THE INFLUENCE OF FEEDSTOCK TYPE AND PROCESSING PARAMETERS ON SCRAP TYRE PYROLYSIS

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Abstract: The paper presents the results of an experimental study conducted on different scrap tyres types using pyrolysis processing for derived fuels production. The influence of processing parameters (process peak temperature, residence time) and tyre type on process kinetics and reaction products formation was investigated. A wide process peak temperature range from 350°C to 750°C was applied to representative feedstock samples using a tubular batch reactor under atmospheric pressure pyrolysis conditions. The solid and liquid fractions of the reaction products were analysed with respect to chemical composition and specific energy content. The pollutant chemical components migration was observed from the solid matrix of the samples into the reaction products. The experiments revealed 450°C to be an optimum peak processing temperature for waste to derived fuels conversion with minimum energy consumption. The results revealed significant differences between the two analysed feedstock with respect to the samples mass loss rate, reaction products distribution, chemical composition and specific energy content.

Keywords: Pyrolysis, Carbonic residues, Scrap tyres, Derived fuels.

I. INTRODUCTION

The increasing production of tyres as well as their disposal after the end of life period represents a well-known problem that requires special attention due the important mass flows and the environmental impact of these residues. In 2013 Europe was considered to be the second biggest tyre consumer after China, closely followed by the US, Japan and India [1]. In Europe about 2.7 million tons end of life tyres were disposed in 2010 after partial recovery of the re-usable ones. About 1.25 million tons were used for energy recovery while the rest was sent for material recovery [1, 2]. As in developing countries the life standard is increasing, a significant boost in this waste sector is expected in the years to come.

The two main constituents of scrap tyres are carbon and metal components. The high carbon content qualifies this solid waste for energy recovery while the metal compound imposes recycling procedures. The energy valorisation of this waste type is currently represented by combustion in the cement kilns [3]. Currently about 70% of scrap tyres are sent to combustion the rest is recovered either as raw materials or re-usable tyres. While the landfill disposal is no longer an option (it is banned in the European Union), the recycling of this residue requires important energy consumption for collecting, shredding and metal fibre removal [4]. Consequently the energy recovery either directly as thermal / power generation or indirectly as derived fuels represents the main valorisation option of this residue. Being used as alternative fuel in the cement factories across Europe since ’70thies it is well known that due to high carbon and sulphur content the scrap tyres combustion raises important environmental issues both to CO_2 and SO_2 release in the flue gas [3]. The modern cement factories use as energy input about 80% renewable sources [5, 6, 7]. The increasing demand for alternative energy vectors led to the use of scrap tyres for electricity generation or derived fuels production.

Thermo-chemical processing is intensively used as the main option for tyres valorisation. The physical structure of the feedstock (limited mechanical preparation by shredding and grinding) has a major influence on the combustion process that requires important excess air for the complete conversion of the fuel (large feed-in fuel particles). Consequently the flue gas flows are high and also the heat losses with their sensitive heat, leading to low energy efficiencies. Alternative processing through pyrolysis for derived fuel production is now a promising option. Nevertheless the operating parameters must be properly adjusted to the feedstock type in order to optimize the conversion efficiency and the reaction products generation.

The paper presents the results of an experimental study conducted on different scrap tyres feedstock (summer and winter tyres) using atmospheric pressure pyrolysis. The influence of processing parameters such as: process peak temperature and the residence time on process kinetics and reaction products formation was investigated.

II. MATERIAL AND METHOD

The samples were prepared by crumbing the scrap tyres (summer and winter) and removing the main steel cord. The rolling and the wall side of the tyrewere used.

For the sample mass variation under pyrolysis conditions a calcination oven having the crucible plate connected to a balance was used (model Nabertherm L 9/11/SW - LT 9/12/SW).

