

PYROLYSIS OF WASTE POLYPROPYLENE PLASTICS FOR ENERGY RECOVERY: INVESTIGATION OF OPERATING PARAMETERS AND PROCESS DEVELOPMENT AT PILOT SCALE

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KEY FINDINGS

The conversion of Polypropylene (PP) into liquid fuels under atmospheric and vacuum conditions were both promising. Nonetheless, vacuum pyrolysis showed greater potential in the conversion of energy stored in waste PP into liquid fuels. Also, it was inferred that condensable products recovered under vacuum conditions contained fewer aromatic compounds (with more paraffinic compounds) because of their prevalent diesel composition. This means these products possess better combustion characteristics than corresponding products obtained under atmospheric conditions, which were mostly dominated by aromatics (due to their dominant gasoline composition). Condensable products recovered under atmospheric and vacuum conditions will therefore be much suited for applications in gasoline (petrol) and diesel engines respectively, although further treatments such as distillation to obtain pure products will be required. Moreover, most of the heavy condensable products recovered were in the form of wax-liquid mixture (for atmospheric conditions) and solid wax (for vacuum conditions) and would have to undergo further processing to convert them into marketable oils. However, their direct use in Heavy Fuel Oil (HFO) boilers is highly applicable. The experimental results with PP were also compared to similar results obtained with polystyrene and multilayer plastic wastes. An economic assessment was done to determine the minimum fuel selling price (MFSP) of the oil obtained from these 3 different waste plastics. Oil from polystyrene had the lowest MFSP at 0.28 US\$/kg, primarily due a high yield of oil. On the contrary, the multilayer had the highest MFSP at 0.44 US\$/kg, because it had the highest capital costs and also the lowest oil yield. Due to the low energy content (calorific value) of the oil from multi-layer plastics, the MSFP on an energy basis was more than double that of polystyrene based oil. The MFSP of the oil from polypropylene pyrolysis (7.2 US\$/GJ) was slightly higher than for polystyrene (6.2 US\$/GJ). However, the oil from polypropylene is the preferred product, as it has more applicability and operational safety, as it is primarily an alkane mixture. The polystyrene oil however, is a mix of aromatic compounds and has lesser range of applicability, while also being a carcinogenic liquid. It could however, be sold as an aromatic additive for jet fuels, if has the correct fuel properties such flash point, boiling point and viscosity.

INTRODUCTION

Polypropylene (PP) has been identified as the second most abundant plastic waste in landfills worldwide and the fastest growing plastic waste in South Africa. This was blamed on the limitation of conventional mechanical recycling techniques not being able to handle real life plastic wastes contaminated with other organic wastes. Recycling via pyrolysis has been identified as a promising route to managing plastic wastes since it can handle significant levels of contamination alongside generating products with interesting fuel prospects. Pyrolysis is mostly conducted under atmospheric conditions. However, pyrolysis can also be conducted under vacuum conditions (pressures below atmospheric). Vacuum

pyrolysis of other organic wastes such as biomass and waste tires have been covered significantly in literature and have demonstrated promising yields of condensable products (oil and wax). Unfortunately, vacuum pyrolysis of plastics has received very little attention and has been identified as a gap. Furthermore, transition from bench to industrial scale processes is mostly complicated. Therefore, pilot scale processes are important and serve as a mediation to both levels. Pilot processes also play a key role towards attaining a sustainable commercialization of plastics pyrolysis into fuels.

Firstly, the research assessed the effects of temperature and heating rate on pyrolysis of waste polypropylene (PP)

plastics into liquid fuel products under atmospheric and vacuum conditions at bench scale. Secondly, a 5 kg/h pyrolysis pilot plant was designed and commissioned as part of the study on which bench scale tests conducted at atmospheric conditions were scaled up to.

METHODS

The effects of four different temperatures (450, 488, 525 and 600°C) at slow (15°C/min) and fast (175°C/min) heating rates on condensable products yield and quality obtained from waste PP pyrolysis were investigated under atmospheric and vacuum conditions on a bench scale reactor. Fast heating rate condition from bench scale tests was then mimicked on a 5 kg/h pyrolysis pilot plant that was installed and commissioned as part of the study. Fast heating rate was chosen due to the similarity of both processes (both employed a pre-heated reactor). Condensable products obtained were characterized for diesel (C11-C23) and gasoline (C6-C10) range compounds. Physico-chemical properties of the condensable products were also performed and compared with commercial liquid fuels.

RESULTS

For the temperature range, 450 - 600°C investigated at bench, 488 and 525°C were observed to be the temperature points where promising yields of condensable products (oil and wax) were attained under both atmospheric and vacuum pyrolysis. Yields of at least 81 wt.% were recovered. However, when comparing the energy conversion from waste PP into condensable products, vacuum pyrolysis seems more promising. Additionally, temperatures beyond 525°C promoted severe cracking reactions which favoured the production of permanent gases to the detriment of condensables (oil

and wax). Compositions of condensable products revealed that they contained compounds in both the diesel and gasoline ranges. However, the proportions of these compounds varied with the alteration of reaction conditions and were seen to affect the Higher Heating Values (HHVs) of the condensable products, reducing the HHVs of condensable products at severe reaction conditions due to the increased production of aromatics (to the detriment of paraffinic compounds). Range of HHVs obtained for all condensable products (41-46 MJ/kg) were consistent with commercial liquid fuels.

Maximum yield of condensable products obtained on pilot scale tests were observed to decrease by about 5 wt.% when compared to similar conditions at bench scale. Considering the elongated length of the pilot reactor which somewhat intensified cracking reactions, the 5 wt.% decrease in yield was promising. Physico-chemical properties (Density, Kinematic viscosity, pour point, Boiling point range, Cetane Index and Aniline point) of condensable products recovered from pilot tests further confirmed that condensable products obtained at all process conditions contained compounds both in the diesel and gasoline ranges.

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