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Production of Diesel Surrogate Fuel from Waste Lubricating Oil

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Abstract: *Waste lubricating engine oil, generated globally at an estimated 24 million metric tonnes per year, represents a critical environmental and resource-management challenge. This paper presents an investigation into microwave-assisted pyrolysis (MAP) as an energy-efficient method for recovering diesel-like fuel from waste automotive lubricating oil. A modified domestic microwave oven (2.45 GHz, 1000 W) was employed, with carbon rods as microwave susceptors inside the reaction kettle and nitrogen gas to maintain an inert atmosphere. Pyrolysis vapours were condensed through a water-cooled condenser. The initial boiling point of the distillate occurred at approximately 110-150°C; effective thermal cracking took place at 280-350°C. The recovered pyrolysis oil exhibited density (0.843-0.862 g/cc), gross calorific value (~10,600-10,750 kcal/kg), and flash/fire points exceeding commercial diesel, indicating safer storage characteristics. Production cost was approximately Rs. 50 per litre - a 35-45% reduction versus retail diesel. Results confirm that microwave-heated pyrolysis is a sustainable, cost-effective route for recycling waste oil into valuable energy products.*

Keywords: Microwave pyrolysis, waste lubricating oil, diesel-like fuel, hydrocarbon recovery, thermal cracking, energy recovery, circular economy

I. INTRODUCTION

Lubricating oil is indispensable in modern mechanical systems, serving to reduce friction, dissipate heat, prevent corrosion, and suspend contaminants. During service in internal combustion engines, it undergoes irreversible degradation via oxidation, thermal cracking, and contamination by fuel residues, metal wear particles, soot, and water. Approximately 50% of oil in service is consumed during combustion; the remainder becomes waste oil requiring safe disposal [1].

Global lubricant consumption is approximately 40 million metric tonnes per year, of which over 60% becomes waste oil - an estimated 24 million metric tonnes annually. Alarmingly, less than 45% of available waste oil is collected for proper treatment; the remainder is illegally dumped, causing severe environmental harm [2]. A single litre of waste oil can contaminate up to one million litres of groundwater. Conventional incineration generates toxic atmospheric pollutants including CO, NOx, SO2, dioxins, and furans.

Pyrolysis - the thermochemical decomposition of organic matter in a non-oxidising atmosphere - offers an attractive alternative, converting waste oil into useful liquid hydrocarbon fuel, combustible gases, and solid char while minimising toxic emissions. Microwave-assisted pyrolysis (MAP) is particularly promising due to its volumetric heating mode, rapid response, selective energy deposition, and demonstrated energy ratio of approximately 8 [3,7].

This paper investigates MAP of waste automotive lubricating oil using carbon rods as microwave susceptors under nitrogen atmosphere, characterises the recovered fuel properties, and assesses economic viability.

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II. LITERATURE REVIEW

Al-Omari [19] established the calorific viability of waste lubricating oil as a supplementary fuel. Fuentes et al. [14] quantified global waste oil generation and analysed pyrolysis decomposition kinetics. Thostenson and Chou [17] established the theoretical foundations of microwave processing, identifying key advantages including selective, rapid, volumetric heating.

Demirbas et al. (Dicle University, Turkey) reported 88 wt% pyrolysis oil yield from waste engine oil via MAP, with 90% energy recovery, low sulphur and PAH content, and a positive energy ratio of 8. A continuous 5 kW apparatus treated waste oil at 5 kg/h with a net energy output of 179,390 kJ/h. Lam et al. [5,7] at the University of Cambridge demonstrated microwave pyrolysis as a novel recycling process, reporting liquid yields of 80-90 wt% and products broadly comparable to fresh oil-derived fuels.

Manasomboonphan et al. [22] (Bangkok) investigated batch pyrolysis at 200-500°C under vacuum; maximum liquid yield (>50 wt%) was obtained at 350°C. Arpa and Yumrutas [13] designed a pyrolytic distillation system recovering diesel-like fuel (DLF) and gasoline-like fuel (GLF) from waste oil, achieving comparable engine performance to commercial diesel. Selukar et al. investigated catalytic pyrolysis using zeolite to reduce viscosity and improve fuel quality.

III. APPARATUS AND EXPERIMENTAL SETUP

The MAP apparatus comprised: (1) a modified domestic microwave oven (2.45 GHz, 1000 W output, 1.6 kW input); (2) a 1000 mL five-necked glass reaction kettle sealed with plaster of Paris; (3) a nitrogen gas supply (purity >99.5%) for inert atmosphere and vapour sweeping; (4) a rotary vacuum pump (0.9 bar vacuum); (5) a glass water-cooled condenser; (6) graduated collection flasks; (7) a K-type thermocouple digital thermometer (0-1200°C); (8) carbon rods as microwave susceptors; and (9) ceramic pieces for nucleation.

Carbon rods are highly microwave-absorbent (high dielectric loss factor) and couple efficiently with the 2.45 GHz field, rapidly heating and transferring energy to the surrounding oil by conduction and radiation. Waste oil itself is a non-polar hydrocarbon mixture with poor microwave coupling. Ceramic pieces prevent superheating and dangerous pressure surges. The oil-to-carbon rod mass ratio was maintained at 2:1.

