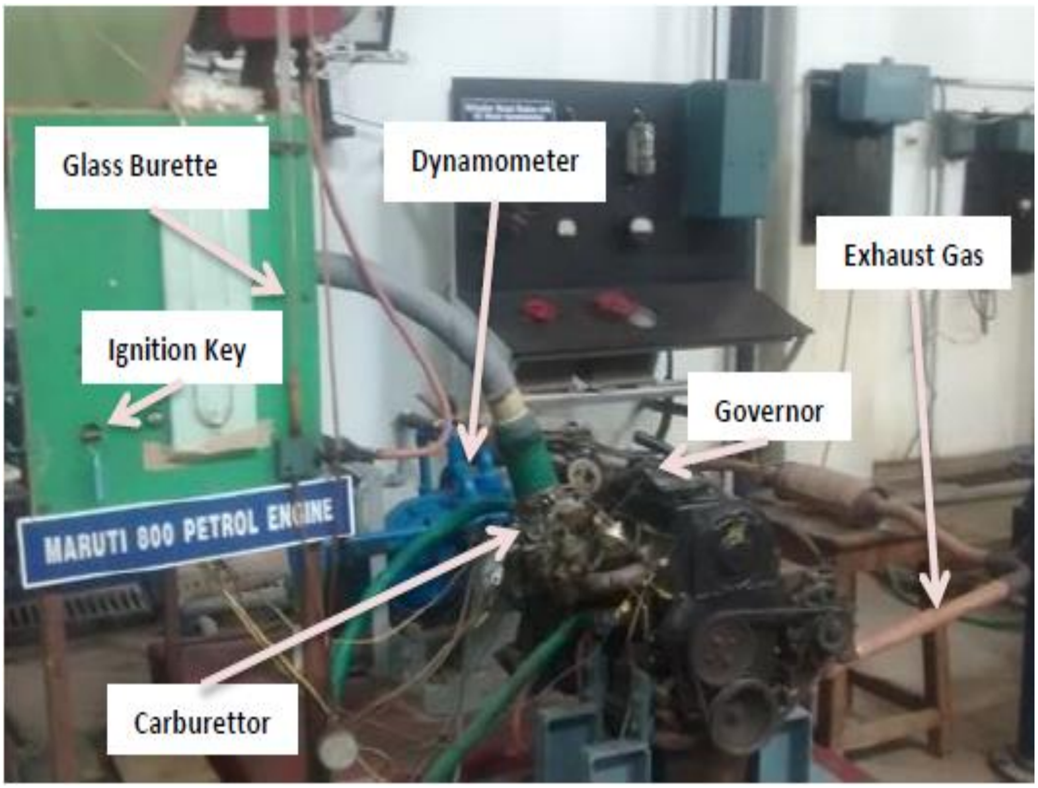
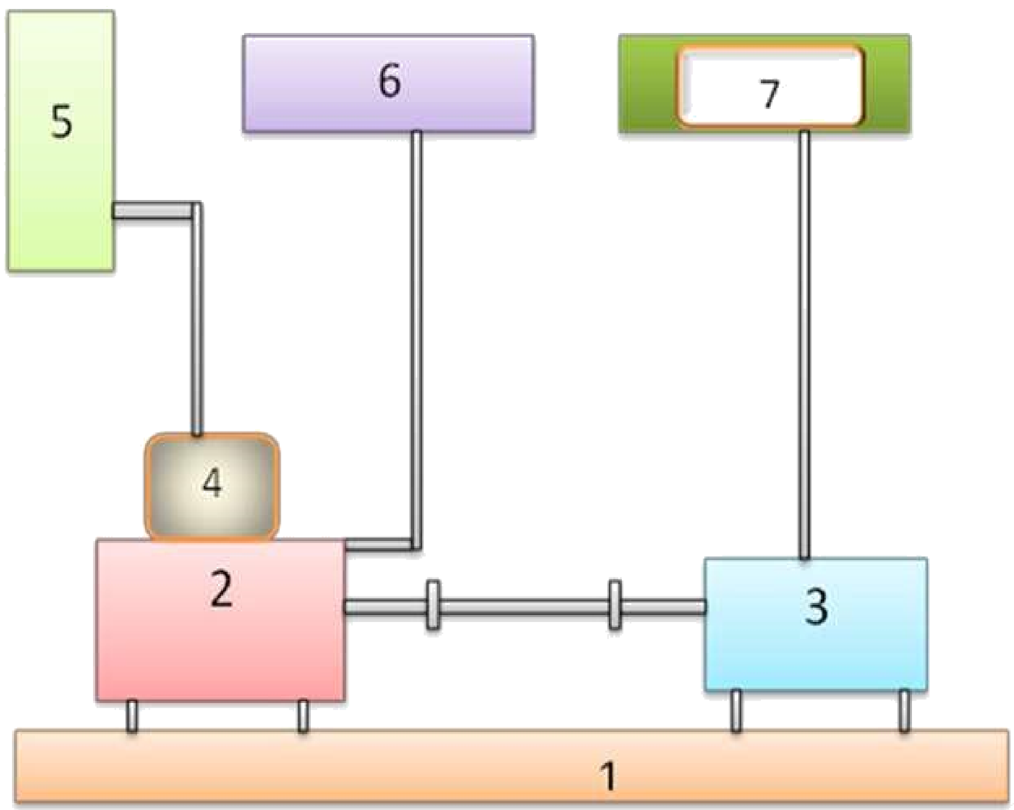


Fig. 4.1. Experimental setup of Maruti 800 Petrol Engine

In the present research, experiments were conducted on a three cylinder 4-stroke water cooled Maruti 800 petrol engine test rig as shown in Fig. 4.1, and schematic diagram of the Maruti 800 petrol engine setup with the Instrumentation as shown in Fig. 4.2. All the experiments are carried out at a fixed constant speed at 1500 rpm and compression ratio of 8.7:1 under different load conditions. Stoichiometric air fuel ratio is maintained to assured complete combustion and to minimize emits from engine. The purpose of dynamometer is to test the load capability of an engine. An engine without any load can only produce speed. Engine consumes very less horse power to maintain rate speed. The dynamometer is a means by which a controlled load can be added and monitored. A hydraulic dynamometer (with water as working fluid) has been used in the present study to load the engine. The hydraulic dynamometer works on the principle of dissipating the power in fluid friction. It consists of an inner rotating member or impeller coupled to the output shaft of the engine. This impeller rotates in a casing filled with water. The outer casing, due to centrifugal force developed, tends to revolve with the impeller, but is resisted by a torque arm supporting the balance weight. In steady flow of water is maintained to well balance the centrifugal force developed during rotation. The spring balance fitted on the casing measures the frictional forces between the impeller and the water. The output can be controlled by regulating the valves to partially or wholly obstruct the flow of water between impeller and the casing. Test rig is attached with a digital indicator to apply and maintain the constant load on engine by creating a resultant trust in the form of reaction torque at the whirl chamber.



1.Test Bed 2.The Engine
3.Dynamometer 4.Carburetor
5.Burette 6.Gas Analyzer
7.Digital Load Indicator

Fig. 4.2. Schematic diagram of Maruti 800 petrol engine setup

4.2.1. Experimental Procedure

The engine was coupled to a water brake dynamometer made by the TECHNOMECH which is equipped with digital load indicator. Fuel consumption was measured by using a calibrated burette and a stopwatch. The engine speed is measured with a fine-tuned tachometer. The concentration of the engine exhaust emissions like CO, HC, and NO_x are measured with an AVL five gas analyser. The engine was started and allowed to warm up for a period of 15 to 20 minutes. For the experimental safety the engine has not been run at rated power and speed, only run at 5.25 BHP @ 1500 rpm instead and is referenced as a full load. The fuel consumption was constant at 10 CC for each performance. Engine tests were performed at a constant speed by varying the loading condition for each individual fuel blends. Before running the engine to a new fuel blend, it was allowed to run for sufficient time to consume the remaining fuel of previous experiments. For each experiment, an average of three readings has been taken for the evaluation of the engine performance. The parameters like brake power, brake specific fuel consumption, brake thermal efficiency are calculated and emissions are analyzed based on the observations.

4.2.2. AVL Exhaust Gas Analyser

Fig. 4.3. AVL Exhaust Gas Analyser

Emissions from the combustion of PPO oil blends are measured using AVL five gas analyser as shown in Fig. 4.3. It measures the five different emissions of unburned hydrocarbons and oxides of nitrogen, carbon monoxide, carbon dioxide, oxygen are measured on relative volume and percentage basis respectively. A nondispersive infrared sensor is used in the analyser to measure emissions of CO, CO_2, and HC. An electrochemical sensor is used to measure the NO_x and percentage of oxygen in the exhaust gases. By allowing the exhaust gas to pass through this analyser, the constituents of the gases are calculated and displayed on the digital display. The strainer at the inlet of analyser will remove or separate the moisture content that enters into the meter with tested gas, because the moisture may cause for error readings.

4.2.3. Iridium Spark Plug

Fig. 4.4. Iridium Spark Plug

In a SI engine, spark plug plays a crucial role to initiate and ignite the charge. The rate of combustion depends on the flame propagation in the combustion chamber. Consistent and continuous combustion may not be the sole function of quality and duration of spark but the instant and duration of spark also define the combustion quality. Therefore, Iridium spark plugs are introduced to serve this purpose. For the investigation, two different types of spark plugs are used one is normal spark plugs and the second type is iridium spark plugs. The iridium spark plug is as shown in Fig. 4.4. It is used specifically due to extreme ignitability, augmented performance, minimal carbon deposits and improved throttle response.

Chapter 5

Results and Discussions

5.1. Introduction

A detailed analysis of results obtained from the experimental outcome is presented in this chapter. Since the waste plastic oil is commercially available, the oil was purchased from GK industries for the experimentation. The present work focuses on using waste plastic oil with and without distillation, adding the additives as an alternative fuel in a spark ignition engine in the form of a blend and as a neat fuel at a constant speed and compression ratio. The first case of this chapter explains the comparative evaluation of SI engine by using different crude PPO blends. the second case contains the analysis of crude PPO blends on the SI engine by changing iridium spark plugs. The third case explains the Influence of plastic oil with addition of 5% ethanol additive blends fuelled in SI engine. The forth case describes the SI engine performance and emission analysis by using crude plastic oil blends with and without addition of 5% methanol additive. The fifth case contains the experimental analysis on SI engine by using PPO-PF and DPPO-PF blends. The sixth case describes the Performance and emission characteristics of SI engine by using distilled plastic oil gasoline blends and pure DPPO. The SI engine performance and emission characteristics are evaluated and compared with base-line fuel.

5.2. Influence of crude plastic oil blends operated on SI engine without any modification of engine design.

5.2.1. Introduction

The exponential growth in both population and industries has created a great demand for energy which is supplied mostly by petroleum fuels. Because of the lavish consumption and continuous usage the fossil reserves are getting depleted rapidly. Also, the exponential increase in the number of automobiles has created problems in the environment because of the emissions. These issues and the ever-increasing price of crude oil have forced the world nations to look for alternate energy resources. Among the different fuels available, plastic oil produced by pyrolysis process has become the centre of attention because of its dual benefit of recovering energy from waste materials and reducing the environmental problems caused by waste plastic. Furthermost investigations were carried out with PPO as an operating fuel in diesel engines and minimal research was reported on petrol grade engines. Thus, crude plastic pyrolysis oil blends are used to conduct the experiments on three cylinder 4-stroke Maruti 800 petrol engine. In the present work

0%, 10%, 20% and 25% of PPO was blended with petrol fuel. All the blends are prepared by emulsification process.

5.2.2. Performance Characteristics

Variation of BSFC with a power output of the three cylinder Maruti 800 petrol engine by using waste plastic oil blends is compared with petrol fuel operation and is shown in Fig. 5.1. It is observed from the figure, the BSFC measures how efficiently an engine is using the fuel supplied to produce work. The BSFC varies from 1.55 kg/kW-hr at no load to 0.37 kg/kW-hr at full load for 10PPO, it varies from 1.71 kg/kW-hr at no load to 0.39 kg/kW-hr at full load for 20PPO, and for 25PPO varies from 1.72 kg/kW-hr at no load to 0.4 kg/kW-hr at full load. The experimental outcomes observed that the specific fuel consumption increased with increase in blend proportion compared to petrol fuel operation at all load conditions. The increased BSFC of PPO blends can be explained by the existence of a high amount of aromatics contained in PPO, because the aromatic bonds require more energy to break [9].

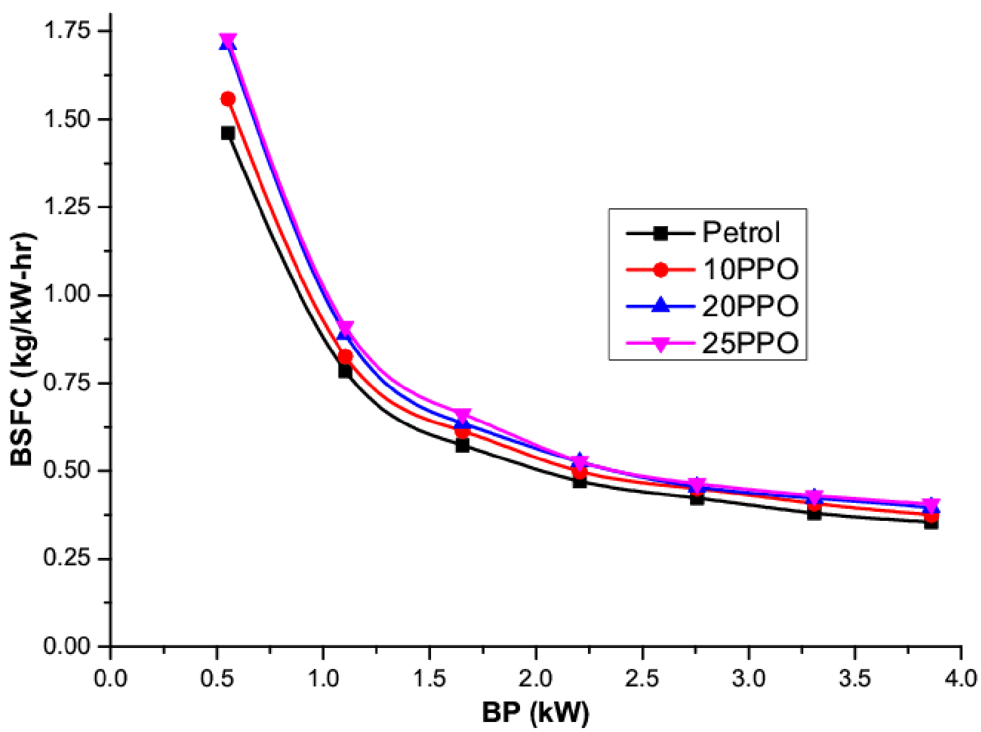


Fig. 5.1. Variation of BSFC with BP by using crude PPO blends

Variation of BTE of petrol engine operated with different PPO blend proportions is compared with petrol fuel operation and is shown in Fig. 5.2. It can be noticed from the figure that the brake thermal efficiency of 10PPO is 22.61% that of 20PPO is 21.22% and for 25PPO blend is 20.7% at full load condition. The experimental outcomes observed that the thermal efficiency decreased with increase in blend proportion compared to petrol fuel operation at full load. Nearly 11.28% decrement in the BTE is observed for 25PPO operation when compared to petrol operation. The possible reason for this reduction is plastic oil blend has lower heating value and octane number compared to petrol. Another reason could be that the higher combustion temperature of PPO results in high heat transfer losses [79].

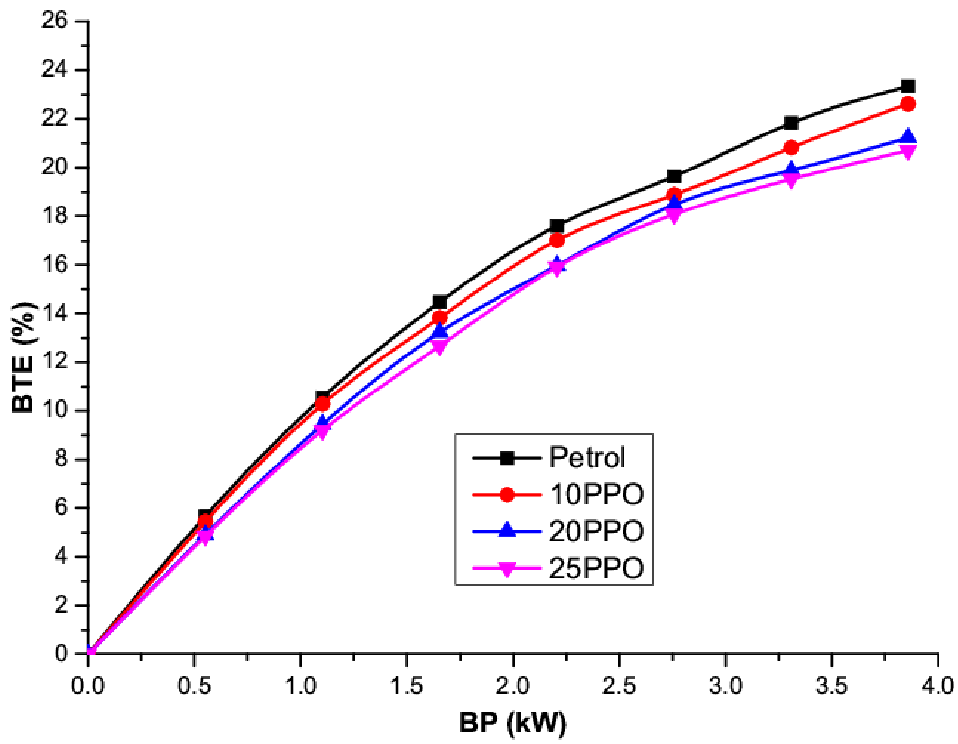


Fig. 5.2. Variation of BTE with BP by using crude PPO blends

5.2.3. Emission Characteristics

Fig. 5.3 shows the variation of CO emissions with different PPO blends operated on Maruti 800 petrol engine. The carbon monoxide formation is mostly due to poor air-fuel mixture supplementation and abnormal combustion as a result of oxygen deficient environment during the combustion process [80]. From the results, it is observed that the CO emissions diminutions linearly with engine load but, these emissions are diminishing in proportion with the blending compared with petrol. The amount of CO emissions emitted from 10PPO varies from 3 vol. % at no load to 1.5 vol. % at full load, from 20PPO varies from 2.8 vol. % at no load to 1.35 vol. % at full load, and from 25PPO varies from 2.65 vol. % at no load to 1.27 vol. % at full load. The minimum CO emissions are noticed at 25PPO compared to all other operated fuels at full load condition. The possible reason for this reduction is more oxygen availability in plastic oil [81].

