



## Research paper

## New energy value chain through pyrolysis of hospital plastic waste

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## HIGHLIGHTS

- The thermal decompositions of hospital plastic waste.
- Controlled pyrolysis can be applied to produce valuable molecules or hydrocarbon-based fuels from hospital plastic waste.
- Maximising of liquid fraction through pyrolysis parameters optimisation.

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This work is dedicated to identify changes in polymers thermochemical behaviours during the pyrolysis run at different reactor scale, and influence parameters that allow adapting the process at larger scale in order to optimise liquid fraction. It was established that the total conversion obtained during pyrolysis in laboratory scale reactor was in close agreement with TGA results, the temperature related to maximum weight loss being in the thermal range of maximum period of vapours condensing.

## Keywords:

Pyrolysis

Hospital waste

Gas-chromatography/mass spectrometry (GC/TCD, GC/FID-MS)

## ABSTRACT

In this paper, the evolution in thermochemical behaviours of hospital plastic wastes and changes in chemical composition and characteristics of pyrolysis liquid products have been investigated by using different fixed bed reactor scales. The main objective is to identify the critical technical parameters enabling thermochemical process adaptation in function of raw materials chemical structure, with the aim of maximising the yield of condensable fraction and optimising its energetic properties related to internal combustion engines.

It is a step-by-step procedure using three reactor capacity levels, which allows various aspects approach of thermochemical process development from the evaluation of global reaction kinetic parameters to the measurement of physicochemical properties of the final pyrolysis products. In order to reduce the gas and solid fractions with corresponding increasing of condensable products, the transposition of thermal and kinetic information provided by thermogravimetric analysis (TGA) to larger reactors is used to control of process parameters. In this experimental work the mass of samples increases from 0.05 g in the thermogravimetric analyser to 600 g in the bench scale reactor.

Gas-chromatography techniques have been used to identify the chemical composition of gases (GC/TCD) and liquids (GC/FID-MS).

It was established that changing the reactor scale does not result in significant differences in pyrolysis product distribution, neither in gas composition. On the other hand, the aspect and the quality of condensable fraction display a high variability. Also, the energy contained in the final valuable pyrolysis product was compared with the energy demand during the thermochemical transformation in order to evaluate the energy efficiency of the process.

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## 1. Introduction

Due to a massive increase in volume and diversity of plastic waste materials generated by human and industrial activity, statistics show that more than over 260 million tonnes of plastics were produced in the world [10,35]. Approximately 15 million tonnes of post-consumer plastic waste are generated throughout Europe each year [9,10], while in the United States 20 million tonnes of

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**Table 1**  
Petrol and energy consumption in plastic making [9,15,36,37].

No.	Material	Petrol consumption [L/kg]		Melting point [°C]	Energy consumption [MJ/kg]		
		Min	Max		Total	Oil	Others
1	PVC	0.75	1.65	100–260	53	24	29
2	PE	0.57	0.72	105–130	70	55	15
3	PP	0.54	0.68	130–170	73	58	15
4	PS	0.50	0.72	240	80	55	25
5	PET	0.47	1.28	250–260	84	31	53
6	PC	0.37	1.10	155	107	36	71

waste are produced [35]. Present in many applications mainly because of its ease of implementation, its strength and lightness, the plastic is still one of the least recycled materials, with a capitalization rate of approximately 5%. As the consumption and production of polymers are continuously increasing, the amount of polymer wastes is increasing too, packaging representing the largest single sector. The sector accounts around 40% of world plastics consumption and plastic is the material of choice in nearly half of all packaged goods [10,11].

In addition, their potentially harmful effects on the environment and human health have led to an increasing awareness about an urgent need for implementation of an appropriate safe disposal. Due to their raw material (Table 1), there is an obvious need to reduce the generation of plastic wastes and to recycle them. On the other hand, the technologies for energy recovery from wastes have an increasingly role in moderating the problems. In addition, these technologies lead to a substantial reduction in the overall plastic waste volume and the remaining products for final disposal are better managed, meeting the pollution control standards [39].

