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Technic-economic analysis of pyrolysis to produce fuel oil

Tailane Hauschild
tailane.hauschild@ufrgs.br
Programa de Pós-Graduação em Engenharia de Minas, Metalúrgica e de Materiais, e Laboratório de Materiais Cerâmicos (PPGE3M/LACER), Universidade Federal do Rio Grande do Sul, RS, Brasil

Carlos Pérez Bergmann
bergmann@ufrgs.br
Programa de Pós-Graduação em Engenharia de Minas, Metalúrgica e de Materiais, e Laboratório de Materiais Cerâmicos (PPGE3M/LACER), Universidade Federal do Rio Grande do Sul, RS, Brasil

Tania Maria Basegio
taniambasegio@gmail.com
Programa de Pós-Graduação em Engenharia de Minas, Metalúrgica e de Materiais, e Laboratório de Materiais Cerâmicos (PPGE3M/LACER), Universidade Federal do Rio Grande do Sul, RS, Brasil

Luís António da Cruz Tarelho
ltarelho@ua.pt
Department of Environment and Planning & Centre for Environmental and Marine Studies (CESAM), University of Aveiro, Aveiro, Portugal

Genyr Kappler
genyr.kappler@gmail.com
UNISINOS – Programa de pós-graduação em engenharia civil, São Leopoldo, RS, Brasil

ABSTRACT

It was made a technic-economic analysis of the feasibility of implementing a pyrolysis plant for the production of fuel oil (FO) from plastic fractions of Municipal Solid Waste (MSW). The catalytic pyrolysis process is carried out in a fixed bed reactor with a capacity of 4 m^3 loaded with crushed and dry plastic waste (volumetric mass of 500 kg/m^3), which is heated at a rate of 2 °C/min until the reaction temperature reaches 270 and 350 °C. Then, the pyrolysis process is then maintained at the established temperature for 6 hours. The retention time of the pyrolysis gases is 90 minutes. Each batch operation cycle lasts an average of 9 hours. It was evaluated production of FO from different plastic fractions resulting from MSW sorting in a medium-sized municipality. In scenario 1 (reference scenario), 1.04 and 3.63 ton/day of plastics of the MSW (PSW) are sent to recycling and landfill, respectively. Three alternative scenarios were defined and analyzed to implement plastic pyrolysis: scenario 2, 3.63 ton/day, the fraction of non-recycled PSW is considered for processing by pyrolysis; scenario 3, it is considered the recycling of PET and PVC, and the remaining PSW represents 4.36 ton/day, and it is considered for processing by pyrolysis; scenario 4, it is maintained the 4.36 ton/day of PSW as valorized by pyrolysis, and it is assumed that an additional 0.64 ton/day of PSW comes from an external source. The FO production costs were estimated at 1.50, 1.29, and 1.13 R$/L, approximately 41%, 49%, and 56% lower than the FO sale price (2.55 R$/L), for scenarios 2, 3, and 4, respectively. Costs of production per unit of energy (GJ) in FO are between 40.88 and 29.67 R$/GJ. The Net Present Value (NPV) of the solution, considering scenarios 2 to 4, increased from R$ 6.72×10^6 to R$ 11.29×10^6. The positive NPV for the scenarios 2 to 4 indicates the economic viability of the pyrolysis plant. The pyrolysis system would need to operate between three and four years to recover the invested capital. The costs of the municipality with the destination of MSW can be reduced in 54.75%, from 139.48 to 63.12 R$/ton MSW, between the reference scenario and scenario 4.

KEYWORDS: Pyrolysis. Plastics. Fuel oil.

INTRODUCTION

According to the Associação Brasileira de Empresas de Limpeza e de Resíduos Especiais (ABRELPE), between 2017 and 2018, the generation of MSW in Brazil increased by 0.82% and reached 216 629 tons day. In 2018, a monthly average of R$ 8.02 per inhabitant was spent by the cities from the South of Brazil in the management of MSW and other urban cleaning services (ABRELPE, 2019). For a medium-sized municipality with a population of 70 thousand inhabitants, this represents annually R$ 6.8×10^6 from the municipal budget.

Despite the Política Nacional de Resíduos Sólidos (PNRS) from Federal Law 12.305/10 (BRASIL, 2017a), which forbids improper waste disposal, about 59.5%wt of MSW is disposed off in sanitary landfills, 23%wt in inadequate sites, such as dumps, and 17.5%wt in controlled landfills (ABRELPE, 2019). According to Plastics Europe (EUROPE, 2019), the generation of plastics in the European Union reached around 62×10^6 tons in 2018, and despite the positive trend and recycling efforts, only 29.1×10^6 tons of plastic solid waste (PSW) was collected and with a recycling rate of 32.5% wt, while more than 24.1%wt of waste still is sent to landfills. These scenarios contribute to the PSW becoming one of the main cause of terrestrial environment contamination and negative impact on marine ecosystems (JAMBECK et al., 2015).

