Renewable and Sustainable Energy Reviews 39 (2014) 1053–1073

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Activation of end of life tyres pyrolytic char for enhancing viability of pyrolysis – Critical review, analysis and recommendations for a hybrid dual system

N. Antoniou, G. Stavropoulos, A. Zabaniotou *

Department of Chemical Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form
4 June 2014
Accepted 19 July 2014
Available online 9 August 2014

Keywords:
ELTs
Pyrolysis
Char
Activation
Activated carbons
Viability
Sustainable operation

ABSTRACT

Taking under consideration the environmental boundaries but also the minimization of operating cost, End of Life Tyres (ELTs) depolymerization technology, via pyrolysis, can be characterized viable, under the condition of the effective valorization of every produced stream. This study aims to investigate which factors determine the path to activated carbon production from tyre-derived char, assuring that the received product will be of accepted quality, thus setting it as a commercially competitive product. To obtain current information on char activation, a comprehensive literature review was undertaken. An assessment based on process parameters, economic aspects and proposed uses of the produced activated carbons, was also presented. The proper selection of activation conditions (time, temperature, activating agent) results to a carbon adsorbent with prescript physical and chemical properties, suitable for specific applications. Towards energy self-sufficiency of the whole plant, a number of recommendations were made for the dual pyrolysis-activation scheme. Eventually, this would be an extra asset for the proposed valorization route of ELTs, via pyrolysis process.

Contents

1. Introduction . . . 1054
2. Pyrolysis products . . . 1055
   2.1. ELTs pyrolysis gas . . . 1055
   2.2. ELTs pyrolysis oil . . . 1055
   2.3. ELTs pyrolysis char . . . 1056
3. Activation . . . 1056
   3.1. Physical activation . . . 1057
   3.2. Chemical activation . . . 1058
   3.3. Type of reactors . . . 1058
      3.3.1. Multiple hearth furnaces . . . 1058
      3.3.2. Fluidized bed reactors . . . 1058
      3.3.3. Rotary kiln reactor . . . 1058
   3.4. Conditions affecting activated carbon quality . . . 1059
      3.4.1. Activation temperature and carbon burn-off . . . 1059
      3.4.2. Char particle size . . . 1060
      3.4.3. Residence time . . . 1060
      3.4.4. Gas phase composition . . . 1060
      3.4.5. Alkali additives . . . 1060
      3.4.6. Type of feedstock . . . 1060
      3.4.7. One-step vs two-step activation process . . . 1060
      3.4.8. Activation with supercritical water . . . 1060
4. Activated carbons originated from tyre's pyrolytic char . . . 1060

* Corresponding author. Tel.: +30 2310 996274.
E-mail address: azampani@auth.gr (A. Zabaniotou).

http://dx.doi.org/10.1016/j.rser.2014.07.143
1364-0321/

4.1. Activated carbons from used tyres as received . . . 1060
4.2. Activated carbon from pyrolytic char of de-mineralized tyres . . . 1063
4.3. Activated carbon applications . . . 1063
4.3.1. Gas phase applications . . . 1063
4.3.2. Liquid phase applications . . . 1064
5. Economic viability and LCA . . . 1064
5.1. Manufacturing cost . . . 1064
5.2. Selling Price . . . 1064
5.3. Life cycle assessment . . . 1065
5.4. Scaling up ELTs pyrolysis system . . . 1067
6. Dual hybrid system barriers and recommendations for successful implementation . . . 1067
6.1. Complexities and obstacles . . . 1067
6.2. Recommendations for an integrated dual scheme of pyrolysis/activation process . . . 1068
6.2.1. A large capacity-continuous double kiln operation plant . . . 1068
6.2.2. A medium capacity-batch one kiln operation plant . . . 1068
6.2.3. Continuous conical spouted reactor technology . . . 1068
6.3. Recommendations for decreasing pyrolysis cost . . . 1069
6.3.1. Reduce raw material cost as low as possible . . . 1069
6.3.2. Minimize plant capital cost . . . 1069
6.3.3. Good choice of Carbon product properties . . . 1069
6.3.4. Application of energy conservation technologies . . . 1069
6.3.5. Use of one step production scheme . . . 1070
6.3.6. Plant capacity . . . 1070
6.3.7. Operation mode . . . 1070
6.3.8. Automation . . . 1070
6.3.9. Selection of Activation method . . . 1070
6.3.10. Energy balance . . . 1070
7. Conclusions . . . 1070
Acknowledgements . . . 1070
References . . . 1070

