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Investigation on Tire Pyrolysis Oil (Tpo) as a Fuel For Cook Stove And Lamps

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Abstract. Pyrolysis is an technology to derive value added products like pyrolytic oil, steel wire and carbon black, which works on the principle of thermo-chemical conversion of any carbonaceous feed stocks. The major factors affecting the pyrolysis are temperature, reactor configurations, residence time, heating source etc. A pilot plant study was conducted in a tire pyrolysis oil production industry located in Oyalapathy, Kerala for collecting the oil samples for the analysis. Tire pyrolysis oil (TPO) is a brownish colored, freely flowing liquid, medium viscosity with complex chemical composition. Due to its complex aromatic structure, presence of acids, aldehydes, oxygenated compounds hinders to apply in engine and stove as a fuel. Upgrading of hydrocarbons are necessary to obtain value added products and to derive thermally stable products. There are limited number of studies are carried out in the field of stove fuel production from hydrocarbon derived waste. An attempt was carried out to find the suitability of pyrolysis oil as a fuel in cook stove and oil lamps. The water boiling test was carried out to examine the boiling time for specific volume of water. The study shows that the TPO boils water in shorter time than kerosene and a clear comparison of two brand of fuels. The present study mainly includes the characterization like FTIR, GC-MS to investigate the components present in the oil and compare with diesel and kerosene. The commercialization and economic feasibility studies will be planned in future.

1. Introduction

Scrap tire waste is one of the challenging issues in modern era and around 1.5 billion tire waste are produced across the world. Out of these, 64% of waste tire are illegally dumped or stockpiled and only 13% of waste tire are recycled in a scientific manner [1]. Pyrolysis is one of the thermo chemical conversion process is utilized for the thermal degradation of waste tire in to three principal products like pyrolytic gas, oil and char at elevated temperature ranging from 300-900^{0}C. The present study focused on the use of liquid products obtained from the tire pyrolysis as a fuel for wick based cook stove and lamp.

Scrap tire pyrolysis oil composed of complex mixture of hydrocarbon consisting of C_6-C_{37} (linear paraffins),C_8-C_{13} (low concentration of alkenes), non-condensed butadiene, pentene, pentadiene and isoprene, high amount of aromatics, naphthenes and terpenes particularly limonene, benzene, toluene xylene, alkylated single ring aromatics [2]. The gas produced from the tire pyrolysis is called as pyrolytic gas, which mainly consist of hydrogen, carbon dioxide, carbon monoxide, methane, ethane, butane and other hydrocarbons. The pyrolytic oil produced is dark brown coloured oil with sulfurous smell due to the presence of paraffins, olefins, aromatic hydrocarbons and its derivatives.

Limonene, is one of the main constituents in the tire pyrolysis oil, which can be considered as a environmentally acceptable solvent, used for cleaning the electrical circuit boards, application in resin and adhesives, dispersing agent for pigments and fragrance in cleaning products. Char is a fine particulate composed of carbon black, ash and other inorganic materials such as zinc oxide, carbonates

