

Microwave pyrolysis, a novel process for recycling waste automotive engine oil

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ABSTRACT

Used automotive engine oil was treated using a microwave-induced pyrolysis process, with the intention of assessing the suitability of the process in recovering valuable products from this otherwise difficult to dispose of waste. The resulting pyrolysis gases were condensed into liquid oil; the yield and composition of the recovered oil and remaining incondensable gases were determined, and these were compared with those arising from fresh oil. Process temperature was shown to have a significant effect on the overall yield and formation of the recovered oils. The recovered liquid and gaseous pyrolysis products contained various light hydrocarbons which could be used as a valuable fuel and as an industrial feedstock. Our results indicate that microwave pyrolysis shows extreme promise as a means for disposing of problematic waste oil. The recovery of commercially valuable products shows advantage over traditional, more destructive disposal methods, and suggests excellent potential for scaling the process to the commercial level.

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1. Introduction

Waste automotive engine oil (WAO) is an environmentally hazardous, high-volume waste that is difficult to treat and dispose of due to the presence of undesirable species such as soot, polycyclic aromatic hydrocarbons (PAHs), and impurities from additives such as chlorinated paraffins and polychlorinated biphenyls (PCBs). On a global basis, nearly 24 million tonnes of WAO are generated each year [1].

Existing treatment processes for WAO, such as incineration and hydro-treating, are becoming increasingly impracticable as concerns over environmental pollution and additional sludge disposal are recognised [2,3]. Although several studies have revealed the potential of pyrolysis as a disposal method for waste oil [4,5], the use of this technology is not widespread at the present time.

Microwave-induced pyrolysis (MP) is a relatively new process that was initially developed by Tech-En Ltd in Hainault, UK; this anaerobic thermal treatment uses a microwave-heated bed of particulate carbon, and has been shown to be an effective method of recovering useful chemicals present in wastes such as plastics [6]. Microwave pyrolysis is able to treat various kinds of real-world waste more effectively than traditional pyrolysis processes by facilitating a more efficient transfer of heat to the waste, offering exceptional control over the heating process, and by providing a strong reducing chemical environment that reduces the

formation of undesirable species. These factors have the potential to increase yields of desirable pyrolysis products such as gaseous and liquid hydrocarbons; these can then be treated and used as valuable industrial feedstock while simultaneously recycling otherwise difficult to dispose of waste.

While studies have been conducted using microwave pyrolysis to treat other wastes [7,8], we believe this is the first application of the technology to WAO. This work has been conducted in order to assess the technical and economic feasibility of using MP to treat and recycle WAO.

2. Experimental

2.1. Apparatus

The experimental apparatus developed and used during this investigation is shown in Fig. 1. It consists of a modified catering microwave oven (1) with a maximum power output of 5 kW. The oven has 4 magnetrons, each of which is controlled by a separate switch such that the power output can be controlled to 25, 50, or 75% of the maximum, with a continuous generation of microwaves rather than with on/off cycles. The reactor (2) is a quartz vessel of 180 mm diameter. This vessel is placed in a moulded base made of a microwave-transparent heat insulating material (VF1500AK prefired, M. H. Detrick, Mokena, IL). The reactor has an agitation system that consists of an impeller with two 45° pitched blades, 11-mm-diameter (pipe) stainless steel shaft, and a motor (3) with a maximum speed of 6 rpm.

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Nomenclature

ANOVA	one-way analysis of variance
BTX	benzene, toluene, xylene
FAO	fresh automotive engine oil
I.D.	internal diameter
n.d.	not detectable
WAO	waste automotive engine oil
N.R.	not reported
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
SD	standard deviation
TIC%	total ion content percentage
GC-MS	gas chromatography–mass spectroscopy

The temperature of the carbon load in the system is monitored using two thermocouples; one is ducted into the carbon through the centre of the shaft, the other enters the reaction chamber through a port on the top of the reactor. Both thermocouples are in direct contact with the carbon inside the reactor. The thermocouples are connected via a data acquisition card (DT302, Data Translation, Marlboro, MA) to a computer that runs a control program developed in the VEE package (Agilent Technologies, Palo Alto, CA). This software reads the temperature at a rate of 100 Hz, averages the readings, and sends on/off commands back to the magnetrons to maintain the desired temperature. The reactor is gravity-fed with the waste oil using the injection vessel (4). Valves permit inert helium gas to purge the incoming material of oxygen to avoid any combustion occurring in the reactor. The flow rate of the purging gas is monitored using a rotameter. The pyrolysis products leave the reactor and pass through a system of three water-cooled Liebig condensers (5,6,7), which collect condensed hydrocarbons in main and secondary collection flasks (8,9). The pyrolysis gases then flow through a cold trap (10); the remaining non-condensable gases are passed through a cotton wool filter (11) to collect any aerosols present before being vented from the system.