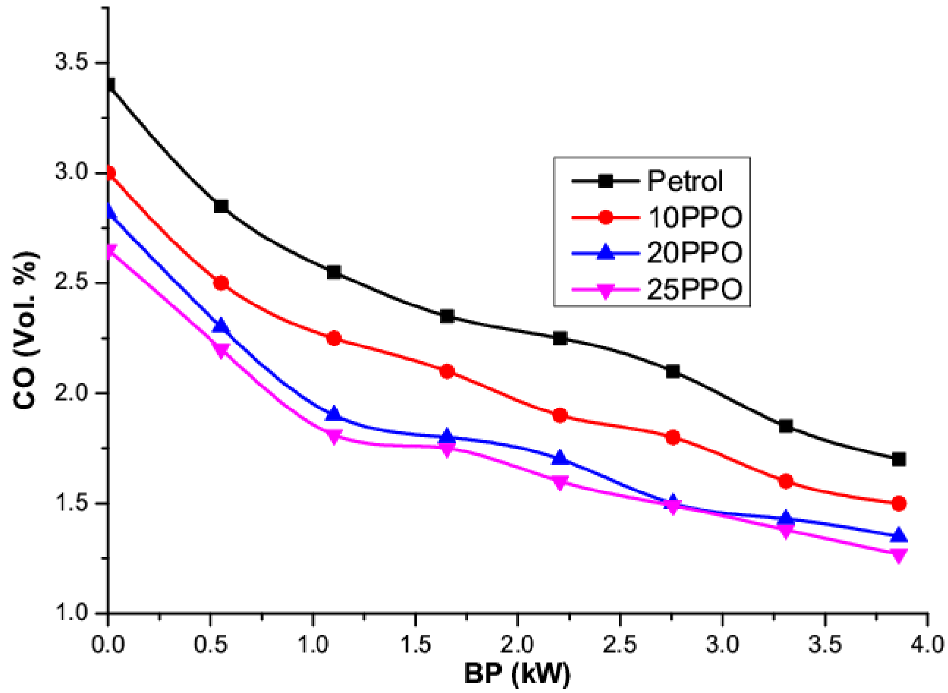


Fig. 5.3. Variation of CO emissions with BP by using crude PPO blends

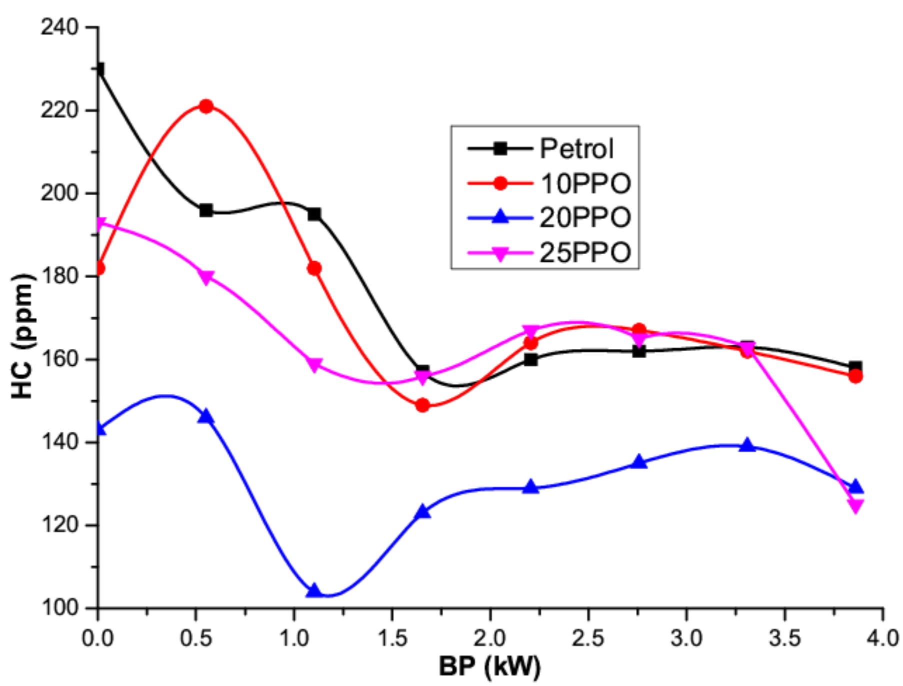


Fig. 5.4. Variation of HC emissions with BP by using crude PPO blends

The effect of petrol-plastic oil blends on HC emissions by varying engine load is shown in Fig. 5.4. The root cause for the formation of the HC emissions is an unburned mixture of PPO blended gasoline [82]. Some of the air-fuel mixture pockets were not participated in the combustion hence, it gives raise to unburned HC emissions due to misfires and HC deposits [83]. The HC emissions of 10PPO vary from 182 ppm at no load to 156 ppm at full load, and it vary from 153 ppm at no load to 129 ppm at full load for 20PPO. The experimental outcomes observed that the un-burnt hydrocarbons are continuously decreasing when the proportion of the plastic fuel is increasing in the blends compared to petrol fuel operation at full load conditions. The minimum HC emissions are noticed at 25PPO compared to all other operated fuels at full load condition. This could be due to the complete combustion of petrol-plastic oil blends.

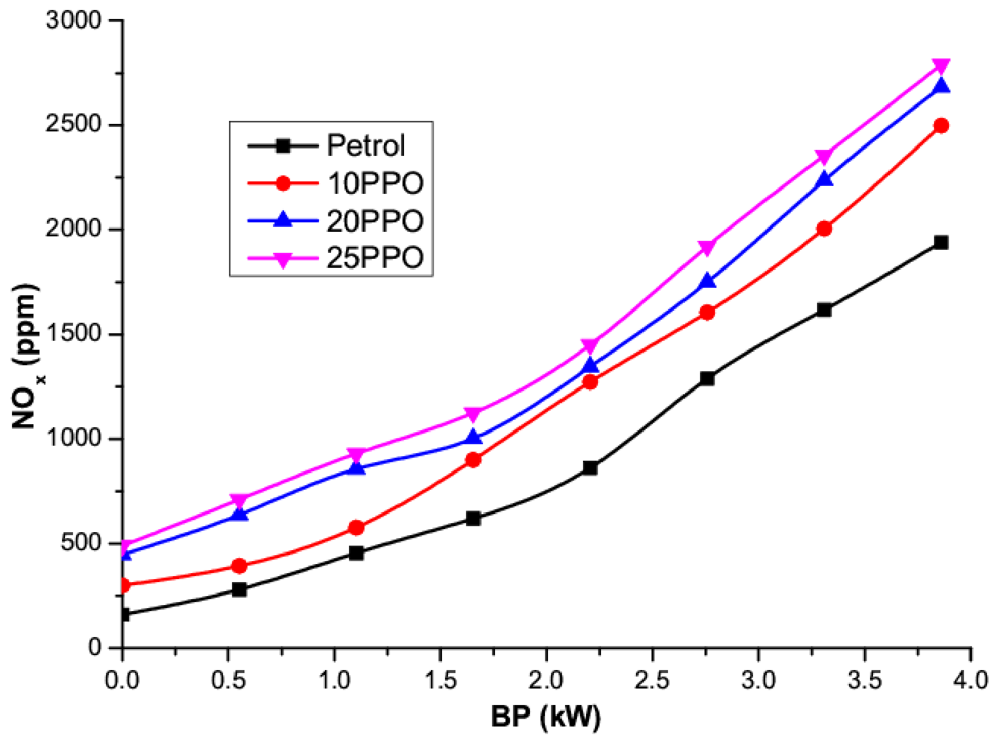


Fig. 5.5. Variation of NO_x emissions with BP by using crude PPO blends

An oxide of nitrogen emissions is the primary concern of the engine designers subsequently the spark ignition engine run at lean air fuel ratios, at higher loads and at higher compression ratios causes higher cylinder temperatures. The formation mechanism of oxide of nitrogen emissions is majorly temperature dependent so any small rise in cylinder temperature would result in increased oxide of nitrogen emissions [84]. Variation of NO_x emissions with power output of the three cylinder Maruti 800 petrol engine by using waste plastic oil blends is compared with petrol fuel operation and is shown in Fig. 5.5. The emissions varies from 300 ppm at no load to 2498 ppm at full load for 10PPO, it varies from 447 ppm at no load to 2683 ppm at full load for 20PPO, and for 25PPO varies from 490 ppm at no load to 2790 ppm at full load. From the results, it is observed that the NO_x emissions are substantially increased when the proportion of the plastic fuel is increasing in the blends compared to petrol fuel operation at full load conditions.

5.2.4. Summary

Experiments were conducted on a three cylinder four stroke Maruti 800 petrol engine by using crude PPO blends and compared with petrol fuel operation. The following conclusions are observed from the tests.

- BSFC of 25PPO is 14% increases when compared to petrol at full load operating conditions.
- BTE of 25PPO is 11.28% decreases at full load operating conditions when compared to petrol.
- CO emissions of 25PPO are 25.29% decreases at full load operating conditions when compared to petrol.
- The engine exhaust HC emission at 25PPO blend is 20.88% decreased compared to the engine operated with petrol.
- NO_x emissions of 25PPO are 43.81% increases at full load operating conditions when compared to petrol.

From the results, it is clear that the engine performance decreases, NO_x emissions are substantially increased and the blend proportion raised beyond the 25 % of PPO causes for misfiring and abnormal engine vibrations. Therefore, experiments are carried out up to 25PPO blend percentage.

5.3. Effect of crude plastic oil blends by changing iridium spark plugs.

5.3.1. Introduction

The spark plug is a pivotal tool to ignite the compressed charge in SI engine. It delivers the electrical current from the ignition system to a compressed charge. The generated spark will initiate the combustion in charge, which is at the pre-requisite state in the combustion chamber. Physically, the spark plug is a metal threaded shell, electrically isolated from a central electrode by a porcelain insulator. The central electrode, which contains the resistor, is connected by a heavily insulated wire to output terminal of an ignition coil. The metal shell of spark plug is screwed into the cylinder head and thus electrically grounded. The central electrode protrudes through the porcelain insulator into the combustion chamber, forming one or more spark gaps between the inner end of the central electrode and usually one or more protrusion structures attached to the inner end of the threaded shell.

From the experimental studies, it is noticed that when SI engine operated beyond 25 percent crude plastic pyrolysis oil causes for misfiring and abnormal engine vibrations. Therefore, experiments are carried out up to 25PPO blend percentage. As an alternative technique to improve the combustion quality, test runs are conducted with the iridium spark plugs by using 0%, 10%, 20% and 25% of plastic pyrolysis oil blended in petrol fuel on a volume basis. The PPO blends by using iridium spark plugs results are compared with the ordinary spark plugs results.

5.3.2. Performance Characteristics

The influence of petrol-plastic oil blends on the brake specific fuel consumption as shown in Fig. 5.6. By increasing the PPO blend proportions the fuel consumption rate is uniformly increased by using ordinary spark plugs. As an alternative technique to improve the combustion quality, pilot test runs are conducted with the iridium spark plugs. The engine operated with pure petrol has the BSFC of 1.46 kg/kW-hr at no load and 0.35 kg/kW-hr at full load, for 25PPO is 1.72 kg/kW-hr at no load and 0.4 kg/kW-hr at full load by using ordinary spark plugs. The BSFC for petrol is 1.39 kg/kW-hr at no load and 0.34 kg/kW-hr at full load, for 20PPOSP are 1.67 kg/kW-hr at no load and 0.37 kg/kW-hr at full load, for 25PPOSP is 1.69 kg/kW-hr at no load and 0.38 kg/kW-hr at full load by using iridium spark plugs. The fuel consumption rate is decreased by using iridium spark plugs compared to ordinary spark plugs results. This possible reason may be due to the improved material characteristics promotes anti carbon deposition which leads to initiate the spark at right intervals in the combustion chamber [85].

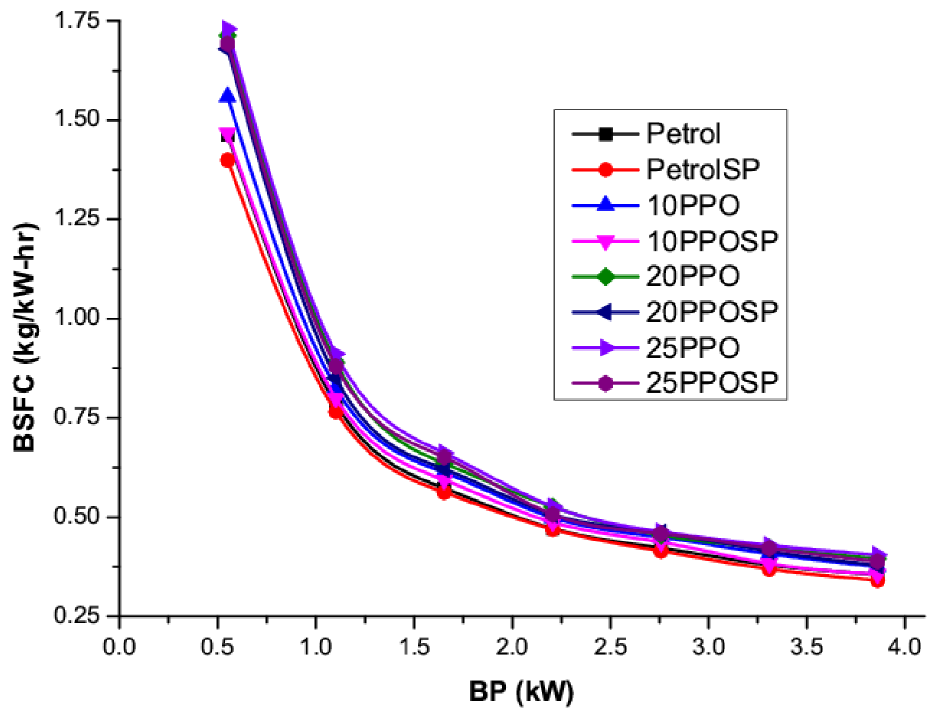


Fig. 5.6. Variation of BSFC with BP by using iridium spark plugs

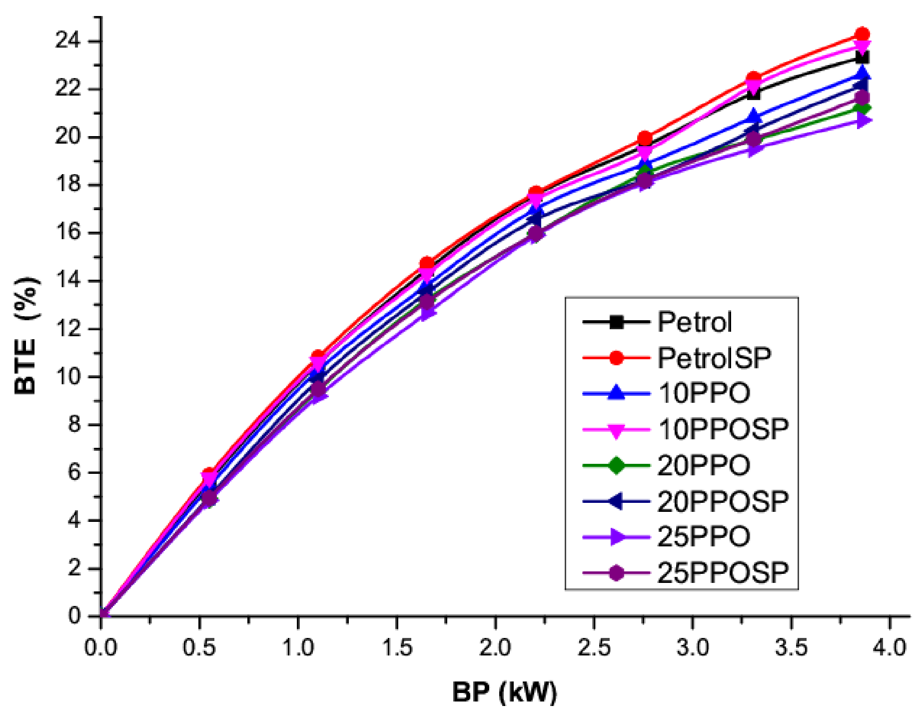


Fig. 5.7. Variation of BTE with BP by using iridium spark plugs

The effect of petrol-plastic oil blends operated in SI engine by using with and without iridium spark plugs on the BTE is as shown in Fig. 5.7. The BTE of the engine decreases with increase in the PPO blend proportion compared to petrol fuel by using with and without iridium spark plugs. The BTE of engine operated with pure petrol and 25PPO are 23.33% and 20.7% at full load by using ordinary spark plugs, whereas for pure petrol and 25PPOSP are 24.28% and 21.65% at full load by using iridium spark plugs. A marginal increment of brake thermal efficiency is noticed with iridium spark plugs compared to ordinary spark plug results at all loads conditions. Because this BTE increment majorly depends on the enhanced combustion quality by using the iridium spark plugs [86].

5.3.3. Emission Characteristics

Major constituents of engine emissions are CO, O_2, CO_2, unburned HC, NO_x and particulate matter are measured by using an AVL five gas analyser. From Fig. 5.8, it is observed that as the emissions of carbon monoxide linearly decreases with brake power but, these emissions are diminishing with iridium spark plugs compared with ordinary spark plugs. The minimum CO emissions are noticed at 25PPOSP compared to all other operated fuels at full load condition. The possible reason for this reduction is by the oxygenated characteristics of plastic oil and improved combustion quality by using iridium spark plug. The engine operating with PPO-PF inhibited oxygenation of additive, surpasses the combustion process and leads to so-called "leaning effect". Owing to that effect, CO emission will decrease substantially.

The Fig. 5.9 elucidates that PPO blends fuelled in SI engine by using iridium spark plugs would diminish the HC emission compared to use of ordinary spark plugs. Unburned hydrocarbon emissions mainly depend on the incomplete combustion of fuel air mixture. The engine exhaust HC emissions at 10PPOSP blend are 175 ppm at no load and 132 ppm at full load, for 20PPOSP blend is 155 ppm at no load and 119 ppm at full load that of 25PPOSP blend is 113 ppm at full load. The minimum HC emissions are noticed at 25PPOSP compared to all other operated fuels at full load condition. While engine operated with iridium spark plugs, continuous flame propagation is possible in the combustion chamber.