According to the Diagnóstico de Manejo dos Resíduos Sólidos Urbanos (SNIS-RS, 2019), only about 5.42%wt of the recyclable dry waste is recovered. Despite all efforts, conventional mechanical recycling methods cannot recycle all plastics due to impurities, as well as the difficulty to recycle blended polymers (ANUAR SHARUDDIN et al., 2016; IGNATYEV; THIELEMANS; VANDER BEKE, 2014). In this context, considering that 13.5%wt of MSW in Brazil is composed by PSW, from the 10.6×10^6 tons of PSW produced in 2018, around 10×10^6 tons were not subjected to any type of treatment, representing a significant economic loss.

This scenario shows the urgent need to develop alternatives for the proper management of the different fractions of the MSW, particularly the fractions of plastics. In addition to the adequate treatment of plastics, the aim should be the introducing of economic value in the management of MSW, contributing to sustainable development and the circular economy. In this context, an alternative that has been gaining attention in the treatment of the PSW is the thermochemical methods, such as pyrolysis to convert plastics into fuel oil (CHO; JUNG; KIM, 2010; WONG et al., 2015; ANUAR SHARUDDIN et al., 2016; LOPEZ et al., 2017).

Pyrolysis is defined as a thermochemical process, where long-chain polymer molecules are broken down into smaller and less complex molecules, by means of heat and pressure, in a temperature range of 400 to 800°C, and in the absence of O_2. The three main products are oil (liquid), char (solid) and permanent gases, which yield and quality depend mainly on the heating rate, process temperature, residence time, waste composition and particle size (KALYANI; PANDEY, 2014; KUMAR; SAMADDER, 2017; LOMBARDI; CARNEVALE; CORTI, 2015). The liquid oil produced is an intermediate product of great value for the industry, mainly for refineries, where it can be integrated as a raw material for the synthesis of liquid fuels, for example, gasoline and diesel (ANUAR SHARUDDIN et al., 2016; NO, 2014).

To boost public and private initiative to explore technological innovations in the treatment of solid waste in Brazil, the government created the Interministerial Ordinance No. 274, of April 30, 2019. It regulates the energy recovery from MSW, as referred in § 1 of art. 9 of Law No. 12,305, of 2010 (BRASIL, 2019b). Some companies in Rio Grande do Sul (Brazil) have been developing national technology for the pyrolysis process. For instance, the company BEINTEC Inovações Tecnológicas is a company from the city of Taquari that has in operation a demonstration pilot-scale pyrolysis unit for solid waste valorization. The company has a project that is under the installation licensing phase for an industrial-scale unit for the thermal treatment of medical waste (classes A, B, D and E). In the city of Gravataí, the company Sílex Tecnologias Ambientais produces industrial-scale reactors for the pyrolysis process of different types of waste. In the city of Canoas, the company ECO Clean Soluções Ambientais LTDA have an industrial waste pyrolysis plant - Class II is in operation, with a maximum processing capacity of 312 ton/month.

Although fuels produced by thermochemical conversion have received more attention in recent years, mainly due to environmental benefits, few studies have addressed the technic-economic potential of pyrolysis technology in the thermal treatment and valorization of PSW. In this context, it is needed to analyze whether the pyrolysis technology for the thermal treatment of PSW and the production of fuel oil will become an economically viable option.

In this context, the aim of this study is to develop a case study in a medium-sized municipality to analyze the technical and economic feasibility of implementing the pyrolysis technology to production of FO from PSW. Analyze the implementation of pyrolysis of non-recyclable PSW fractions and the entire PSW in different scenarios, considering the conversion into fuel oil. It will be also studied the potential decrease on management costs (R$ per ton of MSW) of MSW by adopting the pyrolysis solution.

METHODS

Selection of a case study and the scenarios for technic-economic analysis

The data on waste characteristics for the technic-economic analysis were obtained from a Municipal Solid Waste Sorting Center (MSW-SC), that receives all the MSW collected in a medium-sized municipality with approximately 71117 inhabitants (IBGE, 2020). According to the Fundação Estadual de Proteção Ambiental (FEPAM, 2020a), the activity at the MSW-SC is classified as medium pollution potential and as a small enterprise (from 150.01 to 1500 tons/month). In average, the total amount of MSW generated in the municipality is 10,891.3 tons/year, of which 802.8 tons/year is recyclable waste recovered at the MSW-SC, and 10088 tons/year are sent to the sanitary landfill by the municipality (SINIS, 2018).