To observe the pyrolysis products distribution the samples were submitted to pyrolysis process using a laboratory scale tubular batch reactor (model Nabertherm RO 60/750/13) modified according to experimental requirements, under a nitrogen controlled atmosphere (Fig. 1.). The interior diameter of the reactor is 60 mm, and the sample is introduced in the active heating area that is 750 mm. The reactor has 2 gas inlets which offer the possibility to develop different experimental conditions: air / oxygen / nitrogen /water vapour, and 2 outlets for the gas and liquid discharges resulting from treatments applied to solid products [8].

The process pressure was atmospheric. The process temperature ranged between 350°C and 750°C.

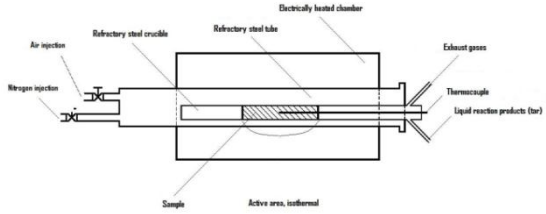


Fig. 1. Tubular batch reactor

The tar was separated from the pyrolysis gases using a condensing system. The char was collected at the end of each processing sequence from the crucible after complete its complete cooling under nitrogen atmosphere to prevent the oxidation.

Liquid and solid reaction products were submitted to elemental analysis (Perkin Elmer S-II) and calorimetric analysis. The higher heating value was measured by using a calorimeter IKA C200.

III. RESULTS AND DISCUSSIONS

By continuously measuring the sample mass, the volatile release sequence was observed for different treatment temperatures and residence time.

By observing the mass variation during 350°C pyrolysis it can be noticed the difference between the two tyres. The volatile release sequence begins after about 35 minutes for the summer tyre, while for the winter tyre it begins after 40 minutes. The volatile fraction released by the summer tyre is higher compared to the winter one. The difference is about 16 % points.

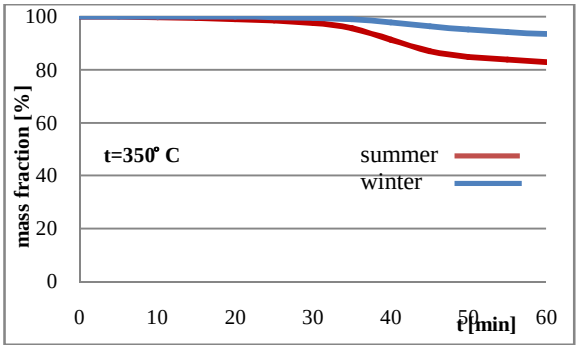


Fig. 2.Samples mass variation at 350°C

At 400°C the variation evolution changes compared to 350°C, the winter tyres losing the volatile matter faster than summer tyres. Also the volatile loss is higher with about 16 percent points for the winter tyre. The devolatilization process starts after about 20 minutes from the samples inlet into the reactor in both cases.

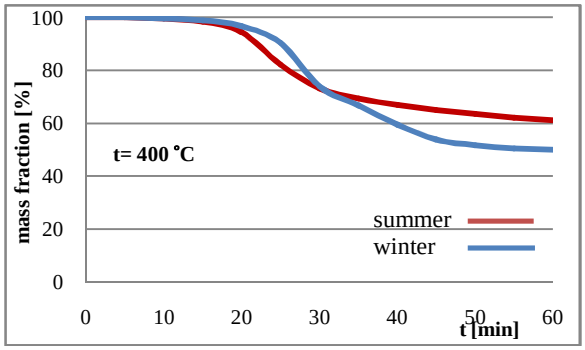


Fig. 3.Samples mass variation at 400°C

At 450°C there is clear difference between the volatile release initiation points. The winter tyre process stars after 4 minutes compared to 12 minutes for the summer tyre.

