24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-0100
ENERGETIC POTENTIAL OF PLASTIC RESIDUES

Solidônio Rodrigues de Carvalho
José Silvio Pessoa Filho
Carlos Alberto Apolinário Júnior
Lívia Domingos Barbosa
Valério Luiz Borges
Federal University of Uberlândia – UFU, 2121 Avenida João Naves de Ávila, Uberlândia-MG, 38408-100, Brazil
solidonio@ufu.br
jose.pessoa@ufu.br
karlossjr@hotmail.com
liviadbarbosa@hotmail.com
valerioluizborges@ufu.br

Abstract. *The current energy scenario requires studies and efforts to develop innovative technologies in a sustainable manner, with respect to optimize the use of renewable and non-renewable energy sources. More specifically, it is noted nowadays an exaggerated consumption and consequent accumulation of plastic residues derived from petroleum. Plastic, one of the symbols of disposable consumer society and one of the most common constituent of garbage, has the following characteristics: low cost, low weight, good mechanical endurance, impermeable, transparency, durability, staining capacity. Such characteristics provide irresistible triumphs for its use in several important applications in society. But, their residues cause considerable problems in the world, due to its large volume and the difficulty of treatment. Thus, alternatives and strategies recycling's and recovery of post-consumer plastics are being developed to reduce the impact created, such as: landfill, physical recycling and thermochemical recycling (incineration, gasification, liquefaction and pyrolysis). The pyrolysis consists of a thermal decomposition in the absence of oxygen, typically used in some industrial processes, such as: charcoal production and polymers formation. But with the recent panorama, there is a growing interest in the application of this process in solids residues to generate fuel and raw materials for chemical industries. Thus, it is proposed in this work to research and develop an equipment to carry out the pyrolysis of plastics residues in order to extract its by-products: condensable and non-condensable gases. In a broader sense, it is proposed to develop new technologies for energy recycling from plastic residues in order to give a correct destination to the hydrocarbons intrinsic to its structure.*

Keywords: *energy recycling, fuel, plastic, pyrolysis, residues, sustainability.*

1. INTRODUCTION

Studies and research are aimed at increasing the diversity of the energy matrix to ensure global energy demand and minimize dependence on fossil fuels. In this case, Costa (2006) recommends in addition to the use of alternative fuel sources, the most efficient use of the petroleum resources that are still available, be requested by techniques of optimization of energy efficiency, request recycling and reuse processes of oil resources.

Another aspect, problematic and current, is a high production of waste and its reuse system. Specific cases of these residues are plastics, whose consumption has increased exponentially in recent years (Paradela, 2007). It is the fact that it is a component of the disposable consumer society and is one of the most common constituents of trash after paper (PIATTI AND RODRIGUES, 2005).

Sharuddin *et al*. (2016) argues that the demand for plastic products has increased due to the rapid growth of the world population. According to the authors Gorni (2004), Piatti and Rodrigues (2005) and Costa (2006), polymer materials are widely used in all areas of economic activity, sometimes accompanying the entire product life cycle. The accelerated consumption and disposal of plastics used in ephemeral applications, such as packaging, creates an alarming accumulation of waste in recyclable and mainly non-recyclable garbage dumps, which generates a great environmental impact.

Typical characteristics of plastics, such as: low cost, low density, good mechanical strength, impermeability, transparency, durability and colorability plus printing, have given it irresistible advantages for its massive use in the form of packaging, an extremely important application in a society (GORNI, 2004).

According to Piatti and Rodrigues (2005), the option of not using plastic materials is considered unfeasible by many experts, who assert that the substitution of these materials by other materials such as paper, wood, glass and metals would imply an increase in volume and weight of garbage, and the consequent increase in costs such as collection and treatment. In addition, the substitution of plastic packaging for paper means an increase in the consumption of trees and destruction of forests.

Plastic waste causes considerable problems in the world due to its large volume and difficult treatment. Although landfill and incineration are the traditional methods of treatment of these wastes, they are not an attractive solution since adequate deposits are expensive and incineration encourages the emission of noxious gases. In addition, plastic waste can only be partly recycled into new products, given the major concern with contamination (BRÁS. 2011).