The determination of the physical composition of the MSW used to estimate the mass of plastics available to the production of FO by the pyrolysis process was carried out according to the sampling method of ABNT NBR 10.007 (ABNT, 2004).

Recyclable materials of the MSW were 13.37%wt of plastics, 12.84%wt for cardboard and paper, 1.49%wt for glass, and 1.84%wt for metal; biodegradable organic matter corresponds to 45.57% wt, and 24.89%wt are other materials.

The scope of the case study for implementation of the pyrolysis process to the production of FO from PSW comprises the analysis of the four scenarios shown in Figure 1.

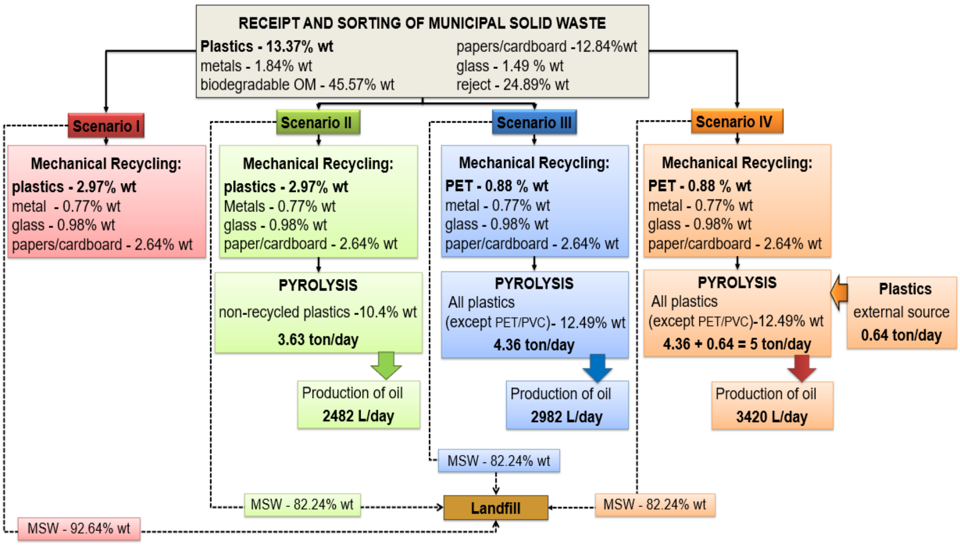


Figure 1 – Flowchart of the scenarios analyzed in the technic-economic study for plastics pyrolysis

The reference scenario, termed as scenario 1, refers to the current situation in the municipality, that is, 2.47%wt of PSW is recovered, while 10.4%wt of PSW is disposed off in landfills. The other materials, as paper, metals, glass, are sent for mechanical recycling, and represent 4.39%wt of the raw MSW. In scenario 2, the PSW fraction not recycled corresponds to 10.4 %wt of the MSW, and it is considered for processing by pyrolysis, while the system for sorting and recovering of the other materials is maintained as in scenario 1. For scenario 3, it is considered the recycling of PET and PVC, and the remaining PSW represents 12.49%wt of the MSW, and it is considered for processing by pyrolysis; the other materials, e.g., paper, glass, and metal, are sent to mechanical recycling. In scenario 4, it is maintained the 12.49%wt of PSW as valorized by pyrolysis, and it is assumed that an additional 0.64 ton/day of PSW comes from an external source, e.g., municipality or company that needs to process this material, to fulfil the total capacity of the pyrolysis installation which is 5 ton/day.

The PSW considered is composed of low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS). It was decided not to use polyethylene terephthalate (PET) and polyvinyl chloride (PVC) in the pyrolysis process, due to the problems of corrosion and clogging ducts in the gas circuit, as well as the production of HCl in the thermochemical degradation of PVC (CHEN; JIN; CHI, 2014; LOPEZ et al., 2012).

The plant will operate 26 days/month and 24 hours/day, thus a total of 7488 hours of operation per year. Therefore, the amount of PSW that will be processed by pyrolysis process is 3.63 ton/day, 4.36 ton/day, and 5 ton/day, in scenarios 2, 3, and 4, respectively.