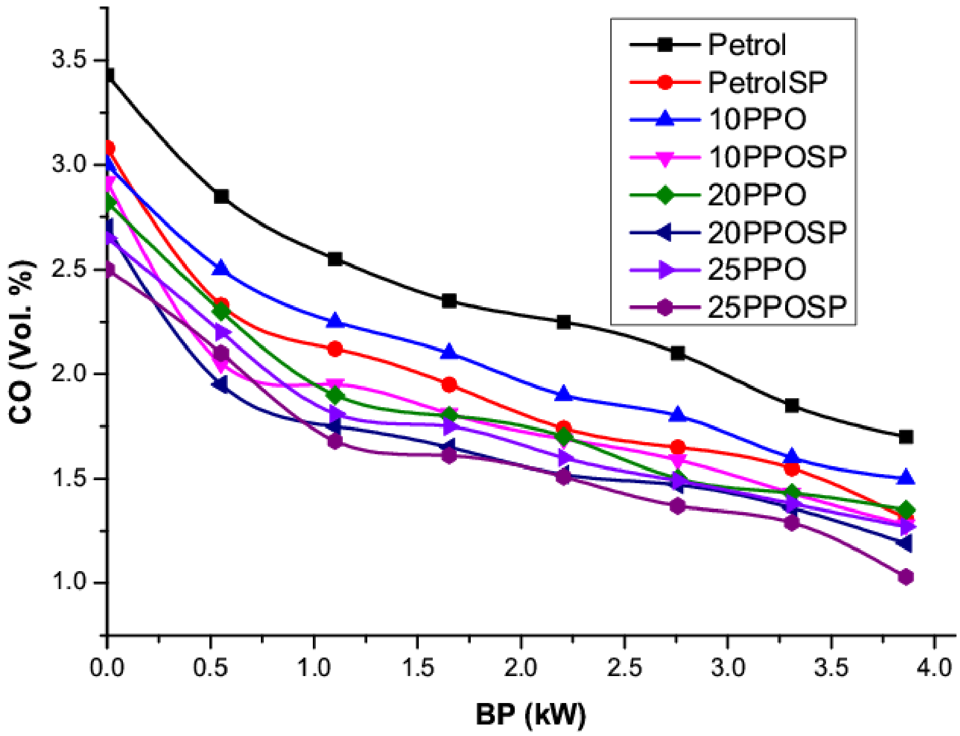


Fig. 5.8. Variation of CO emissions with BP by using iridium spark plugs

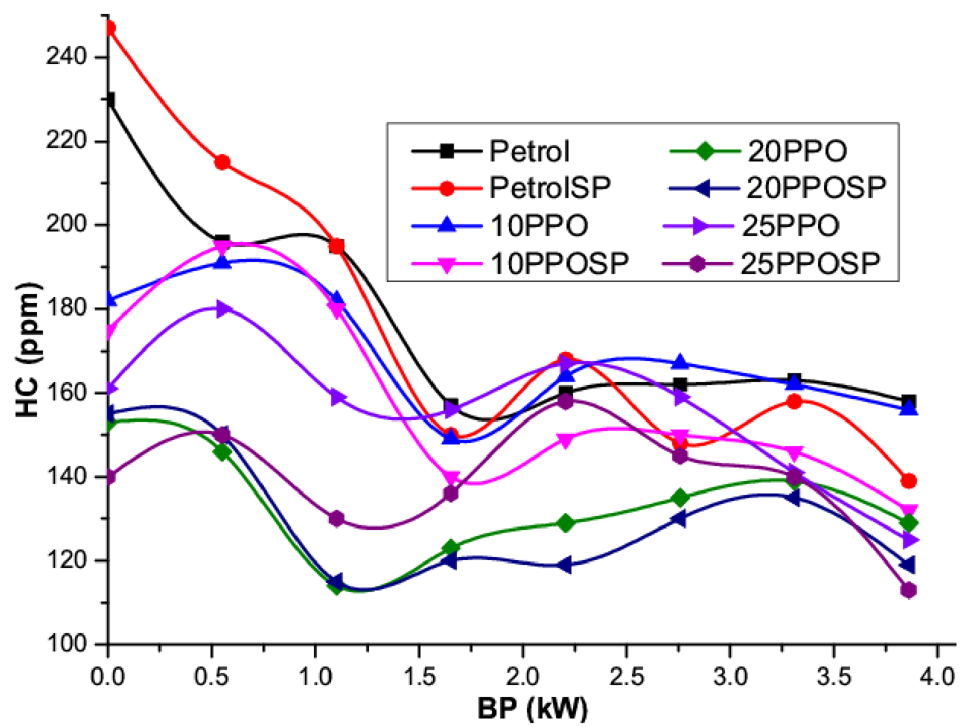


Fig. 5.9. Variation of HC emissions with BP by using iridium spark plugs

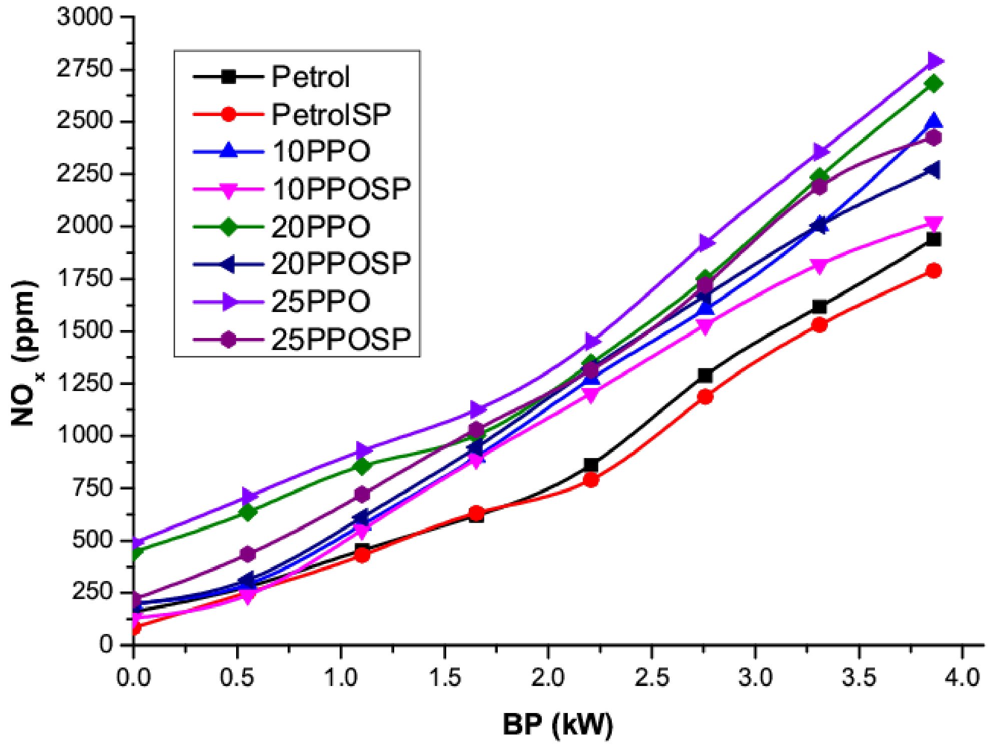


Fig. 5.10. Variation of NO_x emissions with BP by using iridium spark plugs

Formation of nitrogen oxides resulted from the reaction of oxygen and nitrogen with relatively high combustion temperatures. The Fig. 5.10 depicted that, NO_x emissions are more for the 25PPO blend compared to all other operated fuels. This is due to the availability of higher oxygen and combustion temperatures in PPO blends [87]. The engine operated with pure petrol has the NO_x of 160 ppm at no load and 1940 ppm at full load by using ordinary spark plug, whereas using iridium spark plugs NO_x emissions are observed at no load 85 ppm and at full load 1790 ppm. The NO_x emissions at 10PPOSP are 130 ppm at no load and 2020 ppm at full load that of 20PPOSP blend is 196 ppm at no load and 2270 ppm at full load, for 25PPOSP blend is 220 ppm at no load and 2425 ppm at full load. A substantial decrement of oxides of nitrogen is noticed for engine using with iridium spark plugs compared to ordinary spark plugs.

5.3.4. Summary

The following conclusions are observed from the tests conducted on SI engine by using PPO blends with and without iridium spark plugs.

- BSFC of 25PPOSP is 4.09% decreases at full load operating conditions when compared to 25PPO, but greater than the petrol.
- BTE of 25PPOSP is 4.56% increases when compared to 25PPO at full load operating conditions, but less than the petrol.
- CO emission for the 25PPOSP is lower than that of petrol and 25PPO.
- The engine exhaust HC emission at 25PPOSP blend is 9.6% decreased compared to the engine operated with 25PPO.
- The engine exhaust NO_x emission at 25PPOSP blend is 13.08% decreased compared to the engine operated with 25PPO.

From the results, it is clear that the performance and emissions are refined but the blend proportion cannot be raised beyond the 25 % of PPO.

5.4. Influence of plastic oil with addition of 5% ethanol blends.

5.4.1. Introduction

Energy consumption rate is accelerating across the world, while the conventional energy generation methods are not able to compete with requisites. Advancement in technology creates a wave of light-weight materials for common needs. Which in turn promote the polymer material usage at acclivity rate and disposable is become a technical challenge. The current research focusing on usage of the oil derived from the plastic waste as an input fuel for the transportation sector. Initially conducted the experiments using crude plastic oil at different blend proportions and noticed that the thermal efficiency is marginally reduced while the emissions are substantially increased compared to petrol. As an extension and to control the emissions alcohol additives are introduced in PPO blends. Thereby, the investigation was carried out on the multi cylinders Maruti 800 petrol engine operated at 10%, 20% and 25% of plastic pyrolysis oil with and without 5% of ethanol additive is blended in petrol fuel on a volume basis. For example, 10% of PPO and 5% of ethanol blended with 85% of PF is denoted as 10PPO5E, whereas, 10% PPO blended with 90% PF is denoted as 10PPO. A comparison of the engine performance and emission characteristics for the following amalgamations made and the results are reported.

- Petrol
- Waste Plastic Pyrolysis Oil blends
- Waste Plastic Pyrolysis Oil – 5% ethanol blends

5.4.2. Performance Characteristics

The variation of the BSFC with engine brake power for petrol, PPO with and without ethanol blends are shown in Fig. 5.11. By blending the PPO in base fuel at different proportions, BSFC is linearly increasing compared to the baseline fuel at all load conditions. Therefore, in order to modulate the BSFC, ethanol is supplemented at 5% volume. The BSFC at full load for petrol, 10PPO and 25PPO are 0.35 kg/kW-hr, 0.37 kg/kW-hr and 0.4 kg/kW-hr, whereas for 10PPO5E and 25PPO5E are 0.35 kg/kW-hr and 0.38 kg/kW-hr. Since the addition of ethanol enriches the oxygen content in the blend combustion quality should improve and reduces the BSFC. As a result, it is noticed that the fuel consumption rate is reduced with ethanol additive in plastic oil blends compared to without additive plastic oil blends at full load condition.

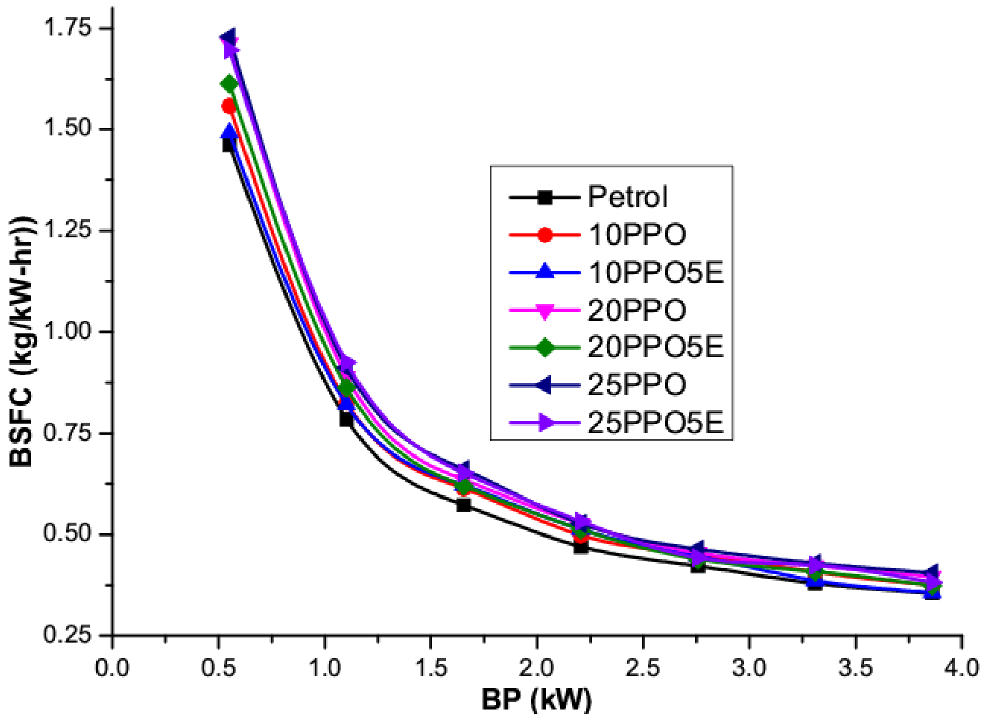


Fig. 5.11. Variation of BSFC with BP by using ethanol additive blends

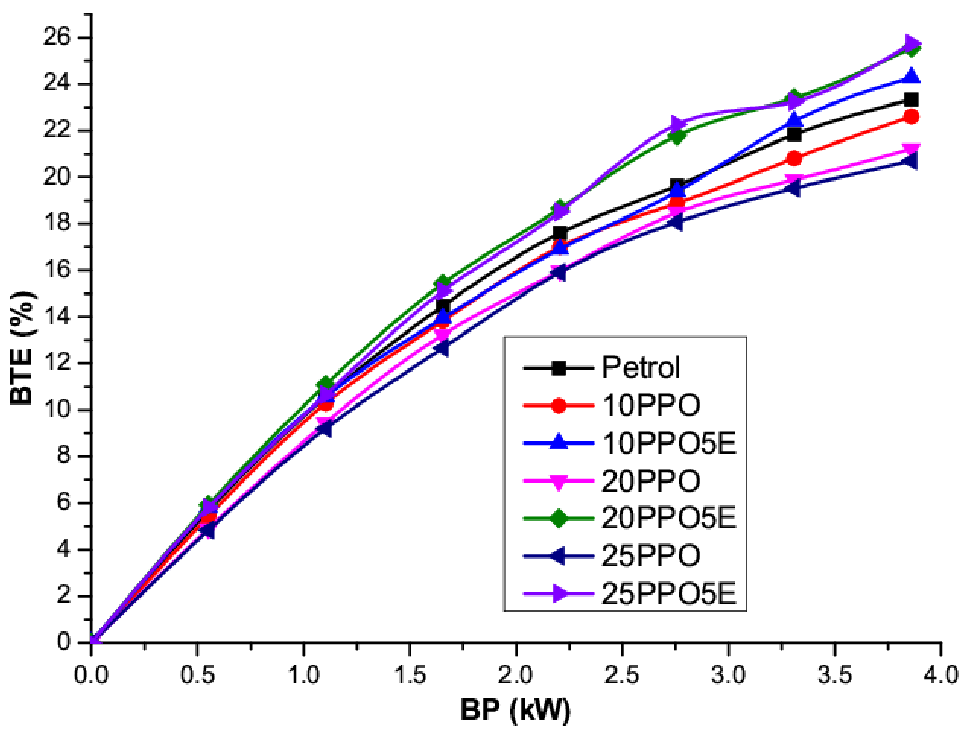


Fig. 5.12. Variation of BTE with BP by using ethanol additive blends

The variation of the BTE with engine brake power for petrol, PPO with and without ethanol blends are shown in Fig. 5.12. The BTE of petrol, PPO blends and PPO with ethanol additive blends increases with increasing engine load. The BTE for petrol varies from 5.6% at initial load and 23.33% at final load. The 10PPO5E efficiency varies from 5.81% at initial load and 24.29% at final load that of 20PPO5E varies from 5.9% at initial load and 25.5% at final load, for 25PPO5E varies from 5.8% at initial load and 25.75% at final load. A marginal increment of brake thermal efficiency is noticed with addition of ethanol additive compared to without additive plastic oil blend. From literature, the ethanol has more octane number compared to gasoline and plastic oil [84]. Because this BTE increment majorly depends on the octane number of ethanol additive, this leads to higher BTE of 25PPO5E blend compared to all other operated fuels.

5.4.3. Emission Characteristics

The effect of petrol-plastic oil blend with and without additive blends on carbon monoxide emissions is shown in Fig. 5.13. It is observed that as the emissions of carbon monoxide linearly decreases with brake power but, these emissions are diminishing in proportion with the blending compared with baseline engine. The amount of CO emissions emitted from petrol varies from 3.4 vol. % at no load and 1.7 vol. % at full load, for 10PPO varies from 3 vol. % at no load and 1.5 vol. % at full load. Whereas, 10PPO5E varies from 2.6 vol. % at no load and 1.39 vol. % at full load that of 20PPO5E varies from 2.24 vol. % at no load and 1.09 vol. % at full load, for 25PPO5E varies from 1.9 vol. % at no load and 0.9 vol. % at full load. In additive plastic oil blends, the oxygenated characteristics of ethanol causes to reduce the CO emissions compared to petrol and PPO blends [88]. The addition of ethanol in PPO blended fuel, more oxygen for the combustion process and leads to the so-called "leaning effect". Owing to the effect, CO emission will decrease tremendously [89]. The minimum CO emissions are noticed at 25PPO5E compared to all other operated fuels at full load condition.

The variation of HC emissions at different gasoline blends are as shown in Fig. 5.14. The HC emissions of 10PPO5E blend is 86 ppm at no load and 200 ppm at full load condition that of 20PPO5E blend is 110 ppm at no load and 210 ppm at full load, for 25PPO5E blend is 125 ppm at no load and 222 ppm at full load. The Fig. 5.14 elucidates that blending of PPO would diminish the emission of HC, whereas, the addition of ethanol to the blended gasoline will shoot up the emission rates. Nearly 77.6 and 40.5% increment in the HC emissions is observed for 25PPO5E operation when compared to 25PPO and petrol operation. At this point, it has to be observed that ethanol has a lower flame speed as compared to gasoline and PPO blends operation. As a result, less mass fraction of the fuel is burnt in the case of ethanol-blended gasoline. Hence, higher amounts of un-burnt fuel are left in each cycle. On account of the cooling effect and increasing quench volume of ethanol in the combustion chamber, the HC emissions were enhanced.

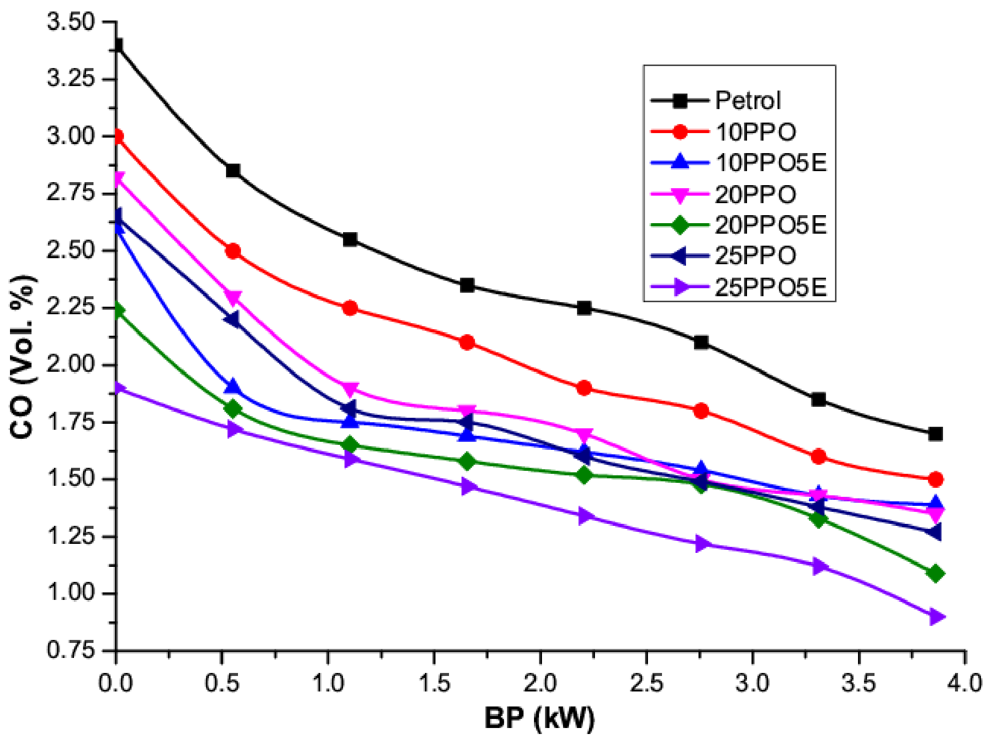


Fig. 5.13. Variation of CO emissions with BP by using ethanol additive blends

It is noticed in Fig. 5.15 that, NO_x emissions are decreased with the addition of ethanol to plastic oil and gasoline blend. The NO_x emissions at 10PPO5E blend are 2100 ppm that of 10PPO blend is 2498 ppm and for petrol fuel is 1940 ppm at full load. A substantial decrement of oxides of nitrogen is noticed for with the addition of ethanol compared to without additive to plastic oil blend [90]. This indicates that they had a lower heating value for ethanol than gasoline and PPO without additive blends resulting in a decrease in the combustion heat energy and reducing the combustion temperature in the cylinder. Due to much lower flame temperatures for ethanol combustion, its NO_x emissions are usually lower than those of gasoline and PPO without additive blends [91]. It is apparent that in any HC oxidation process that takes place during the combustion of ethanol provides leaning of mixtures that reduce the NO_x emissions.