and silicates. The other byproducts from the pyrolysis reaction may include steel (from steel belted radial tires), rayon, cotton or nylon fibers from tire cords depending upon the type of tire used.
In India, government subsidized kerosene to keep the price very low so as to utilize as a fuel for cook stove. Kerosene is an clear organic compound, highly flammable liquid with strong odour. It is a mixture of different types of hydrocarbon depending upon the source by which it is extracted. Kerosene is less volatile and has boiling point in the range of 140-320^{0}C. The major application of kerosene includes in lamps, heaters, furnaces, fuel component for diesel and tractor engine, jet engine, rocket engine and used as a solvent for greases and insecticides.
Ehsan et al [3] modified the design of Score-Stove to implement in both wood and a pressurized kerosene stove burner for the cooking application in rural areas of Bangladesh. The design was adapted to meet performance parameters like rate of heating, efficiency of cook stove, energy distribution, generation of electric power, emissions from exhaust chamber and time taken to the boil specific amount of water using standardized water boiling tests. Performance was also compared with non-electrically generating stoves that use a pressurized kerosene burner. Winijkul et al [4] examined the effects of policies, realistic factors, spatial constraints, existing assumptions and users behavior. The authors mainly focused on residential emissions and control methods for reduction. Chen et al [5] studied the performance of pellet gasifier stoves, efficiencies and pollutants are measured using the china and international standard water boiling test. The pollutants and gaseous emissions like carbon monoxide, particulate matter, poly aromatic hydrocarbons are lower for pellet gasifier than the traditional cook stoves. Honnet et al [6] proposed the experimental and numerical studies are carried out to develop a surrogate that can reproduce the combustion characteristics of kerosene. The numerical studies showed that the chemical kinetic mechanism for the Aachen surrogate can successfully predict the critical conditions of the auto-ignition and volume fraction of the soot. Anil et al [7] developed the ethanol stove running on 50% ethanol water mixture. The major feature of the proposed stove is the easy flame regulation and gives same power output to the conventionally used LPG and kerosene stove. Field study was conducted on the stove shows that it is very safe and can be very suitable for a typical rural house hold applications. Economic analysis shows that the price of ethanol stove is similar to the both liquified petroleum gas and kerosene stoves. Mahesh et al [8] studied the number and size distributions of the aerosols generated from the five commonly used household fuels like firewood, coal, dung cake, kerosene stove and LPG stoves using scanning mobility particle sizer. The authors compared the total number concentrations, geometric mean and geometric standard deviations of test fuels and compared with kerosene. They concluded that geometric mean diameter is higher for dung cake generated aerosols. Dioha et al [9] studied a comparitive analysis on ethanol and kerosene fuels and their performance with house hold kerosene stove with same dimensions and geometry were carried out. The result reveals that the kerosene fuel boils the water in a shorter time. They also compared the advantages and disadvantages of two brands of fuels. Joseph et al [10] investigated the potential causes of accidental fires in lamps and laterns filled with contaminated fuel through controlled test using typical appliances and varying the amount of contamination. Besides a simple model was developed for predicting the flash point of arbitrary mixture. Katsuhero et al [11] predicted the evaporation and diffusion behaviour of fuel mixtures of gasoline and kerosene in an arbitrary ratio. They derived the predictive model of concentration distribution of vapor above the fuel mixture spill on the floor. Sonam et al [12] pointed out the recent advances in cook stoves, CO_2 mitigation potential and economic assessment. There are several issues concerning improved cook stoves for better adaption by user are also addressed. There are huge number of literature available on the application of crude tyre pyrolysis oil as a engine fuel and its performance and emission analysis but scarce studies are available as application in cook stove and lamps. The present study attempts to explore physicochemical characterization of TPO and its application as a fuel for traditional cook stove and lamps.