The revenue and operating costs of the MSW Sorting Center

Table 1 presents the data referring to the indexes of materials sent for recycling, and the estimated financial return on sales of recyclable materials, a courtesy of the company Reciclagem Serrana, that provides sorting and transshipment services in the municipality of the case study. The unitary values for sale agree with the Compromisso Empresarial para Reciclagem (CEMPRE, 2019). From September 2018 to September 2019, the revenue from recycled material sales was R$ 511080.0, which corresponds to an average of R$ 636.32 per ton of recycled materials sold, and R$ 46.93 per ton of MSW generated.

Table 1 - Estimated financial return from the sale of recyclable

Materials	ton/year	%wt.t	Unitary value (R$/ton)	Subtotal (R$/year)
Paper/cardboard	288.0	2.64	390.0	112320.0
Aluminum	10.8	0.10	3350.0	36180.0
Glass	96.0	0.88	57.5	5520.0
Iron scrap	84.0	0.77	240.0	20160.0
PET	96.0	0.88	2000.0	192000.0
Rigid plastic	76.8	0.71	1050.0	80640.0
Film plastic	151.2	1.39	425.0	64260.0
Total	**802.8**	**7.37**		**511080.0**

a: Company RECICLAGEM SERRANA, personal communication, 2020

In the Municipal Solid Waste Sorting Center, the total mass of recyclable waste collected results from manual sorting activity carried out by 9 employees allocated on a conveyor belt. Each employee diverts from landfilling an average amount of recycled material equal to 286 kg/day, which performs an amount of 89.2 tons/year. Since the non recovered PSW is 1132.17 tons/year, it will be necessary to hire 13 more employees to perform the task. The summary of labor and indirect expenses for 12 and 25 employees is shown in Table 2.

Table 2 - Direct and indirect costs of providing service in the MSW Sorting Center

Account	12 employees	25 employees
Labor resources	477479.1	1015399.3
Uniforms and protective equipment	22530.0	49531.0
Vehicles and equipment	92070.0	92070.0
Tools and consumables	20840.0	20840.0
Benefits and indirect expenses (BDI)	131348.6	252411.2
Total (R$/year)	**744267.7**	**1430251.5**

a: Company RECICLAGEM SERRANA, personal communication, 2020

Description of the pyrolysis process

This study was carried out in cooperation with the company BEINTEC Inovações Tecnológicas. It is based in the city of Taquari in the State of Rio Grande do Sul/Brazil, where it has a pilot-scale plant for pyrolysis of solid waste in operation. The company has an industrial-scale pyrolysis plant in the licensing phase (FEPAM, 2020b) for the installation of an industrial-scale unit for the thermal treatment of medical wastes (class A, B, D, and E) and polymeric wastes from the health care system. BEINTEC is a developer of the technology and the company BENDER & ENERGIA is the manufacturer of the pyrolysis plants.

The thermochemical treatment plant, by pyrolysis process, chosen for the technic-economic analysis converts PSW into FO (oil with low pour point, whose commercial nomenclature is OCA and/or OCB) that can be used as fuel or as raw material for petrochemical products. The basic module of the plant is built to produce oil and can process 5 tons of PSW per day, but an equipment for electricity generation with 0.7 MWe of total installed power can be added.

The pyrolysis process consists of four steps: i) pre-treatment of waste, ii) pyrolysis of waste, iii) condensation of gases, and iv) gasification of the char to provide the required heat by the pyrolysis reactor.

i) In the first step, plastic waste undergoes a pre-treatment (WONGKHORSUB; CHINDAPRASERT, 2013) which consists of the grinding process, increasing its volumetric mass to an average of 500 kg/m³ and, if necessary, a drying step takes place to ensure that the moisture is below 20% wt.

ii) After the pre-treatment of PSW, the fixed-bed pyrolysis reactor with a capacity of 4m³ is loaded with pre-treated PSW, and then heated at a rate of 2°C/min until it reaches a reaction temperature between 270 and 350°C. The pyrolysis process is then maintained at the established temperature for 6 hours. The retention time of the pyrolysis gases is 90 minutes. Each batch operation cycle lasts an average of 9 hours. Meanwhile, plastic waste polymer molecules are broken up into smaller organic molecules or monomers by the action of heat in an oxygen-free environment. During this process, volatilization, and fusion reactions occur. To selectively promote specific reactions during pyrolysis and obtain higher yields of liquid products at low temperatures, catalysts are added to the PSW (PARK et al., 2008; SIDDIQUI; REDHWI, 2009). However, the company chose not to publish which materials are used as catalysts within the pyrolysis reactor.