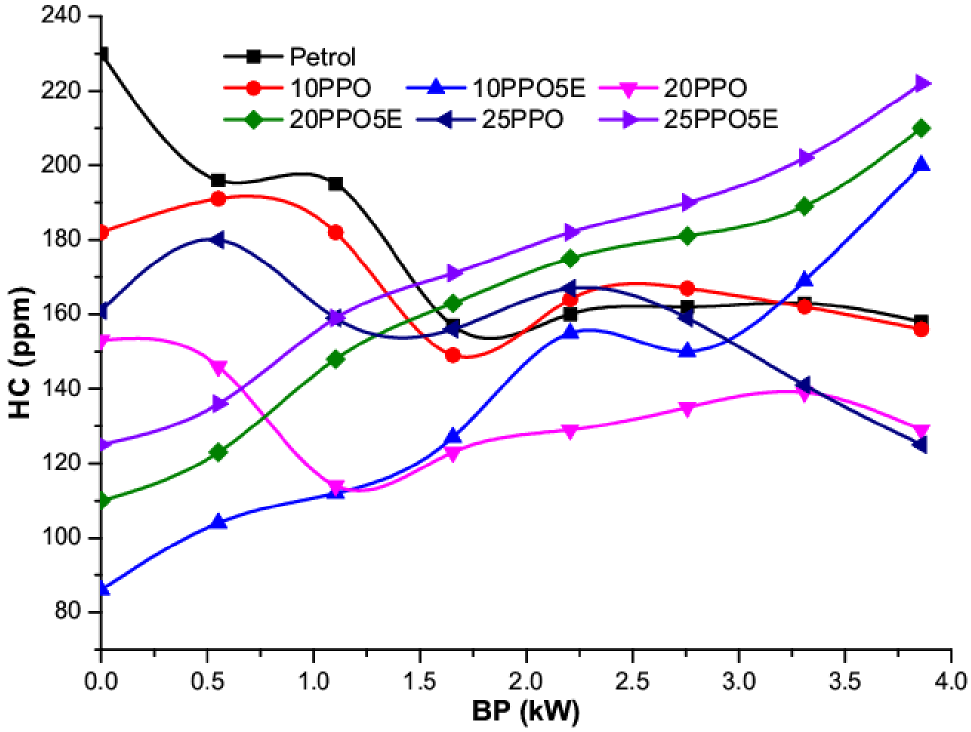


Fig. 5.14. Variation of HC emissions with BP by using ethanol additive blends

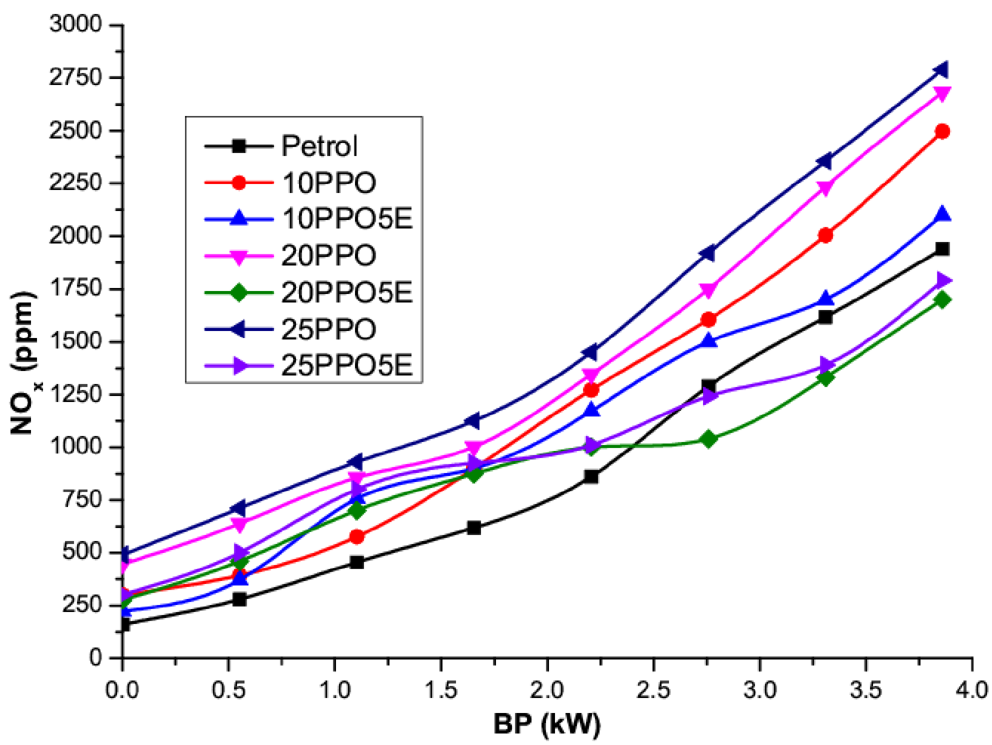


Fig. 5.15. Variation of NO_x emissions with BP by using ethanol additive blends

5.4.4. Summary

The effect of PPO-petrol blends at 10%, 20%, and 25% with and without 5% ethanol additive are experimentally investigated and reported.

- It is observed from the results, the BSFC of 25PPO5E blend 7.7% increases compared to PF and 5.5% decreases than 25PPO.
- The BTE of 25PPO5E blend is 10.35% increases compared to PF and 24.38% increases than 25PPO.
- The CO emissions of 25PPO5E blend decrease 29.1% than 25PPO and 47.05% decreases compared to PF.
- The HC emissions of 25PPO5E blend increase 40.5% compared to PF and 59.7% increase than 25PPO.
- The NO_x emissions of 25PPO5E blend decrease 35.84% compared to 25PPO and 7.7% decrease than PF.

It is noted to worthy from the experimental results that, by adding the 5% of ethanol additive in plastic oil blend the performance improved and control the NOx emissions but unable to control the HC emissions and also blend percentage limited.

5.5. Performance and emission analysis of PPO with addition of 5% methanol blends.

5.5.1. Introduction

Benign awareness of ecosystem together with accelerating energy needs is challenging the homo-sapiens and forcing to search for an alternative energy and increasing pollution ruthlessly cursing with improving civilization. Depends on alternative energy sources are inevitable to meet current technology and human needs. The new source should able to handle the waste and minimize the air pollution. In this scenario, utilizing plastic pyrolysis oil derived from the waste plastics in the internal combustion engine is a viable alternative. In this research work presents the experimental investigations on multi-cylinder petrol engine operating with 10%, 20% and 25% of plastic pyrolysis oil with and without methanol additive at 5% volume basis was blended with petrol. For example, 20% of PPO blended with 80% of PF is denoted as 20PPO, whereas, 20% PPO and 5% of methanol blended with 75% PF are denoted as 20PPO5M. The PPO blends with and without additive results are compared with the PF operation.

5.5.2. Performance Characteristics

The influence of petrol-plastic oil blended with and without methanol additive on the brake specific fuel consumption as shown in Fig. 5.16. By increasing the PPO blend proportions the fuel consumption rate is uniformly increased. Therefore, in order to modulate the BSFC methanol is supplemented at 5% volume fraction. The BSFC of 10PPO5M varies from 1.52 kg/kW-hr at no load and 0.36 kg/kW-hr at full load, for 20PPO5M varies from 1.58 kg/kW-hr at no load and 0.37 kg/kW-hr at full load, for 25PPO5M vary from 1.69 kg/kW-hr at no load and 0.38 kg/kW-hr at full load. Since the addition of additive enriches the oxygen content in the blend combustion quality should improve and reduces the BSFC [92]. The fuel consumption rate is decreased with methanol additive in plastic oil blends compared to without additive plastic oil blends at all load condition. Nearly 5.5% decrement in the BSFC is observed for 25PPO5M operation when compared to 25PPO and 7.7% increment than the petrol operation.

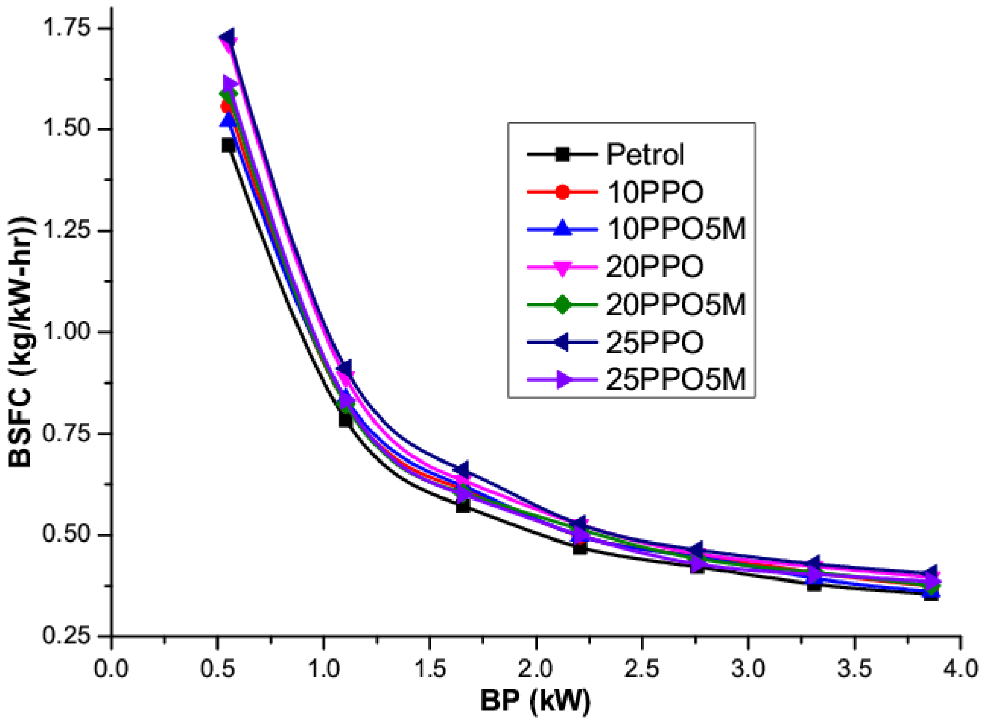


Fig. 5.16. Variation of BSFC with BP by using methanol additive blends

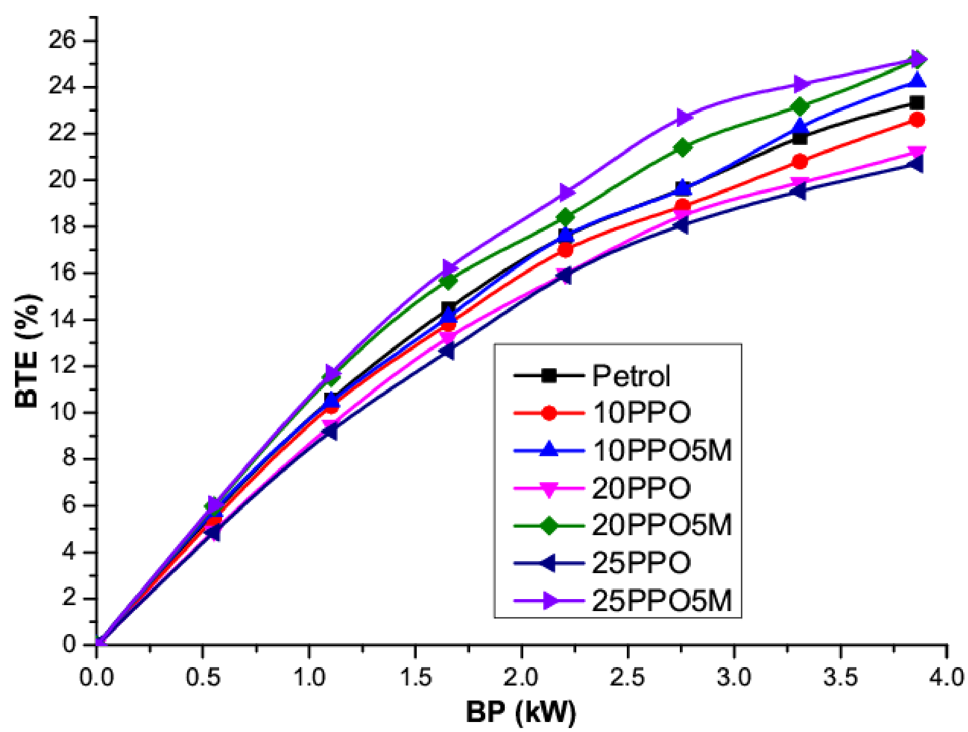


Fig. 5.17. Variation of BTE with BP by using methanol additive blends

The effect of petrol-plastic oil blended with and without methanol additive on the BTE is as shown in Fig. 5.17. The BTE of petrol, PPO blends and PPO with methanol additive blends increases with increasing engine brake power. The BTE of the engine operated with 10PPO5M varies from 5.77% at initial load and 24.24% at final load that of 20PPO5M blend varies from 5.96% at initial load and 25.18% at final load, for 25PPO5M blend vary from 6% at initial load and 25.2% at final load. A marginal increment of brake thermal efficiency is noticed with addition of methanol additive compared to without additive plastic oil blends and PF. From literature, the methanol have more octane number compared to petrol and plastic oil [93]. Because this BTE increment majorly depends on the octane number of additive, this leads to higher BTE of additive PPO blends compared to without additive PPO blends and PF. Nearly 21.74% increment in the BTE is observed for 25PPO5M operation when compared to 25PPO and 8% increment than the petrol operation.

5.5.3. Emission Characteristics

The variation of the CO emissions with engine brake power for petrol, PPO with and without methanol blends are shown in Fig. 5.18. From results, it is observed that as the emissions of carbon monoxide linearly decreases with brake power but, these emissions are diminishing in proportion with the blending compared with baseline engine. The possible reason for this reduction is by the oxygenated characteristics of methanol and plastic oil compared to petrol fuel. The amount of CO emissions emitted from 10PPO5M varies from 2.53 vol. % at no load and 1.44 vol. % at full load that of 20PPO5M varies from 2.11 vol. % at no load and 1.21 vol. % at full load, for 25PPO5M varies from 1.89 vol. % at no load and 1.06 vol. % at full load. The minimum CO emissions are noticed at 25PPO5M compared to all other operated fuels at full load condition. The engine operating with PPO-PF with additive fuels, the oxygenated characteristics of methanol causes to reduce the CO emissions compared to PF and PPO without additive blend [94].

The variation of the HC emissions with engine brake power for petrol, PPO with and without methanol blends are shown in Fig. 5.19. From the results, it is observed that PPO with and without additive blends would diminish the HC emission compared to petrol fuel operation. The engine exhaust HC emissions of 10PPO5M blend varies from 196 ppm at no load and 151 ppm at full load that of 20PPO5M blend varies from 163 ppm at no load and 118 ppm at full load, for 25PPO5M blend varies from 172 ppm at no load and 104 ppm at full load. The minimum HC emissions are noticed at 25PPO5M compared to all other operated fuels at full load condition. While, engine operated with methanol additive blend promotes the flame speed and homogenous combustion.

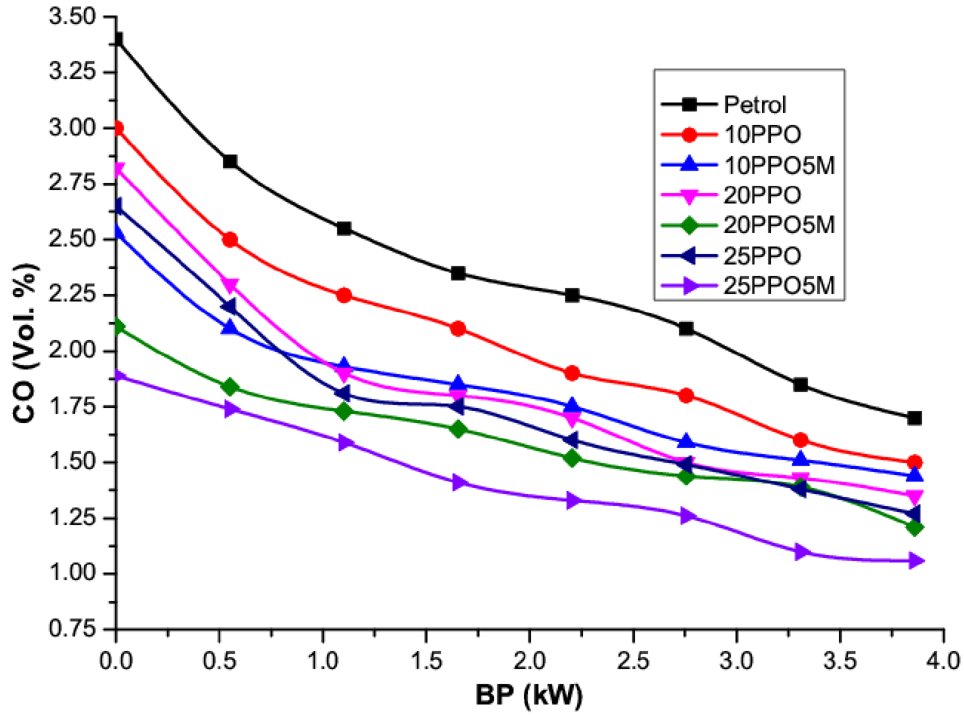


Fig. 5.18. Variation of CO emissions with BP by using methanol additive blends

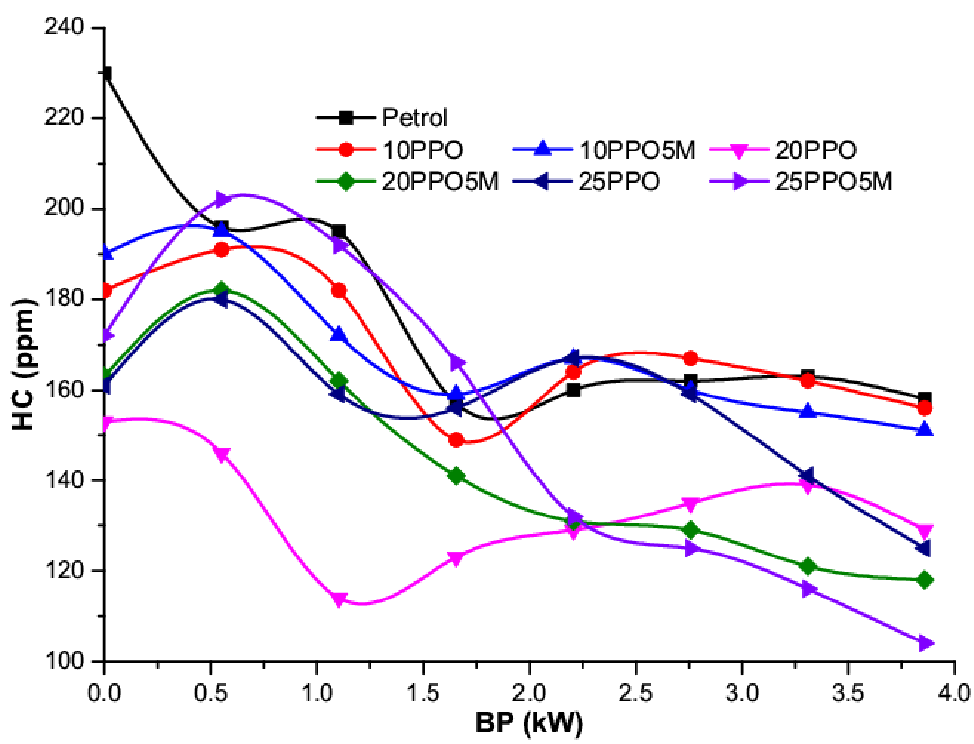


Fig. 5.19. Variation of HC emissions with BP by using methanol additive blends

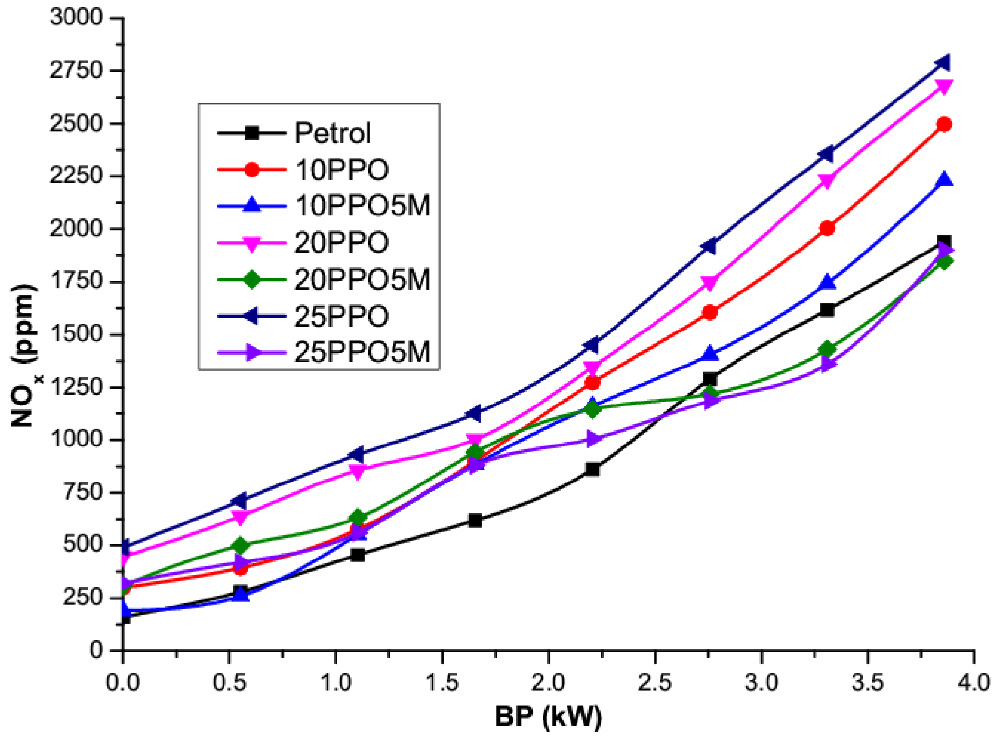


Fig. 5.20. Variation of NO_x emissions with BP by using methanol additive blends

The variation of the NO_x emissions with engine brake power for petrol, PPO with and without methanol blends are shown in Fig. 5.20. From the results, it is noticed that NO_x emissions are more for the 25PPO blend compared to all other operated fuels. This is due to availability of higher oxygen and combustion temperatures in PPO blends [95]. Therefore, in order to control the NO_x emissions methanol is supplemented at 5% volume fraction. The engine exhaust NO_x emissions of 10PPO5M varies from 222 ppm at no load and 2100 ppm at full load, for 20PPO5M blend varies from 310 ppm at no load and 1850 ppm at full load, for 25PPO5M blend varies from 320 ppm at no load and 1900 ppm at full load. A substantial decrement of oxides of nitrogen is noticed for with addition of additives compared to without additive to plastic oil blend. This indicates that they had a lower heating value for additives than PF and PPO blends resulting in decrease in the combustion heat energy and reducing the combustion temperature in the cylinder [96]. Due to much lower flame temperatures for methanol combustion, its NO_x emissions are usually lower than those of PPO blends and PF operation.