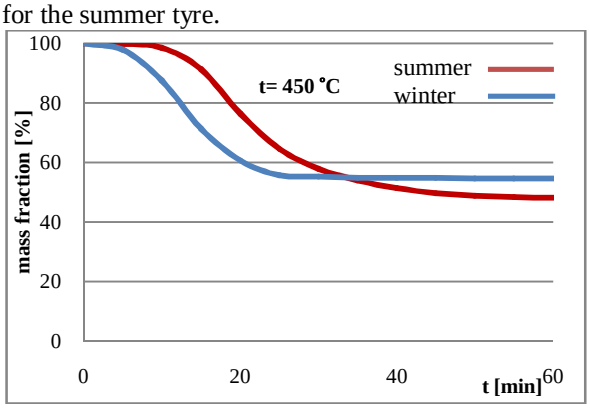


Fig. 4.Samples mass variation at 450°C

Also the char stabilization occurs earlier for the winter tyre (after 27 minutes),while for the summer one the char formation process continues for about 60 minutes.

At 500°C the pyrolysis process is similar for both samples, ending in about 23 minutes. The evolution curves are almost superposed with a minor difference of about 4 percentage points between the char fractions.

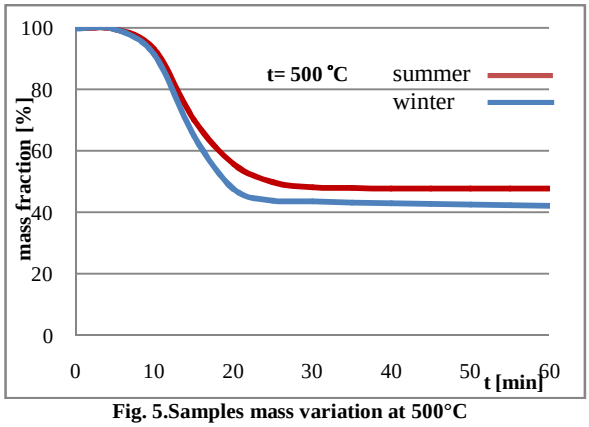


Fig. 5.Samples mass variation at 500°C

At 550°C the evolution of samples masses is similar to the one at 500°C with increased difference between the char fractions and shorter initiation time for the volatile release.

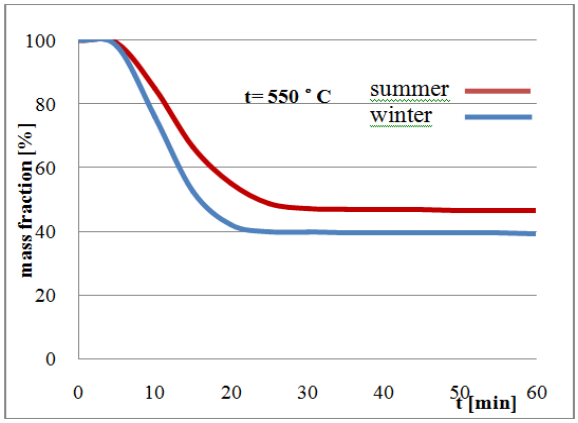


Fig. 6.Samples mass variation at 550°C

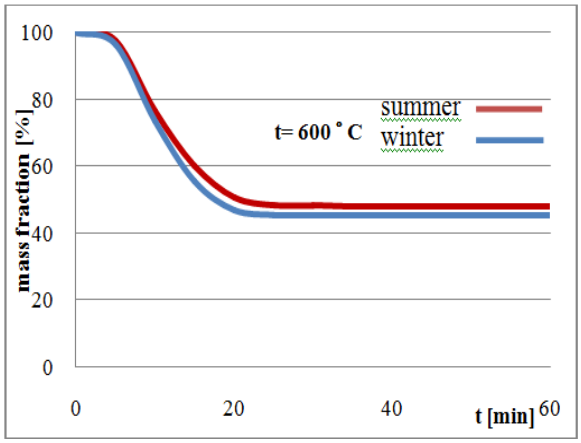


Fig. 7.Samples mass variation at 600°C

At 600°C the two curves have a superposing tendency, the difference between them being of less than 2 percent points. The char stabilizes after about 25 minutes. Starting with this temperature and up to 700°C the devolatilization sequence and char stabilization one is similar for both samples with small differences, less than 3 percent points.