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2. Materials and methods

Pyrolysis oil used for this research work was collected from Mandakan Energy products, Tire pyrolysis industry located at Oyalapathy, Palakkad. The rotary kiln, cylindrical type reactor has the size of 6.6 m in length, 2.8 m in diameter and as a capacity of 8 tonnes per batch. The reactor is rotated with the help of electrical motor. The reactor is fired up using the non-condensable gases evolved during the devolatilization reaction and feed this gas to the air compressor storage system for feeding to the furnace. The shredded tires was feed in to the reactor along with 10% calcium oxide catalyst as a catalyst. The selection criteria of calcium oxide catalyst is due to its low cost, lattice structure and availability. The front end of the reactor has door with fasteners and can be opened or closed by unlocking or locking the fasteners, the other end of the reactor is connected to a square shaped water bath laid with condenser tubes parallelly at the bottom. The volatile vapor evolved during the pyrolysis reaction is passed through the condenser pipe which is aligned parellelly at the bottom of a square shaped water bath in the industry and converted to the liquid and stored in the pressure vessel. The temperature and pressure inside the reactor are maintained at 300^0C-400^0C and 0.1 atmospheric pressure during the process with a retention time of 10 hours. The whole gases evolved during the devolatilization reaction is not to convert to the liquid fractions and some of the volatile vapor fractions escaped during the process can effectively stored in a compressor air storage setup for heating application in the industry itself. The rotary kiln reactor and its accessories are operated by motor and pump. The temperature of evolved at exit of the reactor and condenser can regulated with the help of temperature controlled data acquisition system. During this process 3500 liter oil (40-45%) is produced from 8 tone of tire waste. The major byproduct of the reaction is 30-35% carbon black, 3-5% steel wire and 8-10% non-condensable gases. The major focus of the industry is to produce better quality oil and supply the customers for furnace heating application. The present work aims to find out the suitability of the obtained oil from the industry as a fuel for cook stoves and lamps and the performance and emission studies in wick based cook stove and lamp. The yield of the crude TPO is increased by 10% by adding calcium oxide catalyst during the pyrolysis reaction in rotary kiln reactor.