5.5.4. Summary

The effect of PPO-petrol blends with and without 5% methanol are experimentally investigated and reported. Multi cylinder petrol engine is tested with the 10PPO5M, 20PPO5M and 25PPO5M blends and results are compared with petrol and without additive plastic oil blends.

- The BSFC of 25PPO5M blend is 8.7% increases compared to PF and 4.6% decreases than 25PPO.
- The BTE of methanol additive blend is 8.01% increases compared to PF and 21.74% increases than without additive blend.
- It is observed that the CO emissions of 25PPO5M blend are 16.5% decreases than 25PPO and 37.64% decreases compared to PF.
- The HC emissions of 25PPO5M blend are 34% decrease compared to PF and 25% decreased than 25PPO.
- The NO_x emissions of 25PPO5M blend are 31.8% decrease compared to 25PPO and 2% decreased than PF.

It is note to worthy from the experimental results that, methanol additive augment the thermal performance and also able to control the HC and NO_x emissions. Therefore, methanol additive is best-suited additive for the plastic oil blended with petrol but unable to improve blend percentage.

5.6. Experimental analysis on SI engine by using distilled plastic pyrolysis oil-gasoline blends.

5.6.1. Introduction

Primarily the SI engine was run with untreated PPO blended with petrol. As a result lower thermal efficiency and higher NO_x emissions by increasing load with respect to blend proportion. This possible reason may be due to crude plastic pyrolysis oil having more viscosity compared to petrol. Viscosity affects atomization and vaporisation of fuel and volatility ensure even mixing of fuel with air and combustion process, which can potentially from engine deposits, higher emissions and higher fuel consumption. Poor air-fuel mixing is due to the deflection of spray patterns away from the optimum for a particular combustion system. It might affect the engine components in the long run due to higher viscosity. Therefore, a noteworthy alternative to increase the blend proportions and to control the rate of emissions is altering the thermo-physical properties of the plastic oil. A viable alternative to regulating the thermo-physical properties like viscosity, density and calorific value and octane number of the PPO is distillation. Experimental investigations are conducted to study the performance and emission characteristics of a three cylinder SI engine. Petrol, distilled plastic pyrolysis oil blinds at 10%, 20% and 25% on a volume basis are considered in this chapter. The DPPO blends results are compared with the PPO blends operation.

5.6.2. Performance Characteristics

Fig. 5.21 illustrates the variation of BSFC as a function of BP. From the results, it is noticed that the BSFC is varies from 1.55 kg/kW-hr at low load to 0.37 kg/kW-hr at full load for 10DPPO, and it varies from 1.43 kg/kW-hr at low load to 0.36 kg/kW-hr at full load for 25DPPO. The fuel consumption rate is increased uniformly as a function of crude PPO blending proportions. Whereas engine operated with DPPO blends, the BSFC was decreased compared to crude PPO blends and it is increased compared to PF. Nearly 8.5% decrement in the BSFC is observed for 20DPPO operation when compared to 20PPO and 1.9% increment than the petrol operation. This reduction may be due to the reduced viscosity of DPPO by distillation process compared to crude PPO, and this leads to improve the homogeneous mixing of air-fuel in carburetor [97].

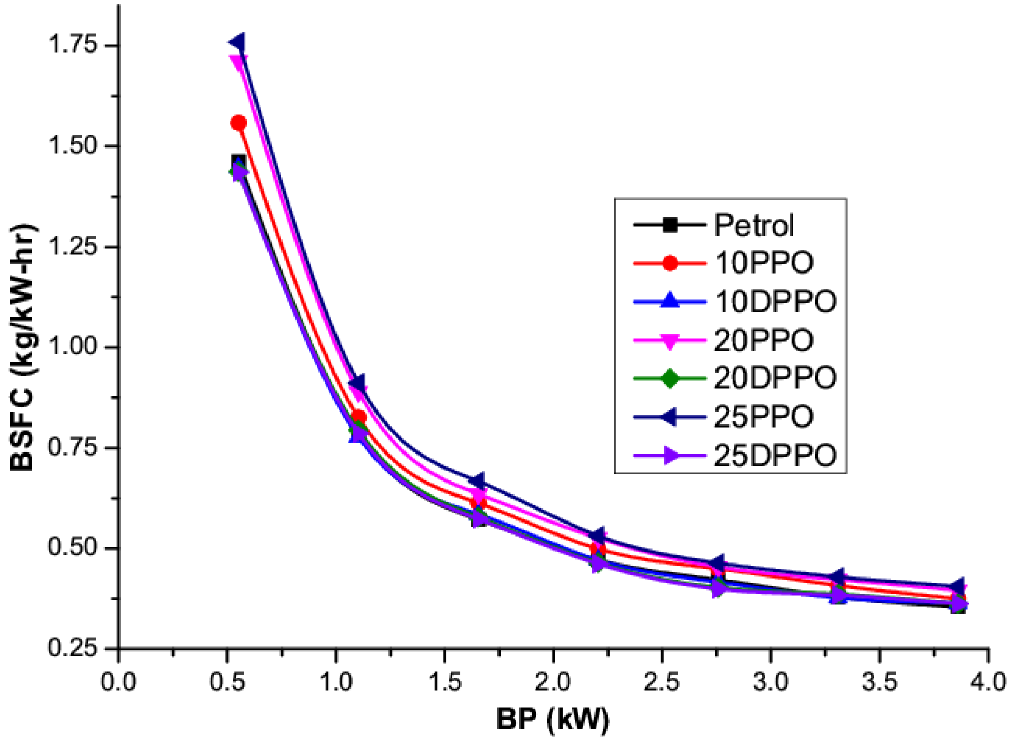


Fig. 5.21. Variation of BSFC with BP by using PPO and DPPO blends

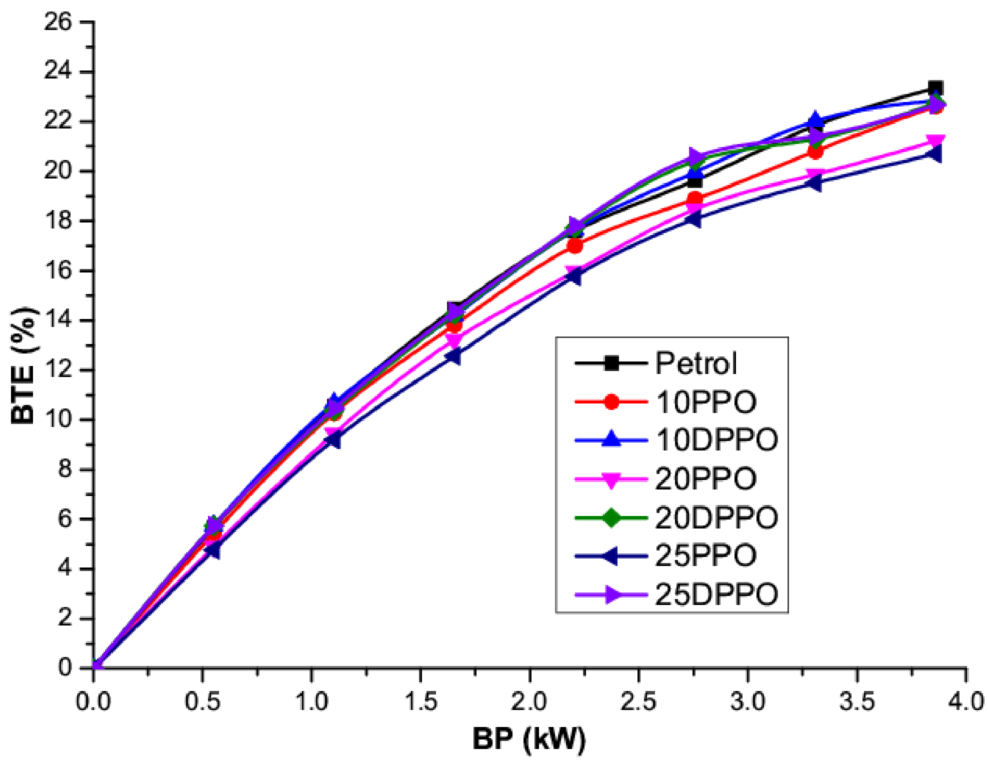


Fig. 5.22. Variation of BTE with BP by using PPO and DPPO blends

The variation of the BTE with engine brake power for petrol, PPO with and without distillation blends are shown in Fig. 5.22. The BTE of petrol, PPO with and without distillation blends increases with increasing engine load. It can be noticed that the BTE of the engine operated with 10DPPO varies from 5.75% at initial load and 22.84% at final load, for 20DPPO varies from 5.72% at initial load and 22.73% at final load. The 25DPPO efficiency varies from 5.72% at initial load and 22.66% at final load. A marginal increment of BTE is observed for DPPO-PF blends compared to PPO-PF. Nearly 9.4% increment in the BTE is observed for 25DPPO operation when compared to 25PPO and 2.9% decrement than the petrol operation. This possible reason for this augment may be due to the improved octane number of DPPO compared to PPO. This improved octane number promotes the uniform flame propagation and complete combustion [98].

5.6.3. Emission Characteristics

The effect of PPO-PF and DPPO-PF blends on carbon monoxide emissions is shown in Fig. 5.23. It is observed that, as the emissions of carbon monoxide drastically decreases with increasing load and these emissions are diminished proportionally with the blending compared with baseline engine. The amount of CO emissions emitted from 10DPPO varies from 2.96 vol. % at no load to 0.2 vol. % at full load, from 20DPPO varies from 1.65 vol. % at no load to 0.18 vol. % at full load, from 25DPPO varies from 1.51 vol. % at no load to 0.15 vol. % at full load. The minimum CO emissions are noticed at 25DPPO compared to all other operated fuels at full load condition. The oxygenated characteristics of PPO-PF and DPPO-PF fuels causes to reduce the CO emissions compared to pure gasoline. The engine operating with PPO-PF and DPPO-PF fuels, more oxygen for the combustion process and leads to the so-called "leaning effect". Owing to the effect, CO emission will decrease tremendously.

The effect of HC emissions using different gasoline blends is as shown in Fig. 5.24. It can be observed that HC emissions are 238 ppm at no load and 190 ppm at full load for 10DPPO, 276 ppm at no load and 181 ppm at full load for 20DPPO, 245 ppm at no load and 175 ppm at full load for 25DPPO. The HC emissions decrease as a function of crude PPO blending proportions compared to PF. Whereas, engine operated with DPPO-PF blends, the HC emissions increased compared to PF and PPO-PF fuels. This may be attributed due to two reasons. While running the engine, certain amount of hydrocarbons is adhering to the cylinder wall and crevice volume left unburned. Another possible one is, presence of unsaturated hydrocarbons in DPPO that are unbreakable during the process of combustion.

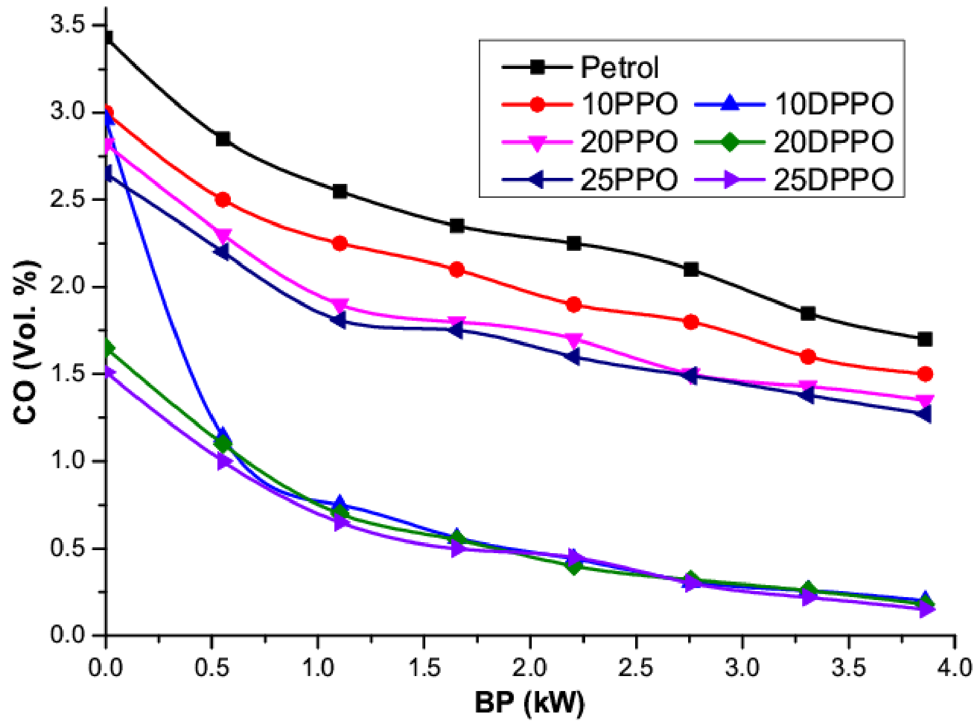


Fig. 5.23. Variation of CO emissions with BP by using PPO and DPPO blends

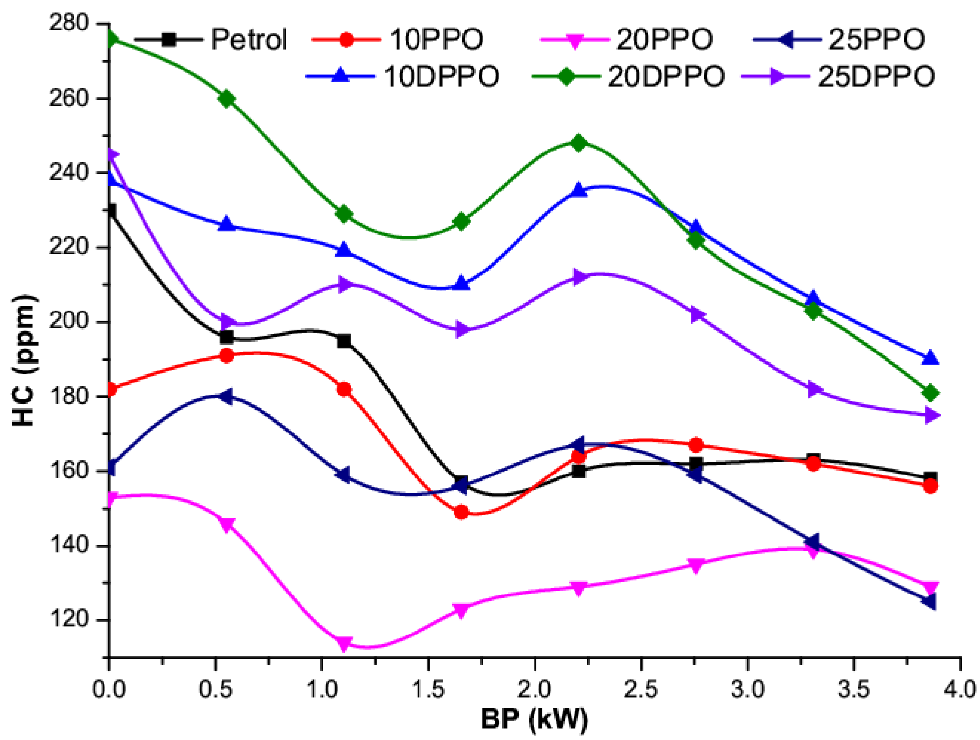


Fig. 5.24. Variation of HC emissions with BP by using PPO and DPPO blends

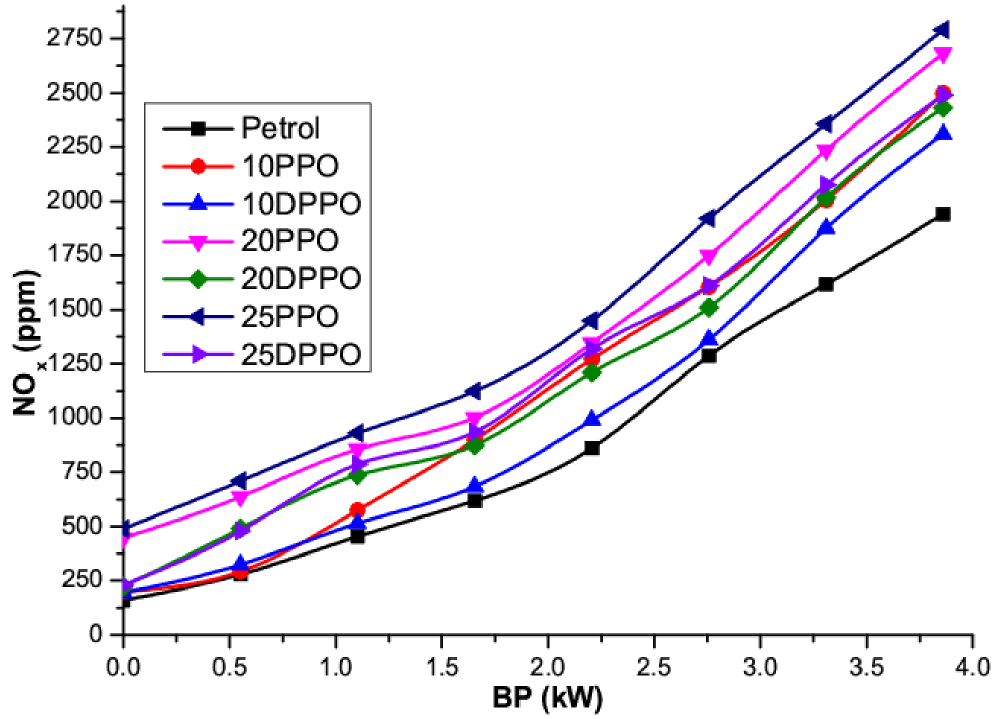


Fig. 5.25. Variation of NO_x emissions with BP by using PPO and DPPO blends

The effect of NO_x emissions using PPO-PF and DPPO-PF blends is as shown in Fig. 5.25. It can be noticed from the Fig. 5.25 that NO_x emissions are proportionally increasing with increasing load for all operating fuels. This may be due to the availability of higher oxygen and elevated in-cylinder temperatures [99]. The NO_x emissions vary from 224 ppm at lower load to 2430 ppm at full load for 20DPPO, for 20PPO it varies from 447 ppm to 2683 ppm. The higher NO_x emissions are noticed with 25PPO as compared to all other operated fuels. Therefore, in order to modulate the NO_x emissions distillation process is carried out in the present study. The NO_x emissions decreased with DPPO-PF blends compared to PPO-PF blends but it is increased than PF at full load conditions, it is may be due to the lower in-cylinder temperatures.

5.6.4. Summary

Thermal performance and consequent pollutants that liberated by the combustion of PPO-PF and DPPO-PF blends that are creating eco-imbalances are analysed and presented. Fuels are tested on multi cylinder engine test rig and exhausts are analysed with AVL exhaust five gas analyser.

- The BSFC decreases with DPPO-PF fuel blends compared to PPO-PF blends but higher than PF. Nearly 10.3% decrement in the BSFC is observed for 25DPPO operation when compared to 25PPO and 2.1% increase compared to PF.
- The BTE increases with DPPO-PF fuel blends compared to PPO-PF blends but less than PF. Nearly 9.4% increment in the BTE is observed for 25DPPO operation when compared to 25PPO but 2.9% decrement compared to PF.
- It is observed that the CO emissions drastically decrease with increase in the percentage of DPPO blends compared to PF and PPO-PF blends.
- The HC emissions of 25DPPO blend are 48% increase compared to 25PPO blend and 8.9% increase compared to PF.
- The NO_x emissions of 25DPPO blend are 10.7% decreased compared to 25PPO blend and 23.8% increase compared to PF.

The thermal performance of the PPO based petrol engine is progressively reducing with blend proportions, and NO_x emissions are proportionally increasing, whereas distillation promotes the performance and NO_x emissions are marginally controlled compared to PPO blends.