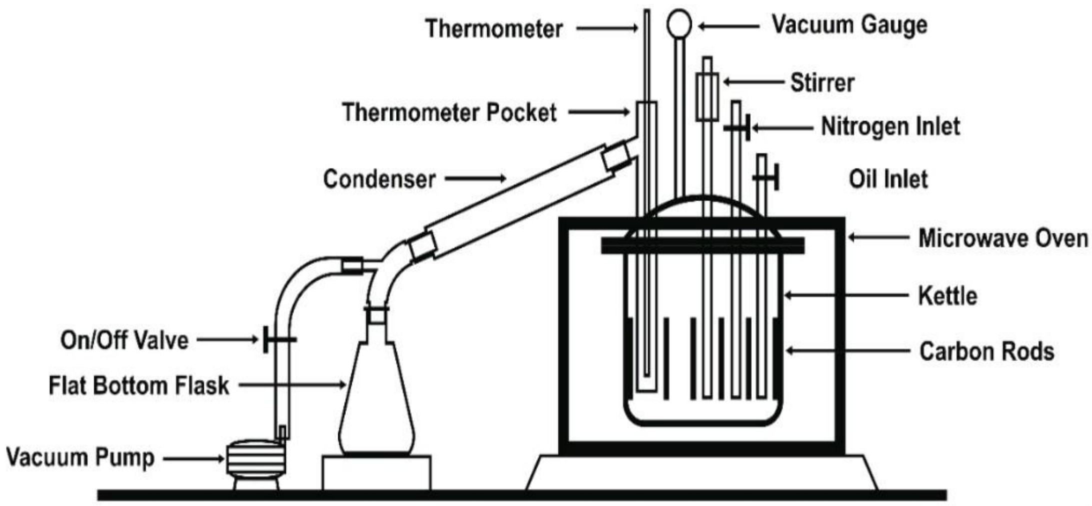

Fig. 1: Schematic diagram of microwave-assisted pyrolysis apparatus

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Fig. 2 & 3: Actual experimental setup showing microwave oven, condenser, collecting flask, vacuum pump, nitrogen cylinder, and temperature indicator

IV. EXPERIMENTAL PROCEDURE

Waste lubricating oil was collected from automotive service centres, filtered through a 200-mesh stainless steel filter, and 750 mL charged per run. Carbon rods and ceramic pieces were added in the prescribed ratio. The system was sealed, evacuated to 0.9 bar vacuum, and purged with nitrogen through three evacuation-fill cycles, followed by continuous nitrogen flow (200-500 mL/min) for 10 minutes before heating commenced.

The microwave oven was operated at full power (1000 W). Temperature was monitored continuously. Heating proceeded in 5-minute on / 2-minute off intervals to prevent overheating. The first condensate was observed at 110-150°C (initial boiling point). Bulk liquid production occurred at 280-350°C. Heating was discontinued when condensate flow ceased. Post-run, the system cooled under nitrogen flow to below 60°C before disassembly. Three replicate runs were averaged for each condition set.

V. RESULTS AND DISCUSSION

A. Fuel Property Analysis

The recovered pyrolysis oil was characterised by ASTM standard fuel property tests and compared with commercial diesel specifications. Table 1 summarises the results.

Property	Unit	Diesel Std.	Sample 1	Sample 2
Flash Point	°C	52-96	208	212
Fire Point	°C	60-110	215	228
Kin. Viscosity	cSt	2-6	70.64	73.6
Density @25°C	g/cc	0.820-0.826	0.843	0.862
Gross Cal. Value	kcal/kg	~10,700	10,599	10,747

Table 1: Fuel properties of pyrolysis oil vs. commercial diesel

B. Discussion

Flash and Fire Points: Both samples (208-212°C; 215-228°C) significantly exceed diesel specification (52-96°C; 60-110°C), indicating superior storage safety. The higher values reflect a greater proportion of heavier hydrocarbon fractions in the pyrolysis oil relative to commercial diesel.

Viscosity: The pyrolysis oil viscosity (70.64-73.6 cSt at 25°C) exceeds the diesel specification (2-6 cSt at 40°C) due to incomplete cracking of heavier chains. Blending with commercial diesel or catalytic upgrading over zeolite would bring viscosity within acceptable limits for CI engines.

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Density: Slightly higher than diesel (0.843-0.862 vs. 0.820-0.826 g/cc), attributable to heavier hydrocarbons and possibly aromatic compounds - small enough for blending without significant impact on fuel system calibration.
Gross Calorific Value: At 10,599-10,747 kcal/kg, the pyrolysis oil retains approximately 99% of the energetic value of commercial diesel, confirming excellent energy recovery from the waste feedstock.

VI. ECONOMIC ANALYSIS

Based on a 1.6 kW microwave oven at 80% load factor and an electricity tariff of Rs. 8/kWh, electricity cost is Rs. 10.24/h. With waste oil feedstock at Rs. 40 per 1.3 kg, total production cost is approximately Rs. 50 per litre
- compared to retail diesel at Rs. 80-90/litre, representing a saving of 35-45%. This compelling cost advantage is further enhanced when waste oil feedstock is obtained at minimal cost through arrangements with automotive service centres.

VII. CONCLUSION

Microwave-assisted pyrolysis of waste lubricating engine oil has been demonstrated to be technically feasible, economically viable, and environmentally superior to conventional disposal methods. Key findings: (i) Bulk liquid production at 280-350°C with IBP at 110-150°C; (ii) gross calorific value (~10,600-10,750 kcal/kg) virtually identical to diesel; (iii) flash/fire points exceeding diesel standards for safer handling; (iv) production cost ~Rs. 50/litre - 35-45% below retail diesel; (v) closed inert-atmosphere operation minimises toxic emissions and groundwater risk. Future work should address engine performance testing, catalytic viscosity reduction, continuous reactor design, and full lifecycle assessment.

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