2.2. Materials and methods

Shell 10W/40 highly refined base oil was used throughout the experiments. The WAO was collected from an MG ZT diesel car driven for approximately 23,000 km. Before pyrolysis, the oil samples were filtered to $<0.45\ \mu\text{m}$ to remove metal particles,

carbon soot, and other impurities; volatiles and water were eliminated by heating at $110\ ^\circ\text{C}$.

Particulate carbon (TIMREX FC250 Coke, TIMCAL Ltd, Bodio, Switzerland) was used as a microwave absorbent to heat the WAO; this was pre-heated to $800\ ^\circ\text{C}$ for 45 min to remove any water and sulphur-containing compounds. Detailed specifications of the carbon are presented in Table 1.

2.2.1. Experimental procedure

One kilogram of carbon was placed into the quartz reactor. The apparatus was assembled as in Fig. 1, and nitrogen gas was vented through the apparatus at a flow rate of 0.2 l/min. A complete purge of air was ensured by washing out the system for at least 10 min before heating. The bed of carbon particles was stirred by the agitator at 6 rpm. The carbon was heated to temperatures ranging from 250 to $700\ ^\circ\text{C}$, and maintained within 1% of the target temperature by computer control. Once the target temperature was attained the reactor was left for 5 min to ensure complete temperature equilibration, the oil sample was then injected into the reactor. During the experiment gas was sampled after the filter (Fig. 1) into 10 l bags for later analysis.

When the accumulation of liquid product had stopped and gaseous products were no longer observed in the system the reactor was visually inspected to ensure that the reaction was fully completed. This was deemed to be the case if no oil sample remained in the reactor and the carbon appeared dry and without 'sticky' texture. Once the reaction had finished, the microwave oven was switched off and cooled with the aid of a fan. The nitrogen flow was continued until the reactor reached a temperature of $80\ ^\circ\text{C}$. The reactor was then disconnected from the condensation system and sealed to prevent contact of the carbon with air.

The yield of solid product was determined by measurement of the weight change in the reactor (no solid products were observed to have left the reactor). The yield of liquid product was determined by measuring the weight increase in the collecting vessels and filter. The yield of gaseous product was determined by mass balance and assumes that whatever mass of added sample not accounted for by the solid and liquid product measurements had left the system in gaseous form.

The data recorded are the average of the results obtained from three valid repeated runs conducted under identical conditions. Later, the pyrolysis products were analyzed by gas chromatography–mass spectroscopy (GC-MS) to identify their chemical composition.

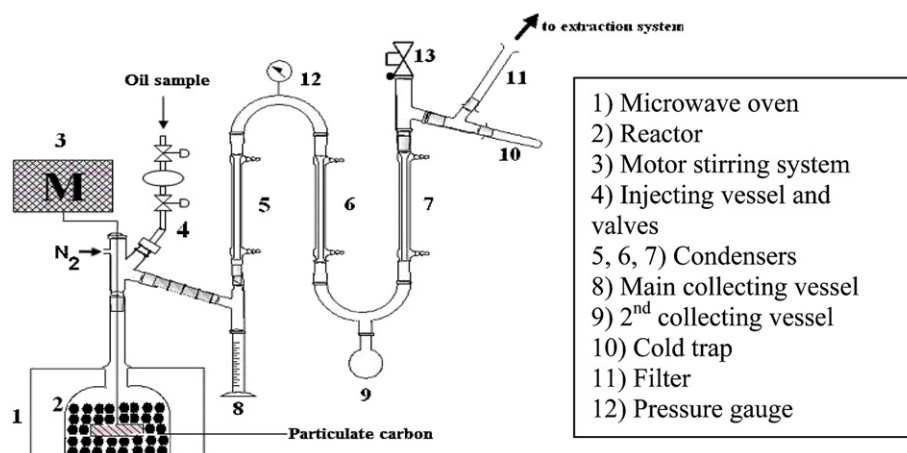


Fig. 1. Schematic layout of bench-scale microwave-induced pyrolysis system.

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