5.7. Distilled plastic pyrolysis oil is an alternate petrol fuel.

5.7.1. Introduction

Many nations in the world are frequently developing methods and materials for effective utilization of the alternative fuel resources available in their region. For the present work, plastic pyrolysis oil is purchased from GK industries Hyderabad, India. Therefore, at the initial runs no further treatment is carried out, and experiments are run at 10%, 20% and 25% of PPO blends in petrol engine. From the experimental outcomes, it is noticed that thermal efficiency of engine is diminished and emissions are increased compared to petrol fuel. Thereby, distillation is carried out on crude plastic oil to further refine the properties of fuel. in this research work aims to present the experimental studies of a three-cylinder SI engine by using distilled plastic pyrolysis oil blends from 0 to 50 percentages with 10% step size on a volume basis and pure DPPO are considered. The results were compared with petrol fuel operations. A comparison of the engine performance and emission characteristics for the following amalgamations made and the results are reported.

- Petrol
- Distilled Plastic Pyrolysis Oil – Petrol blends
- Pure Distilled Plastic Pyrolysis Oil

5.7.2. Performance Characteristics

The variation of the BSFC with engine brake power for petrol, DPPO blends, and DPPO is shown in Fig. 5.26. From the results, it is noticed that the BSFC of 20DPPO is varying from 1.436 kg/kW-hr at low load to 0.367 kg/kW-hr at full load, it varies from 1.403 kg/kW-hr to 0.366 kg/kW-hr for 50DPPO and it varies from 1.461 kg/kW-hr to 0.355 kg/kW-hr for PF. The fuel consumption rate is increased uniformly as a function of DPPO blending proportions compared to PF. Nearly 2.4%, 1.95%, 1.5% and 1.1% increment in the BSFC is observed for 10DPPO, 30DPPO, 40DPPO and 50DPPO respectively operations when compared to petrol operation. This reason may be due to the engine will consume more fuel with DPPO-PF blends than PF, to gain the same power output owing to the heating value of DPPO-PF blends [100]. In figure 5.26, since the points are overcrowded and lines are overlapped the detailed data are incorporated in appendix-K.

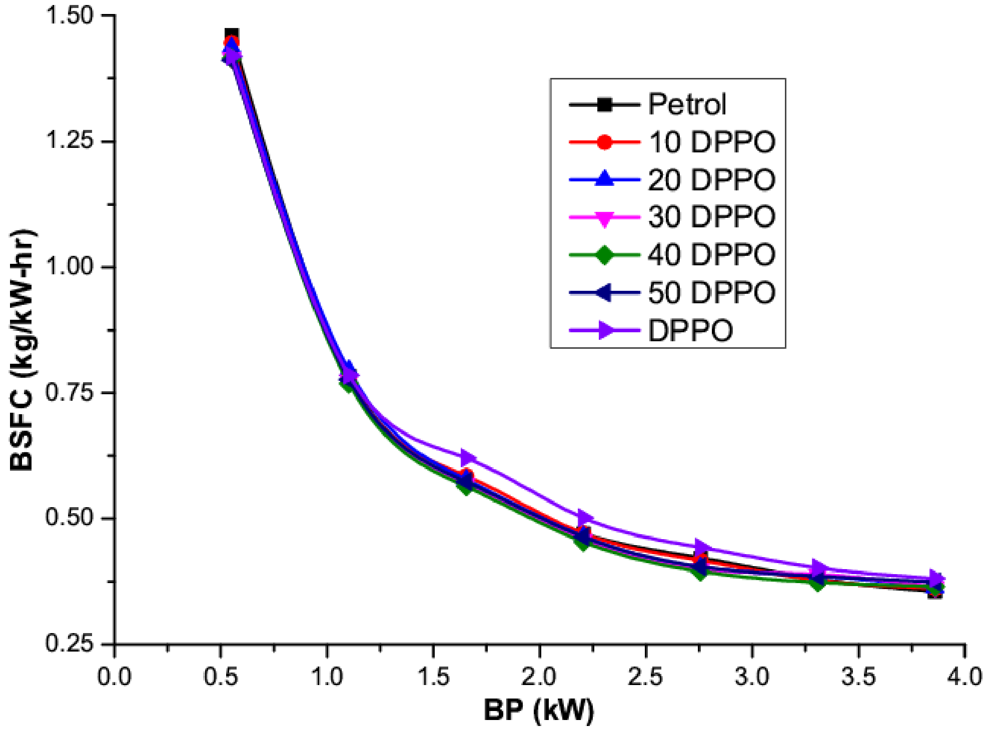


Fig. 5.26. Variation of BSFC with BP by using pure distilled plastic oil

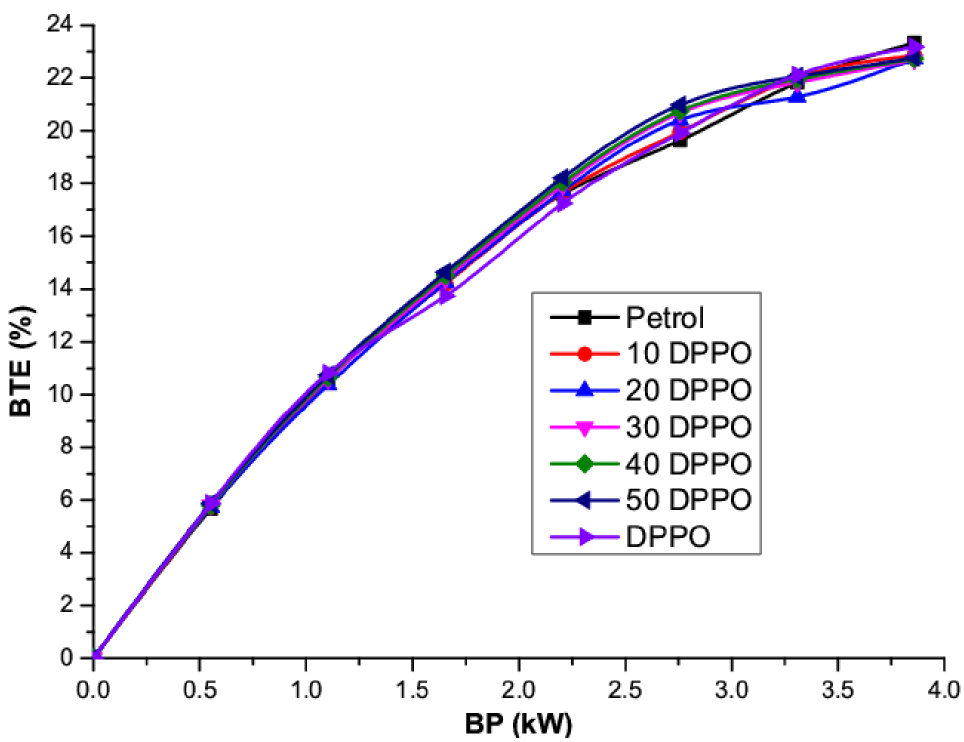


Fig. 5.27. Variation of BTE with BP by using pure distilled plastic oil

Engine brake thermal efficiency is defined as how efficiently the fuel is burnt inside the combustion chamber and gets converted into needful work output. Fig. 5.27 elucidates the influence of the BP on the brake thermal efficiency. It can be noticed that the BTE of the engine operated with 10DPPO, 30DPPO, 50DPPO, DPPO and petrol are 22.28%, 22.57%, 22.31%, 23.17% and 23.33% respectively at full load conditions. The Fig. 5.27 describes the comparison of brake thermal efficiency among different blends and petrol. It is noted to worthy that, even up to 40 % of the blend, the performance of DPPO blends is giving a nearby base fuel performance. Therefore, by using 40 % DPPO in SI engine leads to cost-effective and also had technical feasibility. The possible reason for the marginal deviation of BTE between petrol and blended fuel is, may be due to the inferior combustion of DPPO-PF blends compared to PF. In figure 5.27, since the points are overcrowded and lines are overlapped the detailed data are incorporated in appendix-L.

5.7.3. Emission Characteristics

The effect of DPPO-PF blends on Carbon Monoxide (CO) emissions is as shown in Fig. 5.28. It is observed that as the emissions of carbon monoxide drastically decrease with increasing load and these emissions are diminished proportionally with the blending compared with the baseline engine. It can be observed that the CO emissions of the engine operated with 10DPPO blend are 88% decreased, that of 30DPPO is 91% decreased and for 50DPPO blend is 93% decreased compared to PF operation at full load conditions. The oxygenated characteristics of DPPO-PF blends causes to reduce the CO emissions compared to pure gasoline. The engine operating with DPPO-PF fuels, more oxygen for the combustion process and leads to the so-called “leaning effect”. Owing to the effect, CO emission will decrease tremendously.

The effect of different gasoline blends on HC emissions is as shown in Fig. 5.29. It can be observed that HC emissions vary from 192 ppm at low load to 165 ppm at full load for 30DPPO, it varies from 185 ppm to 160 ppm for 40DPPO, it varies from 180 ppm to 158 ppm for 50DPPO and it varies from 230 ppm to 158 ppm for PF operation. The engine operated with DPPO-PF blends, the HC emissions increased compared to PF. This may be attributed due to two reasons. While running the engine, a certain amount of hydrocarbons is adhering to the cylinder wall and crevice volume left unburned. Another possible one is the presence of unsaturated hydrocarbons in DPPO that are unbreakable during the process of combustion.

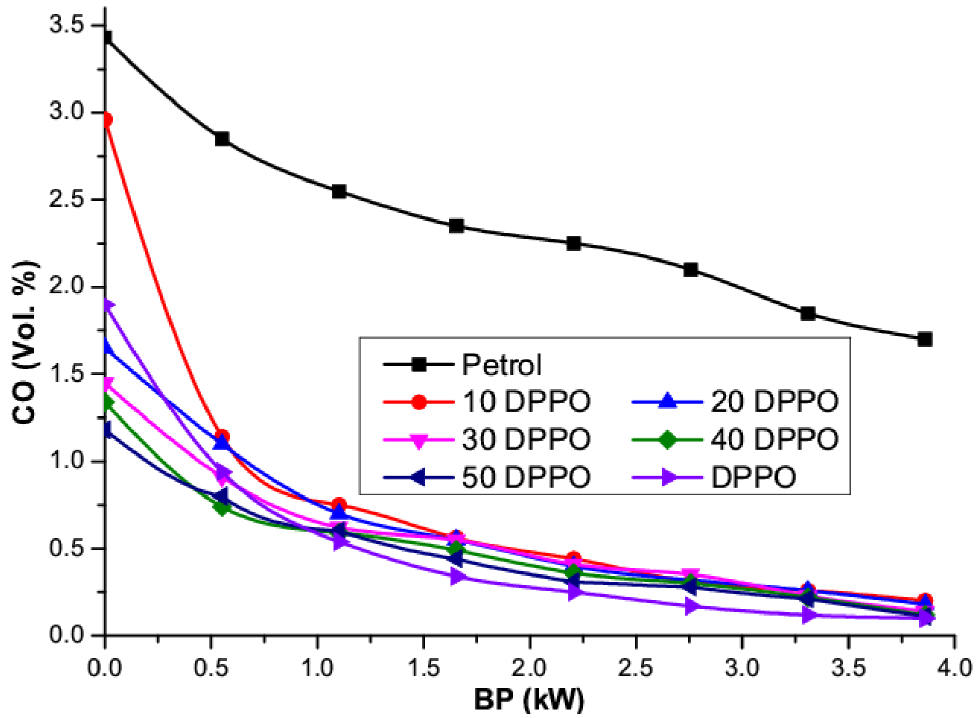


Fig. 5.28. Variation of CO emissions with BP by using pure distilled plastic oil

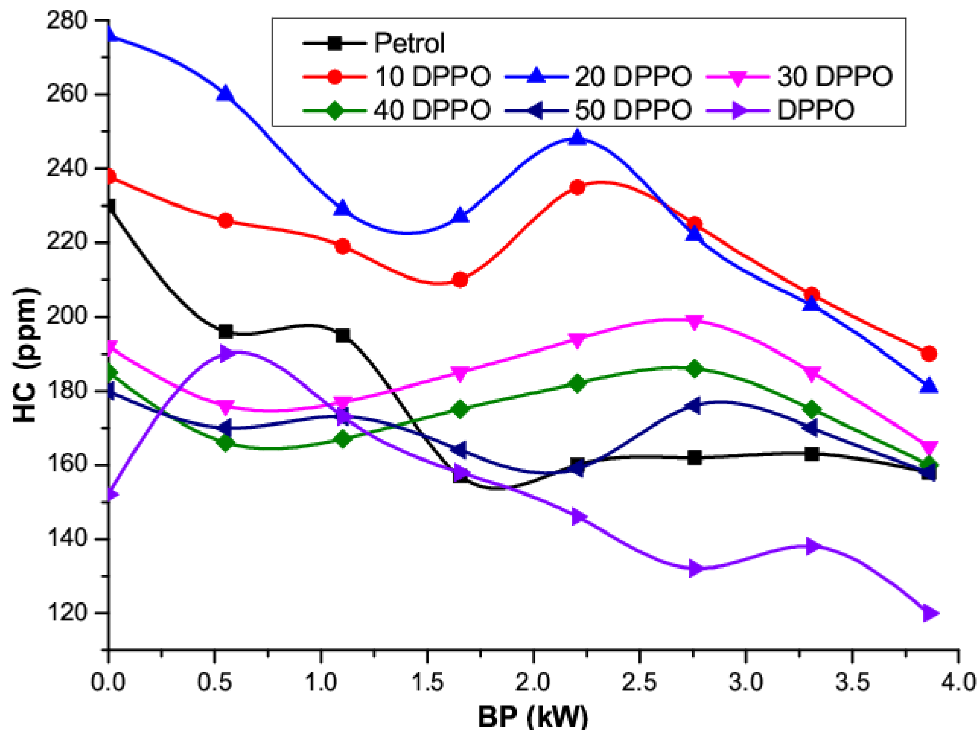


Fig. 5.29 Variation of HC emissions with BP by using pure distilled plastic oil

The effect of DPPO-PF blend on NO_x emissions is as shown in Fig. 5.30. It can be noticed from the Fig. 5.30 that the NO_x emissions are proportionally increasing with increasing load for all operating fuels. The engine exhaust NO_x emissions of 30DPPO blend varies from 245 ppm at no load and 2550 ppm at full load, it varies from 321 ppm to 2800 ppm for 50 DPPO, whereas, for DPPO NO_x emissions varies from 328 ppm to 3357 ppm. From the results, it is noticed that NO_x emissions are more for the DPPO compared to all other operated fuels. This is due to availability of higher oxygen and combustion temperatures in DPPO. It can be also observed that the NO_x emissions of the engine operated with 10DPPO blend 19% increased, that of 30DPPO 31% increased and for 50DPPO blend is 44% increase compared to PF at full load conditions. The NO_x emissions are increases with increasing blend proportions compared to petrol fuel operation.

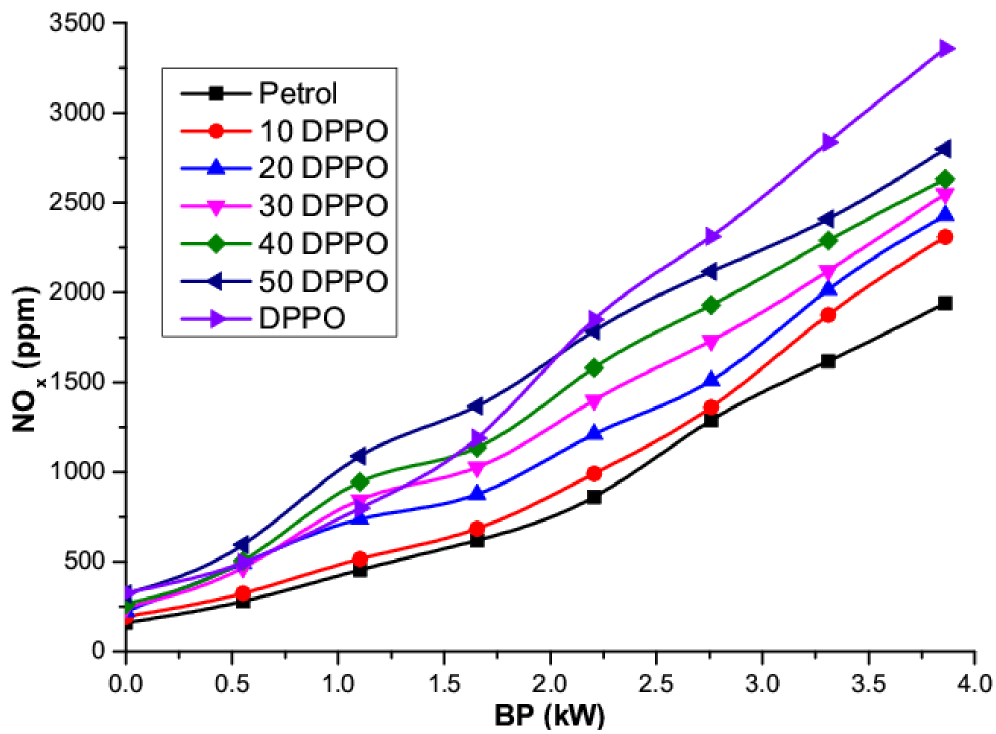


Fig. 5.30. Variation of NO_x emissions with BP by using pure distilled plastic oil

5.7.4. Summary

Thermal performance and consequent pollutants that liberated by the combustion of DPPO-PF blends that are creating eco-imbalances are analysed and presented. Fuels are tested on multi cylinder engine test rig and exhausts are analysed with AVL exhaust five gas analyser.

- The BSFC increases with increase in DPPO blend, proportions compared to PF. Nearly 3.2% increment in the BSFC is observing for 50DPPO operation when compared to PF at full load.

- The BTE increases with increase in DPPO blend, proportions but less than PF. Nearly 2.4% and 0.67% decrement in the BTE is observed at full load for 50DPPO and DPPO operation when compared to PF.

- It is observed that the CO emissions are drastically decreased with increase in percentage of DPPO blends compared to PF. Nearly 93% decrement in the CO emissions is noticed with 50DPPO operation when compared to PF at full load.

- The HC emissions decrease with increase in DPPO blend proportions. The HC emissions of DPPO blend are 24% decrease compared to PF at full load.

- The NO_x emissions increases with increase in DPPO blend proportions compared to PF. The NO_x emissions of 50DPPO blend and DPPO are 44.3% and 73% increases at full load condition compared to PF.

From the experimental studies, it is noticed that the engine can run pure DPPO, but the 100% blend percentage causes for higher NO_x emissions and lower thermal performance compared to PF. Therefore, the experiment is restricted to 50 % DPPO alone.

Chapter 6

Conclusions

The engine performance, exhaust emission characteristics of waste plastic pyrolysis oil blends are experimentally estimated and presented. In order to improve the combustion, a new category of iridium spark plugs are introduced. In further investigations, alcohol additives are added to crude plastic pyrolysis oil blends in view of control the emissions. Nevertheless, the preceding techniques are not able to raise the blend percentage in petrol. Therefore, distillation was carried out as advancement to the earlier research, which improves blend percentage as well as the performance. All the experimental investigations are carried out on Maruti 800 petrol engine. The following broad conclusions have been drawn based on the experimental results.

Influence of crude plastic oil blends operated on SI engine.

- By blending the PPO in the base fuel at 10%, 20%, and 25%, BTE is decreasing and NO_x emissions are increasing compared to baseline fuel at all load conditions. The experimental results observed that the engine can run safely up to 25 percent of plastic oil blend without altering the engine design.

Influence of waste plastic pyrolysis oil blends by changing iridium spark plugs.

- As an extension of trails in view of improving the engine performance, strong spark is initiated to ignite fuel using iridium spark plugs are introduced. Engine performance and emissions are superior compared to normal spark plugs. However, the blend proportion was not able to increase in this case.

The effect of waste plastic pyrolysis oil blends with addition of ethanol additive.

- By addition of ethanol in PPO blends, BTE is increasing and NOx emissions are controlled compared to without additive blend but unable to control the HC emissions.

Performance and emission analysis of waste plastic pyrolysis oil blends with addition of methanol.

- The addition of methanol improves the thermal performance and controls the engine emissions compared to without additive blend.

- Therefore, methanol additive is the best-suited additive in the plastic oil blended with petrol to use in SI engine.