iii) The gas generated in the pyrolysis process passes through the catalytic bed (KOH and NaOH) for the treatment of de-nitrogenization, de-chlorination, and de-sulphurization. The fusion of these materials occurs between the temperatures of 350°C to 400°C. Besides, most of the acid gas such as HCl, SO2, SO3, and H2S, are absorbed using inorganic acid H2SO4 (BEINTEC, 2020; PARK et al., 2008). When the catalytic cracking, and purification process finishes, the gas is conducted through heat exchangers where it is condensed into a liquid mixture of light and heavy hydrocarbons. These oils are an essential intermediate energy carrier with a high added value that can be integrated into conventional refineries as a raw material for the synthesis of liquid fuels, e.g., gasoline and diesel (SHARUDDIN et al., 2016).The permanent gas is used in the pyrolysis reactor as a purge gas, to prevent the entry of O2, and to promote the flow of the pyrolysis gas released during the process. The rest of the permanent gas is burned to generate part of the process heat for the pyrolysis reactor.

iv) The char is mixed with woody biomass and wastepaper, the blend produced is used in co-gasification in a second reactor to generate the heat required by the pyrolysis reactor. Thus, ensuring that the process is thermally self-sustaining.

In slow plastic pyrolysis, the main product is oil, while non-condensable gas and char are by products. According to Lee (2009), MSW plastics can be converted by pyrolysis into up to 80%wt of oil. Table 3 shows the fractions of the products generated in the process developed by BEINTEC.

Table 3 - Mass yield of products in the process developed by BEINTEC [a]

wt %	Oil	Gas	Char	H_2O
Minimum	55	12	10	1
Medium	67.5	16	15	1.5
Maximum	80	20	20	2

a: Company, BEINTEC Inovações Tecnológicas, based in RS/Brazil, personal communication, 2020.

In Table 4 are shown the characteristics of the FO produced during the pyrolysis of PSW in the system under analysis. The characteristics of this FO complies with Resolutions of the Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP) (BRASIL, 2007c, 2016d). From an economic perspective, attention should be paid to the conversion rates of PSW to oil; BEINTEC pyrolysis process has a conversion factor of 0.72 for the ratio liters of oil/mass of PSW, and the efficiency of the oil purification system is 95 %, thus, for each ton of plastics are is produced 684 liters of oil.

Table 4 - Characteristics of the FO produced in the BENTEC process [a]

Lower heating value	46.5 MJ/kg FO
Density 20 °C	0.786 – 0.847 g/cm^3
Viscosity 50°C	2.318 mm^2/s cst
Viscosity 100°C	1.085 mm^2/s cst
Sulphur content	1.785 mg/kg FO

a: Company, BEINTEC Inovações Tecnológicas, based in RS/Brazil, personal communication, 2020.

The FO obtained through the thermochemical conversion of PSW in the BEINTEC technology has a lower heating value (LHV) of 46.5 MJ/kg. This value is higher than market fuels such as diesel oil and gasoline that have LHV of 42 MJ/Kg and 43 MJ/kg, respectively (ANP, 2018e). Other authors cited LHV values in the range of 40.5 MJ/kg to 44.8 MJ/kg for plastic pyrolysis oil (CHO; JUNG; KIM, 2010; LEE, 2009; MANI; NAGARAJAN; SAMPATH, 2011). Wongkhorsub and Chindaprasert (2013) found a LHV of 46.1 MJ/kg for oil from pyrolysis of PSW, which is in agreement with the value of LHV for the fuel oil produced by BEINTEC. According to Lee (2009), pyrolysis oil has a higher hydrogen content, higher H/C ratio, and higher LHV compared to market oils.

Technic-economic Analysis

In the techno-economic analysis it is considered that it will be the municipality the investor and owner of the installation for thermochemical processing of the PSW. That is relevant because then, the PSW feedstock is considered as with no cost, nor revenue, because its municipality responsibility the management of MSW. The data used in the technic-economic analysis are shown in Table 5. The initial investment and operating costs for the pyrolysis system were provided by BEINTEC Inovações Tecnológicas. The total investment cost (TCI) consists of direct costs with installed equipment, indirect costs (e.g., engineering, and supervision), tax, and working capital (FIVGA; DIMITRIOU, 2018). Operating costs cover energy, lease, labor, maintenance, administration, and replacement costs. The costs for water consumption in the heat exchangers are considered zero because the condensation system is in a closed-loop.

Table 5 - Parameters used to economic analysis

Year of analysis	2020	
Useful life of the project in y[a]	15	years
Annual interest rate (r)[a]	8.43	%
Total investment cost (TCI)[a]	2850419.20	R$
Operational costs[a]	860840.00	R$/year
FO per ton of plastics[a]	684	L/ton. PSW
FO price per liter[b]	2.55	R$/L

a: Company, BEINTEC Inovações Tecnológicas, based in RS/Brazil, personal communication, 2020.

b: Company, Energia Brasil, based in SP/Brazil, personal communication, 2020.