An alternative is to apply the thermal treatment of pyrolysis to these wastes and to make use of GC (Condensable Gases) and CNG (Non-Condensable Gases) as fuels (fossil substitutes) or chemicals (Brás, 2011). Pyrolysis consists of a thermal decomposition in the absence of oxygen, typically used in some industrial processes, such as: charcoal production and the constitution of polymers. But in the current scenario, there is a growing interest in the application of this process in waste, in order to generate fuels and raw materials for chemical industries (PARADELA, 2007).

According to Sharuddin *et al*. (2016), the sustainability of the pyrolysis process is unquestionable, since the amount of plastic waste available in each country is reaching millions of tons. With the pyrolysis method, waste management becomes more efficient, with less required landfill capacity, less pollution and low cost. In addition, with the application of pyrolysis to decompose plastic into fuel (valuable energy), dependence on fossil fuels as non-renewable energy can be reduced and this can solve the increased demand for energy.

Still, according to Gonçalves (2007), from the point of view of the conservation of raw material sources, any form of recycling is desirable and should be encouraged. In practice, however, the cost of energy used in recycling and the impacts of the waste in the environment should be considered.

2. REVIEW ON PYROLYSIS OF PLASTIC WASTES

The word "plastic" and its derivatives comes from the Greek adjective "plastikos", which means malleable or moldable (Brás, 2011; Spinace and Paoli, 2005). Plastics are synthetic materials, which means they are either artificial or fabricated (NOBEL PRIZE, 2007).

The substances used as raw material in the preparation of plastics are obtained mainly from petroleum and are denominated monometers (Piatti and Rodrigues, 2005). In fact, oil is the raw material responsible for the production of various comforts related to modern life.

Oil is made up of a mixture of organic compounds, mainly hydrocarbons. It is known that from the fractional distillation of the crude oil, which occurs in the refineries, several fractions are obtained: liquefied gas, naphtha, gasoline, kerosene, diesel oil, paraffinic greases, lubricating oils, tar. Thus, the fraction from which the monometers are obtained is naphtha, which undergoes a thermal cracking process (heating in the presence of catalysts), gives rise to several substances, among them, ethylene, propylene, butadiene, butene, and isobutylene, called basic petrochemicals. These, in turn, are transformed into so-called fine petrochemicals, such as polyethylene, polypropylene, polyvinyl chloride. In the subsequent stage, fine petrochemicals are chemically modified or transformed into consumer products (PIATTI AND RODRIGUES, 2005).

According to Piatti and Rodrigues (2005) and Brás (2011), the chemical reactions that lead to the formation of plastics are called polymerizations. A polymerization is a chemical transformation in which small molecules, monomers, come together to form giant molecules, the macromolecules.

Plastics are a group of polymers that have intermediate mechanical properties between those presented by the elastomers and the fibers. Regarding the technological process of preparation and the behavior during heating, plastics are divided into two groups:

i) Thermoplastic: polymeric material that has the capacity to soften and flow when heated, and can be molded in the desired format. This change is a physical and reversible transformation. Ex.: polyethylene, polyvinyl chloride, polystyrene

ii) Thermoset: are polymerization products in which cross-bonding takes place between cavities, becoming rigid, phenomena known as "cure". After the "cure", they become infusible, insoluble and not recyclable. Ex.: polyurethane, epoxy resin, bakelite (PIATTI AND RODRIGUES, 2005).

There are several classes of polymers composed solely of carbon and hydrogen (hydrocarbons); polypropylene (PP), polybutylene (PB) and polystyrene (PS) are some examples. However, other elements of the basic composition of the polymers (e.g., chlorine in polyvinyl chloride (PVC), nitrogen and oxygen in nylon, fluorine in teflon, etc.) may be included (BRÁS, 2011).

The Brazilian Association of Technical Standards (ABNT), through technical norm NBR 13230: 2008, established a symbology for the identification of plastic packaging (Fig. 1). By means of this standard, it is possible to guide the selective collection programs, especially scavengers and scrap yards that act in the sorting of materials destined to the recycling.