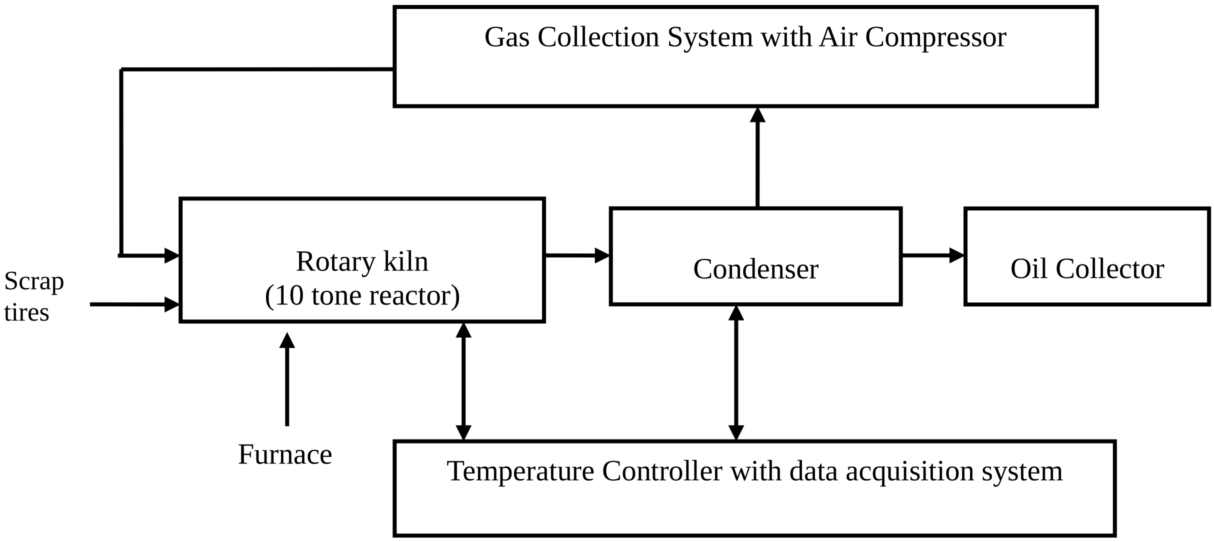


Figure 1. Layout of TPO industry, Palakkad

3. Steam distillation

Steam distillation is one of the most important chemical processes for the purification and separation of the oil samples based on their boiling point. TPO contains a host of aliphatic and aromatic fractions with concentration of 49.54% and 16.54% respectively [2]. The aromatic nature of TPO is due to the aryl chain fragments from styrene butadiene rubber, aromatic ring splitting and the cyclation of olefins during the thermo chemical conversion process. Steam distillation is commonly used to purify very high boiling point liquid. Figure 2, shows the layout of the distillation set up used for purification of crude TPO in to refined distillate. The distillation setup consists of a conical metallic flask by which 600 ml of tyre pyrolysis oil was taken. The metallic flask was supplied with heat at a range of 100-300^{0}C. The heated vapor come from the outlet port of the flask was allowed to pass through a condenser tube in which constant supply of water is supplied. The steam ejected from the flask was condensed and high purity 200ml distillate is obtained with light yellow in colour. Kerosene is a light yellow colored combustible liquid consist of branched or straight chain alkanes and ring shaped cyclo alkanes. Kerosene consists of about 10 different hydrocarbons, each containing 10-16 carbon atoms per molecule. This is produced by the fractional distillation of crude oil at 150-275^{0}C. Kerosene is a major component in the aviation fuel and can be used as a degreaser, solvent and a domestic fuel.

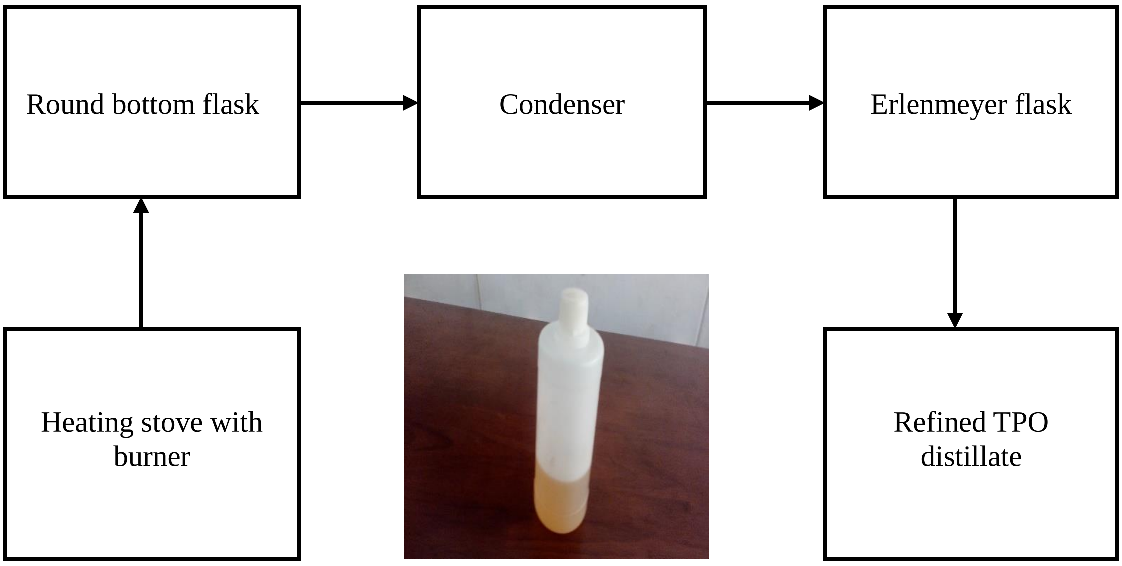


Figure 2. Layout for distillation setup with TPO distillate

4. Results and Discussion

4.1 Fuel property comparison of TPO distillate with kerosene.

The fuel properties like flash point, fire point, calorific value and cloud point are conducted fuels laboratory, Calicut. The flash point of TPO distillate is 36, which lies in range of kerosene. Calorific value is a parameter to investigate the heat content of the fuel. The calorific value of TPO distillate is higher than kerosene fuel. Table 1 gives the comparitive study of tyre oil distillate with kerosene. The fuel properties suggest that the properties like flash point, fire point, cloud point , color and kinematic viscosity are similar to the conventionally used kerosene and can be applied for testing in the wick based lamp and cook stove.