To calculate the production costs of the fuel oil, an annual technic-economic estimation method was applied. The total capital required to install the plant is obtained through a bank loan that will be paid over the lifespan of the plant. The annual capital investment can be determined with Equation 1 (DIMITRIOU et al., 2015; FIVGA; DIMITRIOU, 2018):

$$ACI = TCI \times \frac{r \times (1+r)^N}{(1+r)^N - 1} \quad (1)$$

where *ACI* is the annual capital investment (R$/year), TCI is the total initial capital investment (R$), *r* is the interest rate, and N is the plant's lifespan.

"FO production costs" (R$/L) are calculated according to Equation 2, where the total annual costs (annual investment costs (AIC) plus "Pyrolysis operation costs" in R$/year) are divided by the "FO annual production" (liters of FO/year).

The inflation of capital prices, raw materials, utilities, and labor costs of MSW-SC are not considered for the calculation of oil production costs.

$$FO\ production\ costs = \frac{ACI + Pyrolysis\ Operating\ Costs}{FO\ Annual\ Production} \quad (2)$$

The “Costs per unit energy in FO” are determined by Equation 3:

$$Costs\ per\ unit\ energy\ in\ FO = \frac{FO\ production\ costs\ /Average\ density\ of\ FO}{LHV\ of\ FO} \times 10^3 \quad (3)$$

where “Costs per unit energy in FO” is in R$/GJ; “FO production costs” are in R$/L; the “Average density of FO” is 0.817 g/cm³; and “LHV of FO” is 46,5 MJ/kg.

In order to preliminarily assess the feasibility of the project, the ACI method allows quick and easy relation with the sale prices of the FO. The results are rather realistic as long as the inflation rates are not too different from the interest rate estimated. However, this method does not consider the decrease in the amount of revenue, nor the costs each year.

Therefore, the Net Present Value (NPV) was also calculated. The NPV method adequately accounts for the current value of all net gains received over the lifespan of the plant. A positive NPV means that the plant is economically viable and, therefore, it is handy to determine whether the project is feasible with higher accuracy. A discount rate “*i*" is introduced to represent the decrease in the value of earnings because it is not paid at the time of the capital expenditure, but several years later (SANTOS et al., 2019). The NPV is calculated by Equation 4:

$$NPV = \sum_{t=1}^{m} \frac{(E_n \times T) - C_{o\&m}}{(1+i)^n} - I \quad (4)$$

where E_n is the Annual FO production (liters heavy fuel oil/year); T is the FO sale price (R$/L); $C_{o\&m}$ is the operation and maintenance costs in R$/year; i is discount rate 10% (adopted); I is the initial investment in R$; m is the useful lifespan of the project in a year and n is the years of analysis

Costs of Municipal Public Administration with MSW destination

Therefore, the annual operation costs and revenues for the MSW-SC and the pyrolysis system were calculated. The total values referring to the revenues from the sale of recyclable materials and operating costs of MSW-SC are shown in section 3.1.2. The income from the sale of FO and the costs, for both the investment and pyrolysis operation, is calculated in section 3.3.1. The value for transportation and disposal of MSW is R$ 127.47/ton. This value is the cost for the municipality with outsourced companies. The management cost (in R$/ton) of the MSW generated is calculated by Equation 5. To do so, the difference between revenues and operation costs, specified above, was divided by the generation of MSW.

$$Costs\ of\ public\ services = \frac{\sum Revenue - \sum Operation\ costs}{Annual\ \ MSW\ generation} \quad (5)$$

The *Costs of public services* are the amount paid by the municipality per ton of MSW managed, which includes the treatment, transportation, and landfilling. The *Revenue* is the sum of the revenue obtained per year from the sale of recyclable materials and the annual revenue from the sale of FO. The *Operating costs* are the summation of the annual costs to operate the WSM-SC, transportation, landfilling, and both the annual investment and pyrolysis operating costs. The *Annual MSW generation* is the amount of MSW generated in the municipality in tons/year.