Figure 1: Plastic Packaging Identification Symbols. 1. PET (polyethylene terephthalate); 2. HDPE (high-density polyethylene); 3. PVC (polyvinyl chloride); 4. LDPE (low- density polyethylene); 5. PP (polypropylene); 6. PS (polystyrene); 7. Others. (Fonte: NBR 13230:2008)

Possible destinations for solid waste in general, which include plastics are: landfill, physical recycling and thermochemical recycling (Costa, 2006). In the latter, incineration and pyrolysis are included.

Energy recovery through incineration is the main destination for waste currently used after landfill. It is a process that occurs at high temperatures (600 to 1100 °C) and converts combustible waste into non-combustible waste and ash, significantly reducing the mass and volume of the original material (up to 90%) while ensuring destruction of all pathogenic microorganisms (PARADELA, 2007).

The fact is that incineration consists of incomplete combustion, with high volume of soot, release of gases and toxic substances, need of additional improvements in the burner to allow a good yield. Thus, when applying thermal treatment of pyrolysis in plastic waste, these problems can be remedied, since it is a process of thermo-degradation with complete absence of oxygen.

According to the authors Paradela (2007) and Costa (2006), the term pyrolysis (from Greek: pyro = fire; lysis = drop), by definition refers to the thermal degradation of materials in the absence of oxygen. This degradation applied in plastics has great interest as an alternative source of energy or chemical raw materials, as well as contributes to the solution of environmental problems (GULLON *et al*., 2001)

The pyrolysis technique is commonly used in the industrial production of charcoal from wood. It is especially suitable for the chemical recycling of plastic waste mixtures, as opposed to physical recycling, it is more flexible in relation to the presence of impurities and contaminants or even several types of plastic in the recycling stream (PARADELA, 2007).

According to Spinace and Paoli (2005), pyrolysis at low temperature is thermal degradation in the absence of oxygen. In this case, depolymerization and the formation of small amounts of aromatic compounds and light gases, such as methane, are obtained, obtaining high boiling temperature liquids such as waxes and starting materials for the production of polyolefins. In pyrolysis at high temperature occurs thermal decomposition in the absence of air or oxygen deficiency, obtaining oils and gases that will later be purified by standard petrochemical methods. In a few cases it is possible to recover the monomers as the main product. Pyrolysis is an endothermic reaction, so it is necessary to add heat. Polymers with high impurities may be recycled by pyrolysis.

Therefore, through this project, it is proposed to seek an alternative to recycle such waste. It is hoped with this research, to study and develop equipment to carry out the appropriate pyrolysis of plastic waste in order to extract its by-products, that is, combustible gases for the production of energy. Innovation is to prove to society that plastic waste can also be a synonym for the word fuel. In this way, the post-use plastic will no longer be seen as garbage. Broken the paradigm, such waste will become a lucrative source of energy, similar to any other fuel derived from petroleum.

3. EXPERIMENTAL AND RESULTS (LABORATORY SCALE REACTOR)

The experiments were conducted in the Heat and Mass Transfer Laboratory (HMTL) of the Faculty of Mechanical Engineering of the Federal University of Uberlândia and consisted of applying the thermal treatment of pyrolysis in samples of plastic waste, in order to make use of the condensable gases and non-condensable.

Thus, tests performed on some prototypes have shown that both the condensable and non-condensable portion of the gas coming from plastic waste is combustible. In addition, it was found that the pyrolysis process must be carried out at high temperature and pressure (above 10 bar (1MPa)) to avoid solidification of the plastic in the extraction line. Thus, the importance of developing an appropriate and safe bench to carry out the tests.

Figure 2 shows the combustion of Condensable (GC) and Non-Condensable (CNG) gas from the pyrolysis of 180 grams of plastic by means of a prototype reactor installed inside a muffle. In the experimental tests, the muffle was set to operate at a constant temperature of 500 °C and the synthesis gas was incinerated when the reactor exceeded the pressure of 1 MPa. Before the burner, equipment was installed to cool the gas and store the condensable gas portion.