Experimental analysis on SI engine by using distilled plastic pyrolysis oil-gasoline blends.

- The thermal performance of the PPO based petrol engine is progressively reducing with blend proportions, and NO_x emissions are proportionally increasing, whereas distillation promotes the performance and NO_x emissions are marginally controlled compared to PPO blends.

Distilled plastic pyrolysis oil is an alternate petrol fuel.

- The crude plastic oil purchased from the vendor is processed in view of refining its thermos-physical properties, such that they suit to run in SI engine. Distillation is carried out on crude plastic oil and then thermos-physical properties are measured and compared with the conventional fuel.
- SI engine can operate with 100% DPPO fuel without any alterations in engine design. However, Engine performance is closer to the petrol fuel while the NOx emissions are drastically increased.

6.1. Scope for future work

- By processing the Distilled Plastic Pyrolysis Oil from Hydrodynamic Cavitation the yield is improved. However, further experimental studies have to be carried out to test its performance.
- Emission analysis has to be conducted. In view of controlling the emissions, experimental studies may step forward with additives as well.

Appendix-A

Maruti 800 petrol engine specifications

Engine make and model	Maruti 800
Number of cylinders	Three in-line
Orientation	Vertical
Arrangement of valves	Overhead
Fuel type	Gasoline
Cooling Medium	Water cooled
Ignition	Spark Ignition
Fuel delivery	Carburetor type
Bore	68.55 mm
Stroke	72 mm
Cubic capacity	796 cc

Appendix-B

Basic properties of alternate fuel samples

S. No.	Characteristics	Petrol	PPO	DPPO	Ethanol	Methanol
1	Specific Gravity	0.74	0.83	0.795	0.78	0.7915
2	Kinematic Viscosity mm^2/sec	0.5	2.54	0.78	1.19	0.751
3	Calorific Value (MJ/kg)	43.4	42.8	44.41	26.9	23
4	Density (kg/m^3)	741	830	790	785	792
5	Octane Number	85	76	84	108	111
6	Carbon Content (wt.%)	85	81.93	-	52	37.5
7	Hydrogen Content (wt.%)	15	14.02	-	13	12.5
8	Nitrogen Content (wt.%)	-	1.35	-	-	-
9	Sulphur Content (wt.%)	-	0.30	-	-	-

Appendix-C

Properties of PPO blends

S. No.	Characteristics	10PPO	20PPO	25PPO
1	Specific Gravity	0.76	0.77	0.78
2	Kinematic Viscosity mm^2/sec	0.67	0.84	0.93
3	Calorific Value (MJ/kg)	42.44	42.86	42.95
4	Density (kg/m^3)	763.9	776.6	781.3

Appendix-D

Properties of Ethanol-PPO blends

S. No.	Characteristics	10PPO5E	20PPO5E	25PPO5E
1	Specific Gravity	0.75	0.76	0.77
2	Kinematic Viscosity mm^2/sec	0.7	0.87	0.96
3	Calorific Value (MJ/kg)	41.52	37.67	36.55
4	Density (kg/m^3)	753.8	766.12	779.2

Appendix-E

Properties of Methanol-PPO blends

S. No.	Characteristics	10PPO5M	20PPO5M	25PPO5M
1	Specific Gravity	0.75	0.76	0.77
2	Kinematic Viscosity mm^2/sec	0.68	0.86	0.94
3	Calorific Value (MJ/kg)	41.03	37.99	36.99
4	Density (kg/m^3)	756.8	766.38	778.18

Appendix-F

Properties of DPPO blends

S. No.	Characteristics	10DPPO	20DPPO	25DPPO	30DPPO	40DPPO	50DPPO
1	Specific Gravity	0.75	0.75	0.75	0.76	0.76	0.77
2	Kinematic Viscosity mm^2/sec	0.52	0.55	0.57	0.58	0.61	0.64
3	Calorific Value (MJ/kg)	43.3	43.74	43.78	43.83	43.93	44.02
4	Density (kg/m^3)	753	757	758.5	760.8	765.2	774

Appendix-G

Properties of Fuel Samples after HDC with and without filtration

S. No.	Fuels		Specific Gravity	Kinematic Viscosity (cSt)	Density (kg/m3)	Distillation % (for 100 ml)
1	Petrol		0.72	0.5	720	-
2	Crude	PPO	0.82	2.54	820	42
		DPPO	0.77699	0.78714	776.99	-
3	Only Cloth Filter	PPO	0.8085	2.33741	808.5	42
		DPPO	0.7739	0.776814	773.9	-
4	Cloth & Coil Filter	PPO	0.8047	2.33189	804.7	42
		DPPO	0.7738	0.77523	773.8	-
5	After Hydrodynamic Cavitation	PPO	0.79509	2	795.09	49
		DPPO	0.7734	0.7328	773.43	-
6	After HDC with Micro Filter	PPO	0.7939	-	793.9	44
		DPPO	0.77222	-	772.22	-
7	After HDC with Nano Filter	PPO	0.79853	-	798.53	-

Appendix-H

Uncertainty and Error Analysis

Uncertainty and errors in the experiments can arise from instrument calibration, condition, observation, environment, test planning and reading. Uncertainty analysis is required to prove the accuracy of the experiments. The uncertainty percentage of several parameters like BP, BSFC, BTE and emissions were calculated using the uncertainty percentage of several instruments given in following table. An uncertainty analysis was performed using Eq. 1. The total uncertainty percentage is calculated as ± 2.3%.

$$Total\ Uncertainty\ \% = \sqrt{\left\{\left(\frac{\Delta BP}{BP}\right)^2 + \left(\frac{\Delta BSFC}{BSFC}\right)^2 + \left(\frac{\Delta BTE}{BTE}\right)^2 + \left(\frac{\Delta CO}{CO}\right)^2 + \left(\frac{\Delta HC}{HC}\right)^2 + \left(\frac{\Delta NOx}{NOx}\right)^2\right\}} \ldots .(Eq.\ 1)$$

List of instruments used and its uncertainties

Instruments	Range	Measurement techniques	Accuracy	Uncertainties %
Load	0-7 kg	Stain gauge type	±0.1 kg	±1.4%
Tachometer (speed)	1000-4000 rpm	Mechanical Type	±1%	±0.15%
Burette	0-50 cc		±0.1 cc	±1%
AVL Exhaust Five Gas Analyser	CO 0-10%	NDIR	±0.02%	±0.2%
	NO_x 0-5,000	Electro Chemical Sensor	±10 ppm	±0.2%
	HC 0-10,000	Electro Chemical Sensor	±20 ppm	±0.2%

Appendix-I

Economic Analysis

Fuel selection depends on the amalgamation of technical and economic feasibility. Use of plastic oil in IC engines has been controlling the plastic waste. However, by adding the alcohol additives to this PPO blends will also control the exhaust emissions. The blending of PPO in petrol fuel with methanol additive should be economically and environmentally feasible. The cost of different fuels per liter (in Indian currency) is presented in Table 1.

Table 1. Cost of fuels considered for the current research

S. No.	Fuels	Qty/ Lit	Cost (Rs.)	Address
1	Plastic Oil	1	50	G K Industries, Hyderabad
2	Ethanol	1	1100	Tharanath Scientific Chemicals Co.., Warangal
3	Methanol	1	300	
4	Petrol	1	75	-
5	Distilled Plastic Oil	1	100	-

Appendix-J

CHNS analysis report of crude PPO

सेवा रिपोर्ट फार्म
SERVICE REPORT FORM

आई आई सी टी
क्यू ए एफ - एस आर एफ
IICT / QAF - SRF

TÜV CERT EN ISO 9001:2008

भारतीय रासायनिक प्रौद्योगिकी संस्थान
Indian Institute of Chemical Technology
(वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद)
(Council of Scientific and Industrial Research)
हैदराबाद / Hyderabad - 500 607. (A.P) भारत / India.

पीएबीएक्स सं / PABX No : +91-40-27191234
टेलीफैक्स / ISO Telefax : +91-40-27193237
ई-मेल / E-Mail : harsha@iict.res.in

सेवा में / To,

Mr. Vijaya Kumar
Research Scholar
Mechanical Engineering
NIT Warangal.

सेवा पंजीकरण सं
Service Registration No. 26191

सेवा रिपोर्ट सं
Service Report No. 27867

दिनांक / Date : 23.11.2016

Sample Name	N (%/wt)	C (%/wt)	H (%/wt)	S (%/wt)
Plastic pyrolysis oil	1.35	81.93	14.02	0.30

NF = Not Found

दिनांक सहित विश्लेषक के हस्ताक्षर
Analyst Signature with Date
23/11/2016

आई आई सी टी के तकनीकी प्रबंधक/एम आर के दिनांक सहित हस्ताक्षर
Technical Manager / MR IICT Signature with Date
23/11/16

Appendix-K

Variation of BSFC with BP by using pure distilled plastic oil data

BP (kW)	Petrol	10 DPPO	20 DPPO	30 DPPO	40 DPPO	50 DPPO	DPPO
0.55147	1.46149	1.44576	1.43654	1.41496	1.41508	1.41127	1.41959
1.10294	0.78462	0.77778	0.79448	0.77602	0.7685	0.7766	0.78562
1.65441	0.57263	0.58519	0.57798	0.57086	0.56443	0.57351	0.62067
2.20588	0.47077	0.47084	0.46445	0.45816	0.45411	0.4638	0.50174
2.75735	0.42207	0.41657	0.4034	0.39932	0.39488	0.40466	0.44269
3.30882	0.37953	0.37754	0.38667	0.38925	0.37334	0.38569	0.40216
3.86029	0.35504	0.36185	0.36303	0.36409	0.36511	0.37404	0.38097

Appendix-L

Variation of BTE with BP by using pure distilled plastic oil data

BP (kW)	Petrol	10 DPPO	20 DPPO	30 DPPO	40 DPPO	50 DPPO	DPPO
0	0	0	0	0	0	0	0
0.55147	5.66917	5.7502	5.72935	5.80393	5.79069	5.85583	5.85702
1.10294	10.5599	10.6886	10.3595	10.5827	10.6627	10.7357	10.8082
1.65441	14.4691	14.2064	14.2401	14.3858	14.5177	14.6396	13.7288
2.20588	17.5998	17.6565	17.721	17.9244	18.0446	18.2182	17.2431
2.75735	19.6306	19.9566	20.4025	20.6693	20.7513	20.9834	19.9139
3.30882	21.8305	22.0199	21.2852	21.8268	21.9488	22.057	22.1161
3.86029	23.33666	22.8486	22.73418	22.68659	22.73623	22.77268	23.17816

References

[1] V. A. Soloiu, Y. Yoshihara, M. Hiraoka, K. Nishiwaki, Y. Mitsuhara, and Y. Nakanishi, "The investigation of a new diesel fuel produced from waste plastics," *ISME TOKYO 2000*, 2000.

[2] S. H. Hamid, M. B. Amin, and A. G. Maadhah, *Handbook of Polymer Degradation*. New York: Marcel Dekker, 1992.

[3] J. Saleem, M. Adil, and G. Mckay, "Oil sorbents from plastic wastes and polymers : A review," *J. Hazard. Mater.*, vol. 341, pp. 424–437, 2018.

[4] G. Lei and T. Ozbakkaloglu, "Use of recycled plastics in concrete : A critical review," *Waste Manag.*, vol. 51, pp. 19–42, 2016.

[5] M. S. Al-Salem, P. Lettieri, and J. Baeyens, "Recycling and recovery routes of plastic solid waste (PSW): A review," *Waste Manag.*, vol. 29, pp. 2625–2643, 2009.

[6] P. T. Williams and E. A. Williams, "Interaction of Plastics in Mixed-Plastics Pyrolysis," *Energy and Fuels*, vol. 13, no. 1, pp. 188–196, 1999.

[7] S. Mehdi and G.-R. Bakhshandeh, "Recycling of PVC wastes," *Polym. Degrad. Stab.*, vol. 96, pp. 404–415, 2011.

[8] L. Fangbing, D. Yao, Y. Wang, C. Wang, and P. Zhu, "Recycling of waste nylon 6 / spandex blended fabrics by melt processing," *Compos. Part B*, vol. 77, pp. 232–237, 2015.

[9] B. Han, Y. Chen, Y. Wu, and D. Hua, "Co-pyrolysis behaviors and kinetics of plastics – biomass blends through thermogravimetric analysis," *J Therm Anal Calorim*, vol. 115, pp. 227–235, 2014.

[10] S. Dayana, A. Sharuddin, F. Abnisa, W. Mohd, and A. Wan, "A review on pyrolysis of plastic wastes," *Energy Convers. Manag.*, vol. 115, pp. 308–326, 2016.

[11] S. Dayana, A. Sharuddin, F. Abnisa, W. Mohd, and A. Wan, "Energy recovery from pyrolysis of plastic waste : Study on non-recycled plastics (NRP) data as the real measure of plastic waste," *Energy Convers. Manag.*, vol. 148, pp. 925–934, 2017.

[12] N. Kiran, E. Ekinci, and C. E. Snape, "Recyling of plastic wastes via pyrolysis," *Resour. Conserv. Recycl.*, vol. 29, pp. 273–283, 2000.

[13] D. Kim, S. Shin, S. Sohn, J. Choi, and B. Ban, "Waste plastics as supplemental fuel in the blast furnace process : improving combustion efficiencies," *J. Hazard. Mater.*, vol. B94, pp. 213–222, 2002.

[14] J. Walendziewski, "Engine fuel derived from waste plastics by thermal treatment q," *Fuel*, vol. 81, pp. 473–481, 2002.

[15] N. Miskolczi, L. Bartha, G. Deak, and B. Jover, "Thermal degradation of municipal plastic waste for production of fuel-like hydrocarbons," *Polym. Degrad. Stab.*, vol. 86, pp. 357–366, 2004.

[16] A. Demirbas, "Pyrolysis of municipal plastic wastes for recovery of gasoline-range hydrocarbons," *J. Anal. Appl. Pyrolysis*, vol. 72, pp. 97–102, 2004.

[17] M. F. Ali and M. N. Siddiqui, "Thermal and catalytic decomposition behavior of PVC mixed plastic waste with petroleum residue," *J. Anal. Appl. Pyrolysis*, vol. 74, pp. 282–289, 2005.

[18] K. Adil and A. Y. Bilgesu, "Catalytic and thermal oxidative pyrolysis of LDPE in a continuous reactor system," *J. Anal. Appl. Pyrolysis*, vol. 78, pp. 7–13, 2007.

[19] Vicente G, J. Aguado, D. . Serrano, and N. Sanchez, "HDPE chemical recycling promoted by phenol solvent," *J. Anal. Appl. Pyrolysis*, vol. 85, no. (1-2), pp. 366–71, 2009.

[20] A. K. Panda, R. K. Singh, and D. K. Mishra, "Thermolysis of waste plastics to liquid fuel A suitable method for plastic waste management and manufacture of value added products — A world prospective," *Renew. Sustain. Energy Rev.*, vol. 14, pp. 233–248, 2010.

[21] J. Shah, M. R. Jan, F. Mabood, and F. Jabeen, "Catalytic pyrolysis of LDPE leads to valuable resource recovery and reduction of waste problems," *Energy Convers. Manag.*, vol. 51, no. 12, pp. 2791–2801, 2010.

[22] A. Demirbas, "Waste management , waste resource facilities and waste conversion processes," *Energy Convers. Manag.*, vol. 52, no. 2, pp. 1280–1287, 2011.

[23] R. P. Singh, V. V Tyagi, T. Allen, M. H. Ibrahim, and R. Kothari, "An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4797–4808, 2011.

[24] I. Velghe, R. Carleer, J. Yperman, and S. Schreurs, "Journal of Analytical and Applied

Pyrolysis Study of the pyrolysis of municipal solid waste for the production of valuable products," *J. Anal. Appl. Pyrolysis*, vol. 92, no. 2, pp. 366–375, 2011.

[25] M. Sarker, M. M. Rashid, M. S. Rahman, and M. Molla, "Production of Valuable Heavy Hydrocarbon Fuel Oil by Thermal Degradation Process of Post-Consumer Municipal Polystyrene (PS) Waste Plastic in Steel Reactor," *Energy and Power*, vol. 2, no. 5, pp. 89–95, 2012.

[26] N. Patni, P. Shah, S. Agarwal, and P. Singhal, "Alternate Strategies for Conversion of Waste Plastic to Fuels," *ISRN Renew. Energy*, pp. 1–7, 2013.

[27] K. P. Achyut and R. K. Singh, "Experimental Optimization of Process for the Thermo-catalytic Degradation of Waste Polypropylene to Liquid Fuel," *Adv. Energy Eng.*, vol. 1, no. 3, 2013.

[28] C. Cleetus, S. Thomas, and S. Varghese, "Synthesis of Petroleum-Based Fuel from Waste Plastics and Performance Analysis in a CI Engine," *J. Energy*, pp. 1–10, 2013.

[29] M. Sarker and M. M. Rashid, "Polypropylene Waste Plastic Conversion into Fuel Oil by using Thermal Degradation with Fractional Process," *Am. J. Environ. Energy Power Res.*, vol. 2, no. 3, pp. 1–10, 2014.

[30] Y. Sonawane, M. Shindikar, and M. Khaladkar, "Onsite Conversion of Thermoplastic Waste into Fuel by Catalytic Pyrolysis," *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 3, no. 9, pp. 15903–15908, 2014.

[31] M. Syamsiro, H. Saptoadi, T. Norsujianto, and P. Noviasri, "Fuel Oil Production from Municipal Plastic Wastes in Sequential Pyrolysis and Catalytic Reforming Reactors," *Energy Procedia*, vol. 47, pp. 180–188, 2014.

[32] K. S. Brajendra, B. R. Moser, K. E. Vermillion, K. M. Doll, and N. Rajagopalan, "Production , characterization and fuel properties of alternative diesel fuel from pyrolysis of waste plastic grocery bags," *Fuel Process. Technol.*, vol. 122, pp. 79–90, 2014.

[33] E. P. Rohan, N. K. Hettiarachchi, and B. Sumith, "Conversion of Waste Polypropylene into Hydrocarbon fuel – Analysis of the Effect of Batch Size on Reaction Time and Liquid Yield Yield .," *Engineer*, vol. XLVIII, No, pp. 45–56, 2015.

[34] R. Miandad, M. A. Barakat, A. S. Aburiazaiza, M. Rehan, and A. S. Nizami, "Catalytic

pyrolysis of plastic waste : A review,” *Process Saf. Environ. Prot.*, vol. 102, pp. 822–838, 2016.

[35] R. Miandad *et al.*, “Influence of temperature and reaction time on the conversion of polystyrene waste to pyrolysis liquid oil,” *Waste Manag.*, vol. 58, pp. 250–259, 2016.

[36] K. Tekin, M. K. Akalın, Ç. Kadı, S. Karagöz, and S. Karago, “Catalytic degradation of waste polypropylene by pyrolysis,” *J. Energy Inst.*, pp. 150–155, 2016.

[37] M. Z. H. Khan, M. Sultana, and M. R. Hasan, “Pyrolytic Waste Plastic Oil and Its Diesel Blend : Fuel Characterization,” *J. Environ. Public Health*, pp. 1–6, 2016.

[38] S. M. Al-salem, A. Antelava, A. Constantinou, G. Manos, and A. Dutta, “A review on thermal and catalytic pyrolysis of plastic solid waste,” *J. Environ. Manage.*, vol. 197, no. 1408, pp. 177–198, 2017.

[39] W. Songchai and J. Jamradloedluk, “Distillation of Pyrolytic Oil Obtained from Fast Pyrolysis of Plastic Wastes,” *Energy Procedia*, vol. 138, pp. 111–115, 2017.

[40] R. Miandad, M. A. Barakat, M. Rehan, A. S. Aburiazaiza, I. M. I. Ismail, and A. S. Nizami, “Plastic waste to liquid oil through catalytic pyrolysis using natural and synthetic zeolite catalysts,” *Waste Manag.*, vol. 69, pp. 66–78, 2017.

[41] mmad K. Biddinika, M. Syamsiro, A. N. Hadiyanto, Z. Mufrodi, and F. Takahashi, “Technology for public outreach of fuel oil production from municipal plastic wastes,” *Energy Procedia*, vol. 142, pp. 2797–2801, 2017.