RESULTS AND DISCUSSION

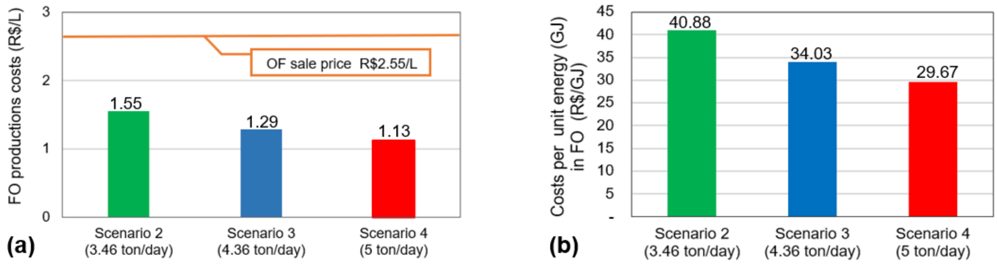
Production costs of fuel oil

The technic-economic analysis is made based on the annual evaluation method, applied to calculate the production costs of FO. The ACI during the lifespan of the pyrolysis plant was R$ 341,807.58. The production costs per liter of FO (R$/L) were calculated using Eq. 2.

The production costs per liter of FO, are shown in Figure 2(a), for the distinct scenarios considered, and were 1.55, 1.29, and 1.13 R$/L from scenarios 2 to 4 respectively. It is observed that the production costs of FO decreased by 27.4% when the production rate of FO increased from 3.63 to 5 tons/day, and decreased by 16.8% when the production rate increased from 3.63 to 4.36 tons/day. These trends indicate that the costs decrease in proportion of the increase of the amount of available plastic waste to be processed. Hence, the higher productivity of the plant should be prioritized. The specific cost of production are 39%, 49%, and 56% below the reference value for the sale price of the product (2.55 R$/L) for scenarios 2, 3, and 4, respectively.

Therefore, a primary comparison of FO production values and FO sale price have shown that the project can be economically attractive. However, it is necessary to evaluate the transportation costs for product delivery, which were not considered in this study.

Figure 1- (a) FO production costs per unit of volume (liter), and (b) FO production costs per unit energy (GJ).

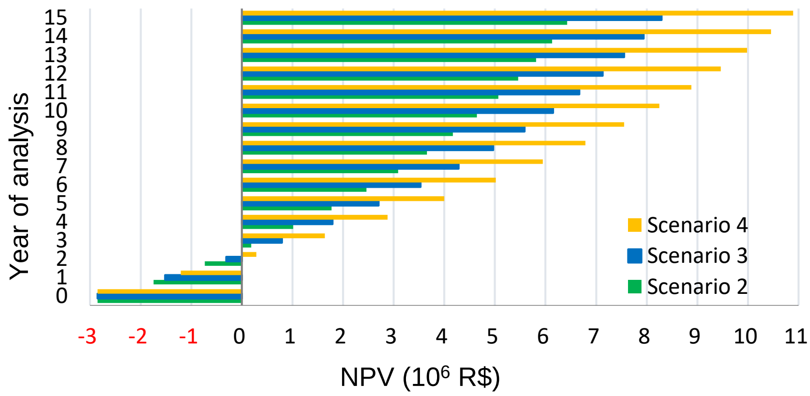


The production costs per unit of energy (GJ) in FO were determined by Eq. (3), and for scenarios 2, 3, and 4 the respective values were 40.88, 34.03, and 29.67 in R$/GJ (Figure 2b). It was observed a cost reduction of 6.85 R$/GJ between scenarios 2 and 3, and 11.21 R$/GJ between scenarios 2 and 4.

Net present value

The NPV determines all net gains obtained over the lifespan (15 years) of the plant, and the economic feasibility of the project is reached when positive NPV are obtained for the three scenarios evaluated. The NPV calculated was R$ 6.72×10^6, R$ 8.65×10^6, and R$ 11.29×10^6 for scenarios 2, 3, and 4, respectively, as shown in Figure 3.

Figure 3 - Net present value



Scenario 4 (5 ton/day) offers a more comprehensive economic attractiveness to install the pyrolysis plant to produce FO. According to the calculated NPV value, the payback period for scenario 2 is about 4.5 years, for scenario 3 is around 4 years, and for scenario 4 it is needed approximately 3 years to recover all the invested capital.

Costs of Municipal Public Administration with MSW destination

Reducing expenses on MSW management is a difficult task because the generation of waste reflects the increasing demand for products to meet population growth and current consumption habits. Assuming that the municipality will implement the pyrolysis technology, it was made an analysis of costs reductions per ton of MSW managed, for each scenario 2 to 4, following the methodology shown in section 3.3.1. In this calculation, labor costs were included for the recovery of plastics from MSW-SC. Operating costs of the pyrolysis plant do not vary because the plant has the same cycle of operating hours in the three assessed scenarios. Table 5 summarizes the revenues and costs.