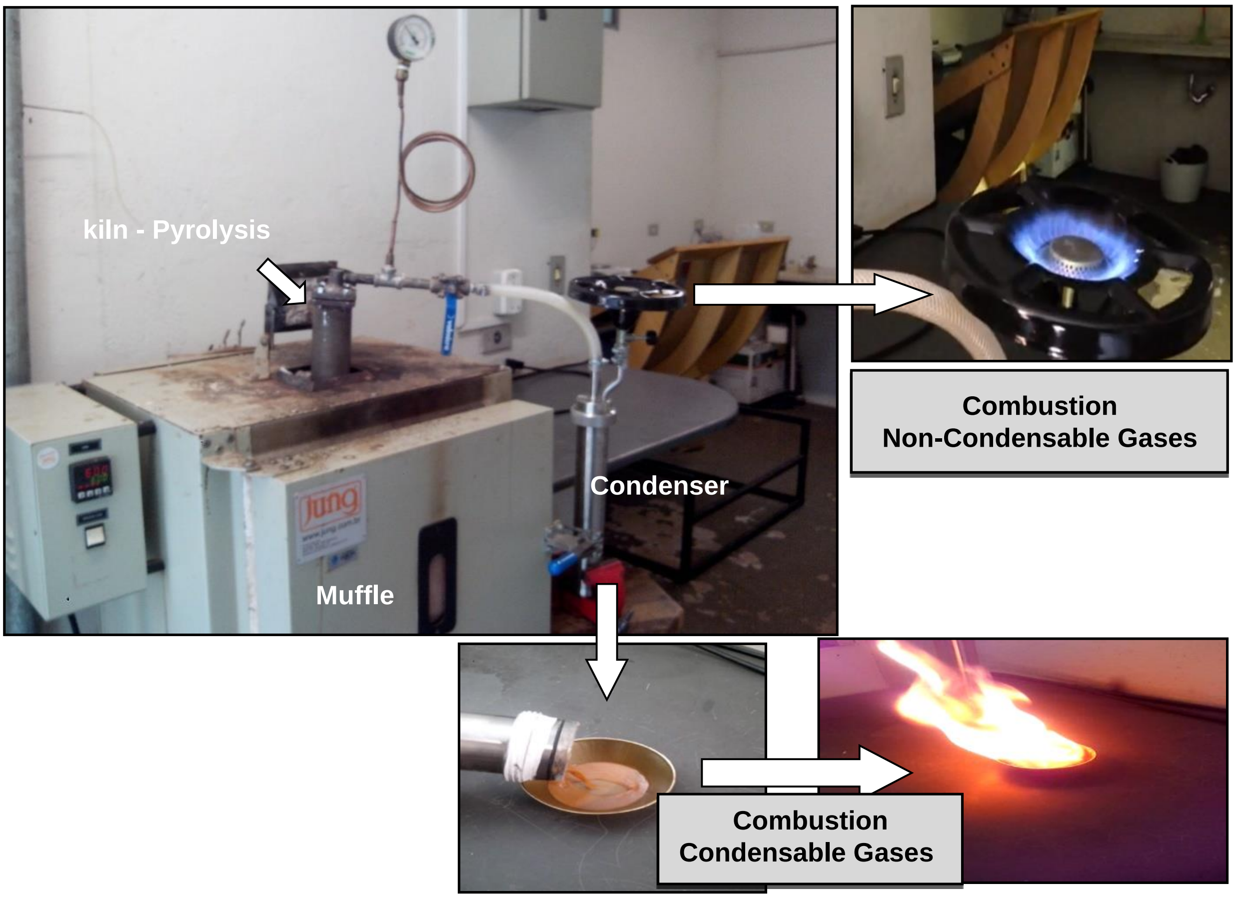

Figure 2: Prototype Reactor to Pyrolysis of Plastic Wastes and Combustion of Condensable (GC) and Non-Condensable (CNG) Gas

In the case of the combustion of CNG, a stable flame of a bluish color is very similar to the combustion of LPG (liquefied petroleum gas). In case GC, the combustion is typical of that derived from oils.