Table 1. Comparison of TPO distillate with kerosene

Fuel property	TPO distillate	Kerosene
Flash point (^{0}C)	36	37-65
Fire point (^{0}C)	41	50
Calorific value (MJ/Kg)	37500	35000
Cloud point (^{0}C)	-45	-47
Chemical constituents	2,2,4- trimethyl pentane Straight alkanes, Cycloalkanes	Straight alkanes, Cycloalkanes
Colour	Light yellow	Light yellow
Kinematic viscosity (cSt)	2.9	2.71

4.2 FTIR analysis of TPO

Fourier infrared spectroscopy (FTIR) mainly used to investigate the functional groups in the fuel sample, which is also termed as the molecular finger print. This study is carried out with the help of a Perkin Elmer Spectrum analyzer with scan range of 7500-4500 cm^{-1} with resolution of 0.2 cm^{-1}. The FTIR results of TPO distillate is depicted in Table 2. It reveals that the tire derived lamp oil distillate consist of cyclohexane, methyl cyclopentane and 2,2,4-trimethylpentane. The following table shows the presence of bonds, wave number, class of compounds, frequency range in TPO and are detailed in the following table. The result shows that the chemical constituents are almost similar in the tire derived distillate and the kerosene and confirms the suitability of tire derived distillate in wick based cook stove and lamps

Table 2. Functional groups identification in Tyre pyrolysis oil

Wave number (cm^{-1})	Bonds	Class of compounds
2921.33	C-H, Stretch	Alkanes
2812.72	C-H, Stretch	Alkanes
1605.47	C=C, C=N, Stretch	Alkenes, Amide
1461.19	O-H, Bending	Alcohol
1376.55	Nitrate	Nitrate
722.05	C-Cl	Chloride

4.3 GC-MS analysis of TPO

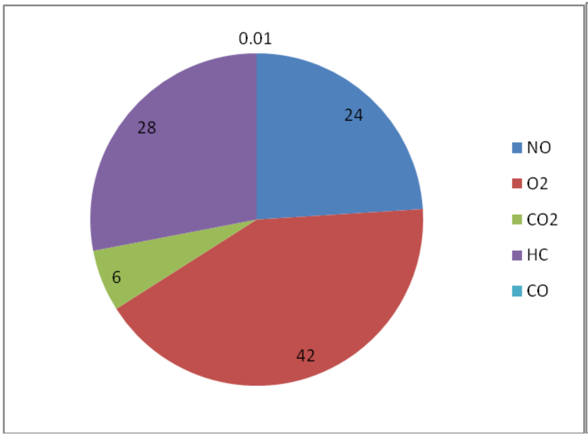
The gas chromatography coupled with mass spectroscopy is an effective combination of investigating the compound present in samples. Liquid were analyzed using GC-MS (Gas Chromatography Mass Spectrometry) (Accu TOF GCV 7890). BP X5 column (cross linked 5% methyl phenyl silicone, 30m*0.25 mm id, 0.25µm film thickness was used along with oven temperature initially at 50^0C for 2 minutes, then programmed to reach 270^0C at rate of 10K/minute and held for 2 minutes. The total runtime was 45 minutes. The temperature of injector port was 280^0C. Helium was used as the carrier gas, and a gas tight syringe was used to inject the 1mL per minute of sample volume of gas. The result from GC-MS study shows that the tyre pyrolysis oil distillate consist of 1,3 dimethyl cyclohexane, n-octane, 1,3 dimethyl benzene, ethyl cyclohexane, ethyl benzene, n-nonane, n-propyl cyclohexane, 1-cyclohexyl 2-buten-1-ol, 3-ethyl toluene, 1-(2-nitro 2-propenyl)-1-cyclo octane, decane, limonene, cyclohexane,1,3 butadienylidene, 1,2 -dimethyl 1-cyclooctene, undecane, 6-7 dimethyl 3,5,8,8 tetra hydro1H-isochromonene , dodecane, P-xylene, Benzene, 1-ethyl-4-methyl, 2,3,6-trimethyl heptadecanitrile, octadecanitrile and hexadecanitrile. The compounds like p-xylene, benzene, 1-ethyl-4-methyl, 2,3,6-trimethyl, heptadecanenitrile, octadecanitrile and hexadecanitrile are found in both kerosene and tyre pyrolysis oil distillate.