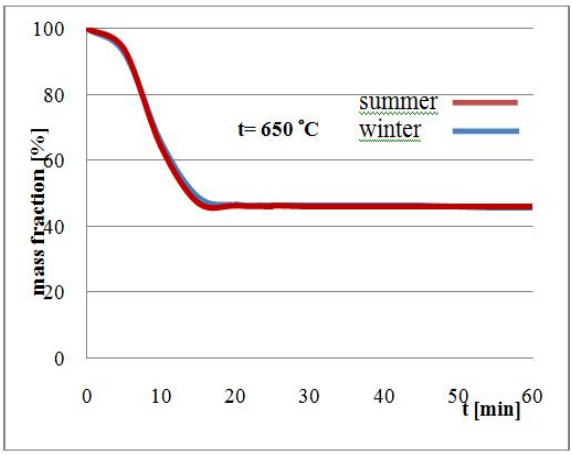


Fig. 8.Samples mass variation at 650°C

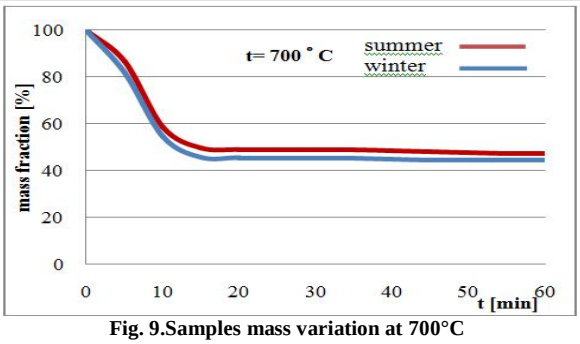


Fig. 9.Samples mass variation at 700°C

At 750°C the volatile release sequences starts simultaneously with the sample feed-in and ends after about 10 minutes. At this temperature the char fraction after stabilization is about 45% for both samples.

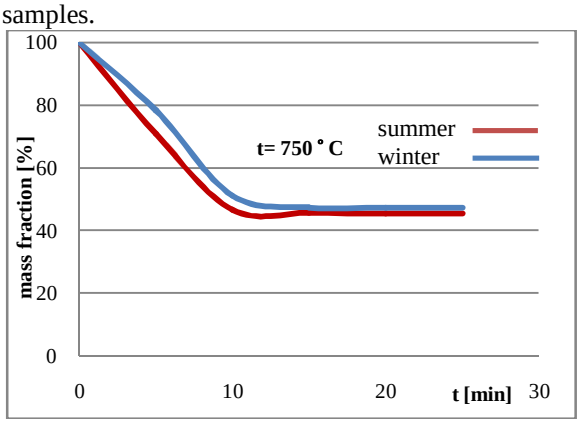


Fig. 10. Samples mass variation at de 750°C

By observing the sample mass evolution across the temperature range of the pyrolysis process we can conclude that the minimum treatment temperature for reaction products formation is 400°C in the case of winter tyre and 450°C in the case of summer tyre. In the range of 350°C – 450°C there are visible differences between the samples evolution under pyrolysis conditions. Starting with 500°C and up to 750°C the differences become smaller, the sample mass evolution being identical at 650°C.

Conducting pyrolysis experiments on the tubular batch reactor the reaction products mass distribution was determined. The results are presented in figures 11 and 12.