In view of this scenario, some doubts have arisen regarding the calorific value of each part of the gas and the relation between the quantity of plastic waste and the quantity of gases (GC and CNG) produced. For such questions, Spinace and Paoli (2005) demonstrated that 1 kg of plastic generates 1 liter (0.001 m³) of condensable gas. In addition, the authors comment that the calorific power would be close to that of fuel oil and larger than that of coal.

The experimental tests and the previously presented results motivated the development of a new pyrolysis bed that was initially fueled by commercial gas: LPG. During the pyrolysis process part of the non-condensable gas would be used instead of the LPG, which would make the bench self-sustaining. As it is a laboratory bench, the rest of the gases (GC and CNG) would be redirected for analysis and later for some application: electricity production or they would simply be incinerated.

Figure 3 shows a schematic of the experimental workbench proposed for the present work.

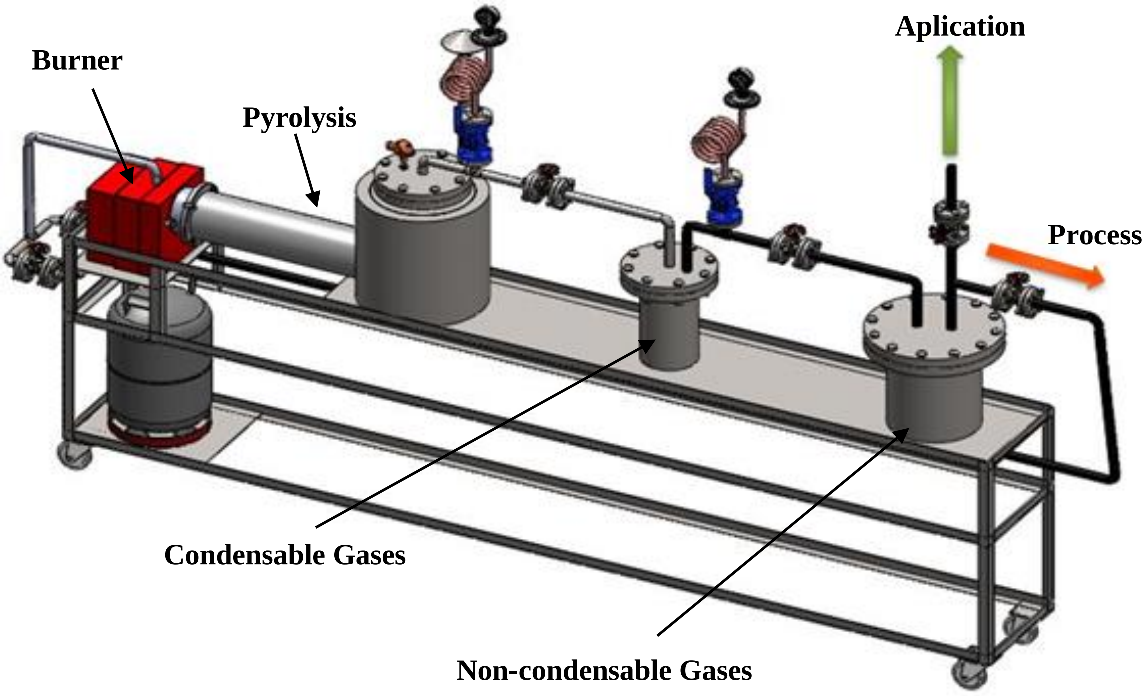

Figure 3 – Experimental Workbench Proposal

By means of calculations, it was possible to remedy the following doubt: the bench is really viable, it would be able to produce a quantity of fuel for the pyrolysis process and there would still be fuel for application in alternative forms of energy production.