4.4 Emission analysis in wick based lamp

The emission analysis provides an idea about the gaseous fraction evolved during TPO combustion and is compared with the pure kerosene. The emission analysis was carried out using AVL gas analyzer 444. Figure 4 shows the percentages of nitrous oxide, oxygen, carbon dioxide, hydrocarbon and carbon monoxide in the tire pyrolysis oil distillate and kerosene. The experimental setup mainly consists of a wick lamp with glass chimney, gas analyzer, gas trap etc. The high temperature and availability of oxygen are the reasons for formation of nitrous oxide. The nitrous oxide emission from TPO distillate flame is 2% less than kerosene due to the heat absorption by calcium oxide catalyst during the pyrolysis reaction. Hydrocarbons are occured due to the incomplete or non-stoichiometric air fuel mixture combustion. Hydrocarbon fraction is 4% lesser for kerosene than TPO distillate. This is due to the presence of host of aliphatics and aromatic groups present in TPO. Oxygen content is greater for kerosene than TPO distillate due to the low oxygenates in the TPO distillate after distillation process. The carbon dioxide is evolved during the combustion of TPO distillate but Carbon monoxide, a toxic product is evolved during kerosene combustion.

Table 3. Specification of AVL gas analyzer

Power supply	11-22VDC/100-300
Operating temperature	5-45^0C
Power consumption	25W
Storage temperature	0-50^0C
Relative humidity	<95%
Gas flow	180 l/hr
Oxygen sensor type	Electro chemical
Oxygen sensor model	O_2- SENS 1



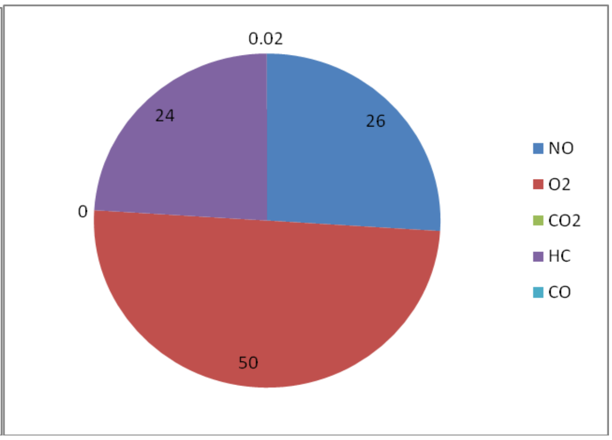


Figure 3. Emission analysis of TPO distillate and Kerosene

The experimental result shows that the component like carbon monoxide is very low in the case of tire pyrolysis oil distillate. The problem in crude TPO have vast amount of oxygenates but after steam distillation, the oxygenates reduces. This oxygenates fraction indirectly tells about the corrosion problems of fuel in stove and its stability issues.

4.5 Smoke point analysis

Smoke point analysis gives an idea about the relative smoke producing tendency of the TPO distillate and the kerosene. The smoke point is a direct measure of the hydrocarbon composition. Generally, more aromatic fuel means to generate flame with high smoke content. A high smoke point reveals the fuel of low smoke producing tendency. The smoke point is quantitatively related to the radiant heat transfer from combustion and hydrocarbon content of fuel. The tyre pyrolysis oil distillate is burned in an enclosed wick feed lamp that is calibrated against hydrocarbon blends of known smoke point. The smoke point analysis shows that the smoke point of the kerosene (30) is higher than tire derived distillate (26) due to the presence of higher molecular weight aromatic fractions in the tire derived distillate than kerosene. The smoke flame of TPO distillate and smoke point lamp are shown in the following Figure 5.