1. Introduction

Generally, almost every ground transportation need is met through vehicles of any kind. As a result, a huge amount of used tyres is generated every year globally. Recent statistical data show a 5% increase of global tyres production in 2011, compared to 2010, reaching 14.68 million tons [1–3]. Asia and Oceania account for almost 60% of the global production (Fig. 1). On the other hand, Japan disposes one million tons of tyres every year while China, generated 5.2 million tons in year 2010, becoming one of the countries with largest production of used tyres [4,5].

The disposal of End of Life Tyres (ELTs) is a serious environmental issue. Although they constitute a problem, at the same time they provide valid opportunities for resources conservation, since they represent waste materials with great potentials as for recovering of valuable materials and fuels [6]. Tyres are a co-polymer of long-chain polymers including isoprene, styrene and butadiene that are cross-linked with the addition of sulphur (vulcanization). Small amounts of inorganic constituents are also used during their manufacturing process.

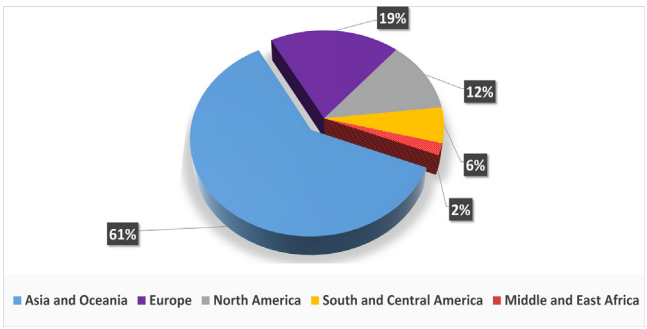

Fig. 1. World tyre global production (2011).

Several techniques and methods regarding ELTs management, including retreating and reclamation, were applied [5,7]. Recycling as a management route, despite its broad acceptance still includes high cost processes, also resulting to end products with questionable characteristics [8]. On the other hand, the most common thermal application of used tyres is in fact, their use as a supplementary fuel in cement kilns (co-combustion) [9,10]. Alternatively, pyrolysis and less frequently gasification are proposed. However, the latter mostly refer to experimental and pilot scale processes.

Pyrolysis attracted much attention due to the characteristics of the expected products. During pyrolysis, heat is supplied at an inert atmosphere to ELTs that decompose via a large number of thermal cracking reactions to a series of gas, liquid and solid products. Research work on ELTs pyrolysis began two decades ago and continues up to date, through the implementation of novel methods and techniques, while focusing mainly on the effect of operating conditions on product yields and on products' qualitative characteristics [11,12]. Few pilot and industrial scale plants were constructed and operated, adopting the prior experience on ELTs pyrolysis [13–24]. Based on the above mentioned developments, used tyres pyrolysis was introduced in industry as a mature technology offering a proven alternative to the disposal of this waste material. Specialized equipment suppliers are scattered worldwide, providing turn-key solutions and expertise, especially for ELTs pyrolysis. Despite these developments and the experience gained from operating plants, some intrinsic problems characterize ELTs pyrolysis as less attractive than expected; thus, not promoting its advantageous characteristics over incineration process [25]. The major obstacle to be overcome, is related with the disposal of process products and especially, of pyrolysis oil and residual carbon black; pyrolysis gas can be consumed in-plant, to fulfil the energy needs of the pyrolysis kiln.

The implementation of pyrolysis, as an alternative waste management process should aim to sustainability, through the