Accordingly, modern incinerators are designed to minimize the air pollution, but they are extremely costly to build. There are lots of incinerators currently operating in the world, but only a few are used to produce energy (Fig. 1). Also, local communities are still very opposed to the building of waste incinerators near their homes and anti-pollution measures become more restrictive, with particular concern about dioxin production. As a result, up to 30% by weight of the original waste remains to be land filled and it is often more toxic than the original material [38].

So that, plastic waste pyrolysis [3,22], gasification [24] and liquefaction [27] processes become promising energy recovery techniques for optimal upgrading fuel [21]. Moreover, pyrolysis of plastic mixture [1], based on the decomposition of polymers at different temperatures, allows the treatment of polymers with simultaneous decomposition and separation [2,18]. Thus, high value chemicals [14,23,31] and gasoline [2] or diesel-range fuels [21] can be easily recovered from plastic waste pyrolysis.

It is well accepted that plastic behaviour during thermal degradation as well as its kinetics play a vital role in establishing pyrolysis procedures from reactor design point of view and scaling up of industrially viable [13,16]. Current technologies studied and applied for plastics/polymer thermochemical processing [26,29,30,33], have been investigated and the results are rather contradictory, especially concerning the yields in liquid products and its properties. Also, there are conflicting views related to plastic behaviour in different scale installations with no mentioned large differences from a county to another concerning the polymers main characteristics: molar masse, additives, and copolymers ratio [12,30].

The enormous range of polymer properties depends on the arrangement and nature of the repeating units and on the types of intra-/intermolecular forces, by the degree of symmetry and uniformity in molecular structure. All these affect the melting and

glass-transition temperature, miscibility with other polymers, and consequently the mutual interaction of polymers in their melt [5,34,36]. As a result, generalization of the pyrolysis behaviour of plastic wastes is not possible mostly due to the variation in the molecular weight distribution of polymer].

This study has been developed in the frame of 3 years research project funded by the Region of Pays de la Loire (France). The aim was the conception and development of an integrated system for plastic waste valorisation as alternative liquid fuel and the validation of this fuel by experimental analysis into a single cylinder, four-stroke, air cooled, direct injection, constant speed diesel engine developing a power output of 4.5 kW. The study responds to several European directives related to reinforcing the efforts in developing waste-to-energy technologies able to reduce the volume and the toxicity of wastes together with their recycling/energy valorising potential.

Knowing that each chemical modification of polymers can induce strong deviation in thermochemical behaviours, the main aim of the first stage of this project was to obtain complete information on plastics waste decomposition during the O<sub>2</sub>-free thermal processes at different reactor capacity levels.

Thus, thermogravimetric analysis and pyrolysis tests in laboratory and bench scale reactors have been performed. The thermogravimetric study was carried out with 0.05–0.18 g of sample, while in laboratory and bench-scale fixed-bed reactors experiments have been conducted on around 50 (±5%) g and 600 (±5%) g, respectively.

In the bench scale reactor, the tests were performed at 550 °C. Instead, limited by heating device power, in the laboratory scale reactor the operating temperature was 470 °C.

## 2. Experimental work

### 2.1. Tested materials

The experiments were performed on used polymers (basically hospital plastic wastes, syringe, petri-dishes, bottles, etc ...) selected by their large applications and the energy and petroleum consumption required for their production. Their ultimate analysis is presented in Table 2.

There are tree plastic classes that concern this study: (1) polyhydrocarbons – olefin-based polymers (polypropylene – PP, polyethylene – PE) and aromatic-based polymers (polystyrene – PS); (2) oxygenated polymer (polymethyl methacrylate – PMMA); (3) nitrogen containing (latex gloves – Latex).

The monomer chemical structures and repeating unit of polymers are shown in Figs. 2 and 3. It can be noticed that the main bond in polymer chains is represented by C – C sigma covalent bond, and, except PE, they have ramification groups, also bounded to the polymer chain by C – C sigma covalent bonds: alkyl (– CH<sub>3</sub>), phenyl (– C<sub>6</sub>H<sub>5</sub>), nitrile (– CN) and methyl-ester (– COOCH<sub>3</sub>).

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