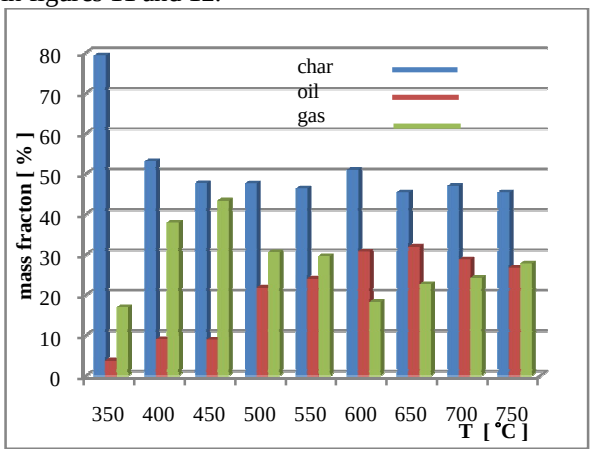


Fig. 11. Pyrolysis products for summer tyres

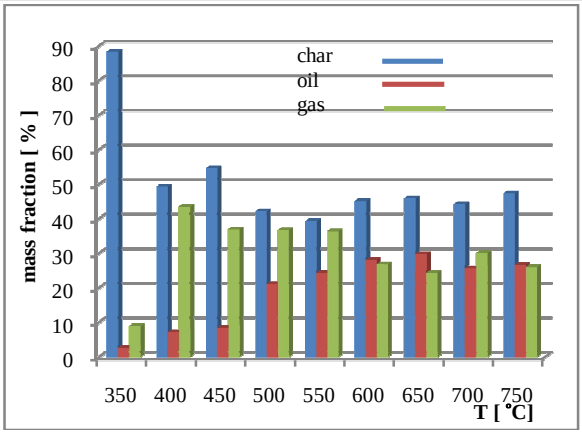


Fig. 12. Pyrolysis products for winter tyres

It can be noticed that at 350°C the char mass fraction is maximum with over 80%: and the tar fraction is minimum for both tyres types. The gas fraction is slightly higher for the summer tyres that reach 15% of the reaction products while for the winter tyres it is about 9%. The maximum gas fraction is reached at 450°C for the summer tyres and at 400°C for the winter ones. Starting with 400°C throughout the entire temperature range the char fractions are quasi constant for both samples, while the tar fraction increases. The tar fraction reaches its maximum at 650°C in both cases. At 750°C the tar and gas fractions are almost equal to 24-26%.

The sulphur content in the char is increasing with the temperature for both samples to a maximum value of about 1.856% at 500°C for the summer tyre and 1.914% at 600°C for the winter tyre. After reaching the maximum value, Sulphur concentration in the char decreases for both samples.

The variation of char higher heating value HHV is similar for the two analysed feedstock. The maximum HHV of about 36.7 MJ/kg (summer tyre) and 37.2 is obtained at 350°C. The char HHV is decreasing with the temperature to 25.6 MJ/kg (summer tyre) and 29.2 MJ/kg (winter tyre) at 750°C. The winter tyre char has the HHV superior to summer tyre char throughout the entire pyrolysis temperature range.The tar specific energy content is similar for both analysed samples. Its HHV is quasi constant about 43-44 MJ/kg reaching is maximum of 45.9 MJ/kg at 450°C.Based on the specific energy content of the reactants and reaction products the optimum processing temperature for derived fuels production with minimum energy consumption was identified in the range of 450°C – 500°C [9]. Nevertheless there are differences between the two feedstock that will require adjustments of the processing parameters (temperature and residence time) to optimize the industrial application with respect to the global process energy efficiency.

CONCLUSIONS

The pyrolysis experimental study conducted on summer and winter scrap tyres for derived fuels production revealed the importance of feedstock type and the processing parameters on devolatilization process kinetics and reaction products formation. By applying a wide temperature range from 350°C to 750°C the differences in pyrolysis products formation was observed. The minimum treatment temperature for reaction products formation is 400 C in the case of winter tyre and 450°C in the case of summer tyre. In the range of 350°C – 450°C there are visible differences between the samples evolution under pyrolysis conditions. Starting with 500°C and up to 750°C the differences become smaller, the sample mass evolution being identical at 650°C.At 350°C the char mass fraction is maximum with over 80%. The maximum gas fraction is reached at 450°C for the summer tyres and at 400°C for the winter ones. The tar fraction reaches its maximum at 650°C in both cases. At 750°C the tar and gas fractions are almost equal to 24-26%.The sulphur content in the char is increasing with the temperature for both samples to a maximum value of about 1.856% at 500°C for the summer tyre and 1.914% at 600°C for the winter tyre. Beyond these temperatures the Sulphur concentration in the char decreases for both samples.

The study revealed the importance of adjusting the pyrolysis operating parameters to feedstock type for better conversion efficiency and optimized global energy efficiency.

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