According to Blest (2016), to carry out the pyrolysis of 1 kg of plastic waste 3 hours of heating are required and approximately 1000 watts of energy are spent. Therefore, it can be concluded that the energy cost of the process (EC) (energy required to perform the pyrolysis of 1 kg of plastic), according to Eq. (1), will be:

$$EC = 1000 \cdot 3 \cdot 3600 = 10800 \left[\frac{kJ}{kg\ of\ plastic}\right] \tag{1}$$

By means of thermogravimetric analyzes performed by Bannach et al. (2011), it was found that the pyrolysis process provides around 20% by mass of solid waste and 80% by mass of fuel (GC and / or CNG). According to Copagaz (2016), the average calorific value of hydrocarbon gases is approximately 41000 kJ/kg of fuel (energy produced from the combustion of 1 kg of fuel). Therefore, by means of Eq. (2):

$$M = \frac{10800 \cdot 1}{41000} = 0.26\ [kg\ of\ fuel] \tag{2}$$

Therefore, it is concluded that 0.26 kg of fuel would be required to carry out the pyrolysis process and the remaining 0.80 kg - 0.26 kg = 0.54 kg could be availed in alternative energy production systems.

In addition, in order to better substantiate the feasibility of this research project, a new bench was developed similar to the one proposed in Figure 3. However, in a reduced scale and with the source of heat coming from an electric resistance, according to Figure 4.

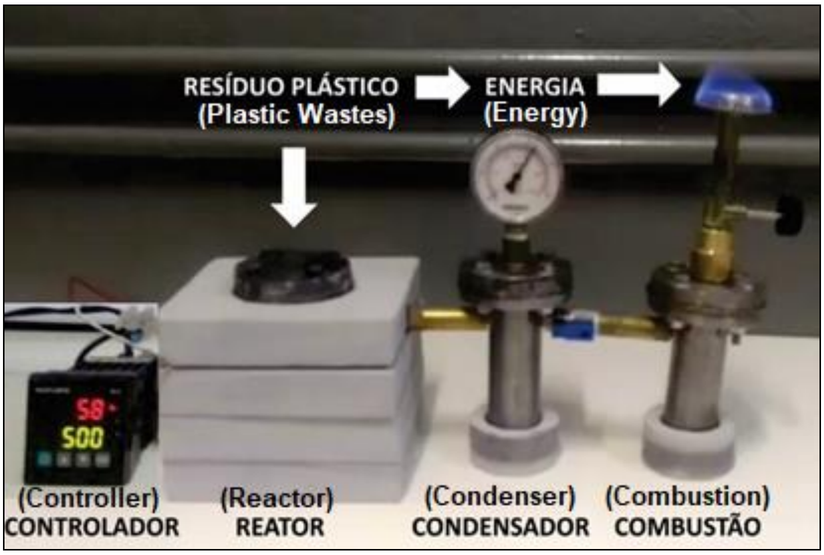

Figure 4: Laboratory Scale Reactor

In Figure 4 the mobile bench is presented, composed of a furnace-reactor, kept heated at 500ºC by an electric resistance coupled to a temperature controller, to accommodate the waste samples. During the process, the condensable gases are retained in the condenser and the non-condensable gases enter the reservoir (combustion) to be burned or later analyzed.

Experimentally, the energy consumption of this bench was, according to Eq. (3), of 6.03 kWh/kg of plastic, that is, 660 W (220V and 3A) of electrical power was supplied during 0.21h (12.5 min) to perform the pyrolysis of 23 g (0.023 kg) plastic waste sample.

$$Energy\ Consumption = \frac{220 \cdot 3 \cdot 0.21}{0.023 \cdot 1000} = 6.03\ \frac{kWh}{kg\ of\ plastic} \tag{3}$$

In this process, 21 g (0.021 kg) of fuel gas was obtained. Thus, the energy recovered by burning the synthesis gas (calorific value of 41000 kJ / kg of gas) was 10.39 kWh/kg of plastic, according to Eq. (4).

$$Energy\ Recovered = \frac{0.021 \cdot 41000}{0.023 \cdot 3600} = 10.39\,\frac{kWh}{kg\ of\ plastic} \tag{4}$$

Therefore, it is concluded that the process of converting plastic waste into fuel is feasible. However, it should be pointed out that this research is in the first semester of development and is expected to end in 2019. However, preliminary and visual results have already been satisfactory.