Figure 4. Smoke point lamp

4.6 Water boiling test

Water boiling test consist of wick based stove, thermometer, stopwatch, weighing balance. Various quantity of water were boiled using TPO distillate and the kerosene respectively. 0.5 litre stainless steel vessel is used for boiling various volume of water during the experiment. The TPO distillate was initially tested and later the stove was washed and sun dried. The study was repeated with TPO distillate after replacing wick under same condition. The time required to boil the water for two different brand of fuel like TPO distillate and kerosene are plotted in the Figure 6.

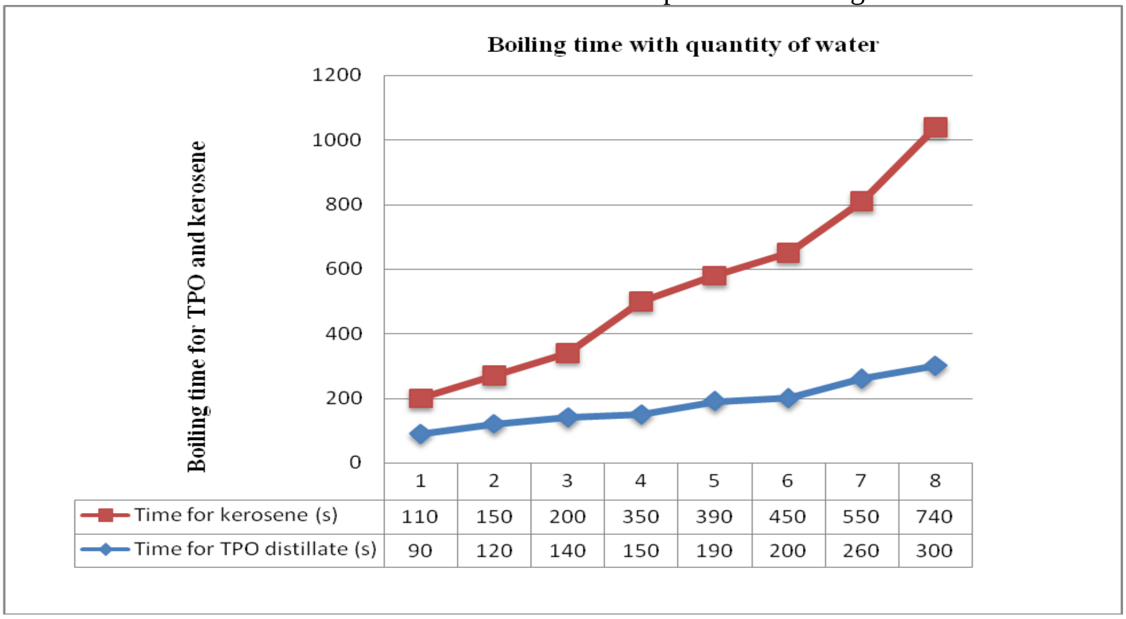


Figure 5. Boiling time for TPO distillate and kerosene

5 Conclusion

The study shows that the tire pyrolysis oil distillate can be effectively used in wick based cook stove and lamps and also a better option for immense increase in the scrap tires around our society. The Fourier transform infrared spectroscopy studies explores the various functional groups like alcohol, ketone, aldehyde, alkane, alkene present in TPO distillate. The GC-MS analysis point out the host of aliphatic and aromatics present in the TPO distillate, which causes high smoke fraction than kerosene fuel. The commercial value of tire pyrolysis oil improves after the steam distillation process. The Presence of aromatic hydrocarbon is a major challenge of TPO distillate for the development of stove based fuels. The emission properties of fuel can be improved using diethyl ether, an additive to reduce the ignition lag, and promotes the complete combustion and improves fuel efficiency. The upgrading of TPO by modified catalyst is required for the application of TPO distillate as fuel for lamp and cook stoves. The studies on distillates at various temperature and pressure will be attractive scope of study to analyze the oil properties and application as a fuel for stove and burners.

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