[42] M. Sogancioglu, G. Ahmetli, and E. Yel, “A Comparative Study on Waste Plastics Pyrolysis Liquid Products Quantity and Energy Recovery Potential,” *Energy Procedia*, vol. 118, pp. 221–226, 2017.

[43] N. Singh, D. Hui, R. Singh, I. P. S. Ahuja, L. Feo, and F. Fraternali, “Recycling of plastic solid waste : A state of art review and future applications,” *Compos. Part B*, vol. 115, pp. 409–422, 2017.

[44] A. O. Prosper, N. Banadda, A. Zziwa, J. Seay, and N. Kiggundu, “Reverse engineering of plastic waste into useful fuel products,” *J. Anal. Appl. Pyrolysis*, vol. 130, pp. 285–293, 2018.

[45] O. Nishida *et al.*, “Application of Waste Plastic Disposals to Marine Diesel Engines ---In

case of Marine Residual Fuel---," *Bull. JIME*, vol. 29, no. 1, pp. 28–34, 1999.

[46] M. Mani, C. Subash, and G. Nagarajan, "Performance , emission and combustion characteristics of a DI diesel engine using waste plastic oil," *Appl. Therm. Eng.*, vol. 29, no. 13, pp. 2738–2744, 2009.

[47] M. Mani and G. Nagarajan, "Influence of injection timing on performance , emission and combustion characteristics of a DI diesel engine running on waste plastic oil," *Energy*, vol. 34, no. 10, pp. 1617–1623, 2009.

[48] M. Mani, G. Nagarajan, and S. Sampath, "Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine," *Energy*, vol. 36, no. 1, pp. 212–219, 2011.

[49] J. Pratoomyod and I. K. Laohalidanond, "Performance and Emission Evaluation of Blends of Diesel fuel with Waste Plastic Oil in a Diesel Engine," *Int. J. Eng. Sci. Innov. Technol.*, vol. 2, no. 2, pp. 57–63, 2013.

[50] S. Chumsunti and A. Janyalertadun, "Influence of Nozzle Pressure on Performance and Emission in Compression Ignition Engine Running on Distilled Waste Plastic Oil (DWPO)," *Int. J. Environ. Sci. Dev.*, vol. 4, no. 3, pp. 4–8, 2013.

[51] S. Kumar, R. Prakash, S. Murugan, and R. K. Singh, "Performance and emission analysis of blends of waste plastic oil obtained by catalytic pyrolysis of waste HDPE with diesel in a CI engine," *Energy Convers. Manag.*, vol. 74, pp. 323–331, 2013.

[52] K. Naima, A. Liazid, and B. P. El Mnaouer, "Waste oils as alternative fuel for diesel engine : A review," *J. Pet. Technol. Altern. fuels*, vol. 4, no. March, pp. 30–43, 2013.

[53] V. T. Shanmuga, P. Balashanmugam, and T. Sivakumar, "Performance and Emission Characteristics of Nano Engine Running on Plastic Oil Extract," *Int. J. Sci. Res.*, vol. 3, no. 7, pp. 193–197, 2014.

[54] V. K. Kaimal and P. Vijayabalan, "A detailed study of combustion characteristics of a DI diesel engine using waste plastic oil and its blends," *Energy Convers. Manag.*, vol. 105, pp. 951–956, 2015.

[55] C. A. Rinaldini, E. Mattarelli, T. Savioli, G. Cantore, M. Garbero, and A. Bologna, "Performance , emission and combustion characteristics of a IDI engine running on waste

plastic oil," *Fuel*, vol. 183, pp. 292–303, 2016.

[56] A. Janyalertadun, S. Chumsunti, and Sompop Sanongraj, "Fuel production , performance , and emission of a CI engine using waste plastics oil," *World J. Eng.*, vol. 14, no. 2, pp. 114–120, 2017.

[57] I. Kalargaris, G. Tian, and S. Gu, "The utilisation of oils produced from plastic waste at different pyrolysis temperatures in a DI diesel engine," *Energy*, vol. 131, pp. 179–185, 2017.

[58] I. Kalargaris, G. Tian, and S. Gu, "Combustion , performance and emission analysis of a DI diesel engine using plastic pyrolysis oil," *Fuel Process. Technol.*, vol. 157, pp. 108–115, 2017.

[59] I. Kalargaris, G. Tian, and S. Gu, "Experimental evaluation of a diesel engine fuelled by pyrolysis oils produced from low-density polyethylene and ethylene – vinyl acetate plastics," *Fuel Process. Technol.*, vol. 161, pp. 125–131, 2017.

[60] I. Kalargaris, G. Tian, and S. Gu, "Investigation on the long-term effects of plastic pyrolysis oil usage in a diesel engine," *Energy Procedia*, vol. 142, pp. 49–54, 2017.

[61] V. Hariram, S. Sivamani, K. Bhutoria, and H. H. Vora, "Experimental study on combustion and performance characteristics in a DI CI engine fuelled with blends of waste plastic oil," *Alexandria Eng. J.*, pp. 1–7, 2017.

[62] V. Hariram, S. Seralathan, K. Bhutoria, and H. H. Vora, "Assessment of Waste Plastic Oil Blends on Performance and Combustion Parameters in Direct Injection CI Engine Assessment of Waste Plastic Oil Blends on Performance and Combustion Parameters in Direct Injection CI Engine," *Int. J. Ambient Energy*, p. DOI: 10.1080/01430750.2017.1381155, 2017.

[63] V. K. Kaimal and P. Vijayabalan, "A detailed investigation of the combustion characteristics of a DI diesel engine fuelled with plastic oil and rice bran methyl ester," *J. Energy Inst.*, vol. 90, no. 2, pp. 324–330, 2017.

[64] M. Mani, G. Nagarajan, and S. Sampath, "An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation," *Fuel*, vol. 89, no. 8, pp. 1826–1832, 2010.

[65] J. Devaraj, Y. Robinson, and P. Ganapathi, “Experimental investigation of performance , emission and combustion characteristics of waste plastic pyrolysis oil blended with diethyl ether used as fuel for diesel engine,” *Energy*, vol. 85, pp. 304–309, 2015.

[66] P. Senthilkumar and G. Sankaranarayanan, “Effect of Jatropha methyl ester on waste plastic oil fueled DI diesel engine,” *J. Energy Inst.*, vol. 89, no. 4, pp. 504–512, 2016.

[67] P. Bridjesh, P. Periyasamy, A. Vijayarao, and K. Chaitanya, “MEA and DEE as additives on diesel engine using waste plastic oil diesel blends,” *Sustain. Environ. Res.*, vol. 28, no. 3, pp. 142–147, 2018.

[68] D. Damodharan, A. P. Sathiyagnanam, D. Rana, B. R. Kumar, and S. Saravanan, “Combined in fl uence of injection timing and EGR on combustion , performance and emissions of DI diesel engine fueled with neat waste plastic oil,” *Energy Convers. Manag.*, vol. 161, no. January, pp. 294–305, 2018.

[69] L. Shenghua, E. R. C. Clemente, H. Tiegang, and W. Yanjv, “Study of spark ignition engine fueled with methanol / gasoline fuel blends,” *Appl. Therm. Eng.*, vol. 27, pp. 1904–1910, 2007.

[70] W. Yanju, L. Shenghua, L. Hongsong, Y. Rui, L. Jie, and W. Ying, “Effects of Methanol / Gasoline Blends on a Spark Ignition Engine Performance and Emissions,” *energy and fuels*, vol. 22, pp. 1254–1259, 2008.

[71] C. A. Srinivasan and C. G. Saravanan, “Study of Combustion Characteristics of an SI Engine Fuelled with Ethanol and Oxygenated Fuel Additives,” *J. Sustain. Energy Environ.*, vol. 1, pp. 85–91, 2010.

[72] H. Zhao *et al.*, “Effects of different mixing ratios on emissions from passenger cars fueled with methanol/gasoline blends,” *J. Environ. Sci.*, vol. 23, no. 11, pp. 1831–1838, 2011.

[73] M. Al-Hasan, “Effect of ethanol – unleaded gasoline blends on engine performance and exhaust emission,” *Energy Convers. Manag.*, vol. 44, pp. 1547–1561, 2003.

[74] Y. Fikret and B. Yu, “The use of ethanol – gasoline blend as a fuel in an SI engine,” *Renew. Energy*, vol. 29, pp. 1181–1191, 2004.

[75] A. N. Basavaraju, J. Gonsalvis, and B. Yogesha, “Performance study of Methanol blended petrol in SI Engine,” *Int. J. Eng. Sci. Invent.*, vol. 2, no. 3, pp. 1–7, 2013.

[76] V. V Jose Ananth, R. Solomon, and S. Sreenath, “Performance Analysis of Spark Ignition Engine Fueled with Methanol / Petrol Fuel Blends,” *Indian J. Sci. Technol.*, vol. 6, pp. 4579–4582, 2013.

[77] M. A. Ghadikolaei, “Effect of alcohol blend and fumigation on regulated and unregulated emissions of IC engines — A review,” *Renew. Sustain. Energy Rev.*, vol. 57, pp. 1440–1495, 2016.

[78] F. Catapano, P. Sementa, and B. M. Vaglieco, “Air-fuel mixing and combustion behavior of gasoline-ethanol blends in a GDI wall-guided turbocharged multi-cylinder optical engine,” *Renew. Energy*, vol. 96, pp. 319–332, 2016.

[79] S. Ananthakumar, S. Jayabal, and P. Thirumal, “Investigation on performance , emission and combustion characteristics of variable compression engine fuelled with diesel , waste plastics oil blends,” *J. Brazilian Soc. Mech. Sci. Eng.*, p. DOI: 10.1007/s40430-016-0518-6, 2016.

[80] S. Murugan, M. . Ramaswamy, and G. Nagarajan, “Performance , emission and combustion studies of a DI diesel engine using Distilled Tyre pyrolysis oil-diesel blends,” *Fuel Process.*, vol. 89, no. 2, pp. 152–159, 2016.

[81] D. K. Ramesha, G. P. Kumara, and A. V. T. Mohammed, “An experimental study on usage of plastic oil and B20 algae biodiesel blend as substitute fuel to diesel engine,” *Env. Sci Pollut Res*, p. DOI: 10.1007/s11356-015-5981-6., 2015.

[82] V. K. Kaimal and P. Vijayabalan, “A study on synthesis of energy fuel from waste plastic and assessment of its potential as an alternative fuel for diesel engines,” *Waste Manag.*, vol. 51, pp. 91–96, 2016.

[83] W. K. Cheng, D. Hamrin, J. B. Heywood, S. Hochgreb, K. Min, and M. and Norris, “An Overview of Hydrocarbon Emissions Mechanisms in Spark Ignition Engines,” *SAE Tech.*, p. DOI: 10.4271/932708, 1993.

[84] K. Mustafa, S. Yakup, T. Topgul, and H. S. Yucesu, “The effects of ethanol – unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine,” *Renew. Energy*, vol. 34, pp. 2101–2106, 2009.

[85] D. Jung and N. Lida, “An investigation of multiple spark discharge using multi-coil

ignition system for improving thermal efficiency of lean SI engine operation," *Appl. Energy*, vol. 212, pp. 322–332, 2018.

[86] V. Ravi, V. Pandurangadu, C. P. Reddy, and V. V. P. Bharathi, "Investigations on lean burn spark ignition engine using high intensity spark plugs," *Int. J. Eng. Res. indu. appls.*, vol. 3, no. 4, pp. 369–378, 2010.

[87] C. Bilge Albayrak, "Experimental investigation of the effect of spark plug gap on a hydrogen fueled SI engine," *Int. J. Hydrogen Energy*, vol. 37, no. 22, pp. 17310–17320, 2012.

[88] V. K. Kaimal and P. Vijayabalan, "An investigation on the effects of using DEE additive in a DI diesel engine fuelled with waste plastic oil," *Fuel*, vol. 180, pp. 90–96, 2016.

[89] A. Pikunas, S. Pukalskas, and J. Grabys, "Influence of composition of gasoline – ethanol blends on parameters of internal combustion engines," *J. KONES Intern. Combust. Engines*, vol. 10, pp. 1–7, 2003.

[90] S. M. Younus, V. R. Kumar, and Y. V. H. Rao, "Performance and Emissions Characterstics of Diesel Engine Fueled With Tyre Pyrolysis Oil & Diesel Blends with Additives," *Int. J. Eng. Sci. Invent.*, vol. 2, no. 5, pp. 32–37, 2013.

[91] I. Schifter and U. Gonzalez, "Effects of ethanol , ethyl- tert -butyl ether and dimethyl-carbonate blends with gasoline on SI engine," *Fuel*, vol. 183, pp. 253–261, 2016.

[92] S. B. Shayan, S. M. Seyedpour, F. Ommi, S. H. Moosavy, and M. Alizadeh, "Impact of Methanol – Gasoline Fuel Blends on the Performance and Exhaust Emissions of a SI Engine," *Int. J. Automot. Eng.*, vol. 1, no. 3, pp. 219–227, 2011.

[93] M. . Mallikarjun and V. R. Mamilla, "Experimental Study of Exhaust Emissions & Performance Analysis of Multi Cylinder S . I . Engine When Methanol Used as an Additive," *Int. J. Electron. Eng. Res.*, vol. 1, pp. 201–212, 2009.

[94] E. Ashraf, "Investigations on the effects of ethanol e methanol e gasoline blends in a spark-ignition engine : Performance and emissions analysis," *Eng. Sci. Technol. an Int. J.*, vol. 18, no. 4, pp. 713–719, 2015.

[95] A. S. Ayodhya, V. T. Lamani, M. Thirumoorthy, and G. N. Kumar, "NOx reduction studies on a diesel engine operating on waste plastic oil blend using selective catalytic

reduction technique," *J. Energy Inst.*, vol. XXX, pp. 1–10, 2018.

[96] M. K. Balki and C. Sayin, "The effect of compression ratio on the performance, emissions and combustion of an SI (Spark ignition) engine fuelled with pure ethanol, methanol and unleaded gasoline," *Energy*, vol. XXX, pp. 1–8, 2014.

[97] S. Murugan, M. C. Ramaswamy, and G. Nagarajan, "Performance , emission and combustion studies of a DI diesel engine using Distilled Tyre pyrolysis oil-diesel blends," *Fuel Process. Technol.*, vol. 89, pp. 152–159, 2008.

[98] X. Wang, Z. Chen, J. Ni, S. Liu, and H. Zhou, "The effects of hydrous ethanol gasoline on combustion and emission characteristics of a port injection gasoline engine," *Case Stud. Therm. Eng.*, vol. 6, pp. 147–154, 2015.

[99] R. Abburi, B. Srinivas, and K. S. Rao, "Experimental Investigations on Diesel Engine Fueled with Tyre Pyrolysis Oil and Diesel Blends," *Int. J. Eng. Res. Technol.*, vol. 3, no. 1, pp. 1213–1219, 2014.

[100] S. Murugan, M. C. Ramaswamy, and G. Nagarajan, "A comparative study on the performance , emission and combustion studies of a DI diesel engine using distilled tyre pyrolysis oil – diesel blends," *Fuel*, vol. 87, pp. 2111–2121, 2008.

List of Publications resulted based on the thesis

SCI journals

- **Kareddula Vijaya Kumar**, Ravi Kumar Puli, “An effect of Alcohol-Plastic oil blends on SI engine performance and exhaust emissions”, Journal of Mechanical Science and Technology, 32 (4), (2018), pp: 1849-1855.
- **Kareddula Vijaya Kumar**, Ravi Kumar Puli, “Experimental Studies on SI engine by using distilled plastic pyrolysis oil-gasoline blends”, (**Under Review**), International Journal of Green Energy.
- **Kareddula Vijaya Kumar**, Ravi Kumar Puli, “Experimental Studies of SI engine using waste plastic oil-gasoline blends”, (**Under Review**), Renewable Energy.

Scopus and ESCI journals

- **Kareddula Vijaya Kumar**, Ravi Kumar Puli, “Influence of plastic oil with ethanol gasoline blending on multi cylinder spark ignition engine”, Alexandria Engineering Journal, DOI: 10.1016/j.aej.2017.07.015.
- **Kareddula Vijaya Kumar**, Ravi Kumar Puli, “Study of Plastic Oil blended with Ethanol-Gasoline on Three Cylinder Petrol Engine”, World Journal of Engineering, 15/1, (2018), pp: 82-85, DOI: 10.1108/WJE-02-2017-0033.
- **Kareddula Vijaya Kumar**, Ravi Kumar Puli, “Effect of Plastic Oil-Methanol blends operated on Petrol Engine performance and exhaust emissions”, Australia Journal of Mechanical Engineering (**Under Review**), Taylor and Francis.
- **Kareddula Vijaya Kumar**, Ravi Kumar Puli, “Influence of Plastic Oil-Ethanol additive blends fuelled in Petrol Engine”, (**Under Review**), International Journal of Ambient Energy.

Scopus Indexed Journals

- Published paper entitled “Performance and Emission Studies of a Spark Ignition Engine using Distilled Plastic Pyrolysis Oil-Petrol Blends”, MATEC Web of Conferences 45, 03002 (2016), DOI: 10.1051/matecconf/20164503002.

- Published paper entitled “Effects of Waste Plastic Oil Blends on a Multi Cylinder Spark Ignition Engine” MATEC Web of Conferences, 108, 08005, (2017).

- Published paper entitled “Investigation on Waste Plastic Oil as an Alternative Fuel for Si Engine”, WEENTECH Proceedings in Energy, Volume 5, ISSN: 2059-2353, ISBN: 978-0-9932795-3-9, 25th January 2018, pp: 13-16.

International Conferences in (Abroad)

- Presented a paper with entitled “Investigation On a CI engine Fuelled with Blends of Waste Tyre Oil” at the 3rd International Conference On Advances in Mechanical, Aeronautical and Production Techniques (MAPT’15), during 11th and 12th April 2015, organized by Institute of Research Engineers and Doctors at Hotel G Tower, Kuala Lumpur, Malaysia.

-

International Conferences in (India)

- Kareddula Vijaya Kumar, Ravi Kumar Puli, Monika Dixit, D Ravi Chandra, paper entitled “Performance and Emission Evaluation of Tyre Oil blended with Diesel Fuel in Compression Ignition Engine” at the International Conference on Environment and Energy (ICEE-2014) during15-17 December 2014 in JNTUH Kukatpally, Hyderabad, INDIA. (pp: 64)

- Kareddula Vijaya Kumar, Ravi Kumar Puli, A Veeresh Babu, J.A. Ranga Babu, paper entitled “Performance and Emission Evaluation of Plastic Oil blended with Diesel Fuel in Compression Ignition Engine” at the International Conference on Environment and Energy (ICEE-2014) during 15-17 December 2014 in JNTUH Kukatpally, Hyderabad, INDIA. (pp: 88)

- Presented a Paper entitled with “Performance and Emissions Characteristics of Multi Cylinder Petrol Engine by Plastic Oil with Methanol Gasoline Blending” in International Conference on Current Recent Topics in Power, Nuclear, Fuel and Energy (PNFE-2016), during 25th to 27th October 2016, organized by SPEC, Dullapally, Hyderabad, Telangana, INDIA.

- Presented a Paper entitled with “Influence of Gasoline and Plastic Oil Blends with Ethanol additive on Multi Cylinder Spark Ignition Engine” in 1st International and 18th ISME Conference on Enabling Sustainable Development in Mechanical Engineering at National Institute of Technology Warangal. During 23rd to 25th February 2017 held at NIT Warangal.

- Presented a Paper entitled with “Experimental Investigation of Multi Cylinder Spark Ignition Engine using Gasoline with Plastic Oil-Methanol Blends” in 1st International and 18th ISME Conference on Enabling Sustainable Development in Mechanical Engineering at National Institute of Technology Warangal. During 23rd to 25th February 2017 held at NIT Warangal.

BIO-DATA

Name	K Vijaya Kumar
Date of Birth	01-06-1982
Marital Status	Married
Present Position	Research Scholar
	Department of Mechanical Engineering
	National Institute of Technology
	Warangal-506004
	Telangana, India
Permanent Address	S/O K Rammohan
	D.No.: 42-3/1-63
	Koduru Raju Street
	Ramakrishna Puram
	Vijayawada-520003, Krishna (Dist.)
	Andhra Pradesh, India.
	E-mail: vijay701414@gmail.com
	vijay.nitw2@gmail.com