4. CONCLUSION

In this work, a proposal was presented to convert plastic wastes into energy. Through data from the scientific literature and preliminary laboratory tests, it is expected to develop an experimental bench of tests. Preliminary results shows that the process of converting plastic waste into fuel would be feasible, ie about 32.5% of the fuel gas generated would be used by the experimental bank itself, and the surplus, about 67.5%, would be used for power generation. Thus, in view of such scenario, the next step is to build the bench and prove in practice the feasibility of this research project.

5. ACKNOWLEDGEMENTS

The authors thank the Government Agencies - CAPES, CNPq and FAPEMIG – for their continuous financial support.

6. REFERENCES

ABNT, 2008. "NBR 13230: Embalagens e Acondicionamento Plásticos Recicláveis – Identificação e Simbologia". Rio de Janeiro, 8p.

Bannach, G., Perpetuo, G.L., Cavalheiro, E.T.G., Cavalheiro, C.C.S. e Rocha, R.R., 2011. "Efeitos da História Térmica nas Propriedades do Polímero PET: Um Experimento para Ensino de Análise Térmica". *Química Nova*, Vol.34, Nº 10, pp.1825-1829.

Blest, 2016 "Desk – Top Waste Plastic Oiling System Be-h". 18 Jan. 2016. <http://www.blest.co.jp/be-h_eng.html>.

Brás, D.M., 2011. "Estudo da Pirólise de Resíduos Plásticos Provenientes do Abate de Automóveis". Dissertação de Mestrado, UNL/FCT, Lisboa. <http://run.unl.pt/bitstream/10362/6888/1/Bras_2011.pdf>.

Copagaz, 2016. "Gás Liquefeito de Petróleo". 20 Jul 2016. <http://www.copagaz.com.br/representantes/o_que_e_glp.asp>.

Costa, P.A.C., 2006. "Produção de Hidrocarbonetos Líquidos e Gasosos por Pirólise de Resíduos Plásticos". Tese de Doutorado, UNL/FCT, Lisboa. <http://repositorio.lneg.pt/handle/10400.9/415>.

Gonçalves, C.K., 2007. "Pirólise e Combustão de Resíduos Plásticos". Dissertação de Mestrado, Escola Politécnica da Universidade de São Paulo, São Paulo.

Gorni, A.A., 2004. "Aproveitamento de Plástico Pós-Consumo na Forma de Combustível para Altos-Fornos e Coquerias". *PastShow*,Aranda Eventos, São Paulo.

Gullon, I.M.,Esperanza, M.,Font, R. "Kinetic Model for the Pyrolysis and Combustion of Poly-(ethylene terephthalate)(PET)". *Journal of Analytical and Applied Pyrolysis*, Vol.58, 2001, pp. 635-650. DOI:10.1016/S0165-2370(00)00141-8

Nobel Prize. "Plastics and Polymers". 2007. 12 Jan. 2016. <http://www.nobelprize.org/educational/chemistry/plastics/readmore.html>.

Paradela, F.M.R., 2007. "Estudo da Pirólise de Misturas de Resíduos Plásticos e de Biomassa". Dissertação de Mestrado, UNL/FCT, Lisboa. <http://repositorio.lneg.pt//handle/10400.9/450>.

Piatti, T.M,Rodrigues, R.A.F., 2005. "Plásticos: Características, Usos, Produção e Impactos Ambientais". *EDUFAL*, Maceió/AL. 51p. il. – (Conversando sobre ciências em Alagoas).

Sharuddin, S.D.A.,Abnisa, F.,Daud, W.M.A.W.,Aroua, M.K., 2016. "A Review on Pyrolysis of Plastic Wastes". *Energy Conversion and Management*, Vol.115, pp. 308-32. DOI: 10.1016/j.enconman.2016.02.037.

Spinace, M.A.S.,Paoli, M.A., 2005. "A Tecnologia da Reciclagem de Polímeros". *Química Nova (Online)*, Vol. 28, Nº 1, São Paulo, 2005, pp.65-72. ISSN 1678-7064. 23 Fev. 2016. <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-40422005000100014>.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.