The MSW management costs for the municipality can be reduced as much as approximately 55 % in scenario 4, that is, pyrolysis of the PSW (excluding PET and PVC), 4.36 ton/day, from MSW-SC plus 0.64 ton/day of PSW from an external source, e.g., other municipality. Between the current situation (Scenario 1), and the implementation of Scenario 3 (pyrolysis of PSW (excluding PET and PVC) available at MSW-SC, 4.36 ton/day), the reduction would be around 32 %. This means that the implementation of pyrolysis represents savings of approximately 832×10^3, 483×10^3, and 230×10^3 R$/year, for scenarios 4, 3, and 2, respectively.

FINAL CONSIDERATIONS

This study analyzed the technic-economic feasibility of implementing the pyrolysis of PSW to the production of FO. The analysis of different fractions of PSW from MSW in a medium-sized municipality was made. It were defined 3 scenarios for implementation of the pyrolysis process, and following the available amount of PSW. Using the ACI method, the costs to produce FO were calculated at 1.5; 1.29 and 1.13 R$/L, for Scenarios 2, 3, and 4, respectively. The production costs of FO for scenarios 2, 3, and 4 are 39%, 49%, and 56% lower than the market price of FO, estimated as 2.55 R$/L. Costs per unit of energy (GJ) in FO decreased from 40.88 to 29.67 R$/GJ between scenarios 2 and 4. The NPV of the solution, considering scenarios 2 to 4, increased from R$ 6.72×10^6 to R$ 11.29×10^6, thus indicating the economic viability of the pyrolysis plant. Additionally, the payback period for scenario 4 is three years, and for scenarios 2 and 3 is around 4.5 and 4 years, respectively.

The costs with the MSW destination can be reduced up to 54.75%, from 139.01 to 63.12 R$/ton of MSW, as observed in scenario 4. Additionally, when compared to scenario 1, it is achieved a total saving of 832 thousand R$/year. For scenario 3, the cost reduction was 32 %, achieving savings of about 483 thousand R$/year. Additionally, Scenario 3 can be more appropriate for a short term period, because of the existing availability of PSW at the MSW-SC, and without the need of external PSW. Nevertheless, a subsequent scale-up to scenario 4 is achievable.

Therefore, the implementation of the pyrolysis process from the company BEINTEC to produce FO from the different fractions of PSW is an attractive alternative to reduce costs with MSW management in the city under analysis. Besides, in the context of the circular economy, increasing the fraction of treated plastics, in this way by chemical recycling to fuels, makes MSW management more sustainable. The pyrolysis process of PSW is economically feasible. However, it is essential to improve the segregation of materials at the source to reduce operating costs at the MSW-SC.

Visando a uma apresentação coerente e de alta qualidade da publicação da Revista Tecnologia e Sociedade, solicitamos aos autores que sigam os critérios e características técnicas, as orientações de estilo e formatação de texto apresentadas neste documento. O modo mais simples de fazê-lo é substituir o conteúdo do modelo pelo de seu artigo, cuidando para não adicionar novos estilos, ou redefinir os estilos do modelo.

Avaliação tecno-econômica da pirólise para produção de óleo combustível

RESUMO

Foi realizada a análise da viabilidade técnica-econômica da implantação de uma planta de pirólise para a produção de óleo combustível (OC). O processo de pirólise catalítica ocorre num reator de leito fixo com capacidade de processar 4 m³ de resíduos plásticos secos e triturados (massa volúmica de 500 kg/m³), o qual é aquecido a uma taxa de 2 °C/min até atingir a temperatura da reação entre 270 e 3500 °C. O processo de pirólise é então mantido à temperatura estabelecida durante um período de 6 horas. O tempo de residência dos gases de pirólise é igual a 90 minutos. Cada ciclo de batelada dura em média 9 horas. Analisou-se a produção de óleo por processo de pirólise das diferentes frações de plásticos dos Resíduos Sólidos Urbanos (RSU) de um município de médio porte. No cenário 1, cenário de referência, 1.04 e 3.63 ton/dia de plásticos são encaminhados para a reciclagem mecânica e para o aterro sanitário, respectivamente. A partir do cenário de referência, foram analisados três cenários com a implantação de pirólise de plásticos: cenário 2, 3.63 ton/dia, fração de plásticos não reciclados; cenário 3, 4.36 ton/dia, fração total de plásticos contida nos RSU; e cenário 4, 5 ton/dia, capacidade total da planta. Os custos de produção do OCP foram calculados em 1,50; 1,29 e 1,13 R$/L, aproximadamente 41; 49 e 56% inferiores ao preço de venda do combustível (2,55 R$/L), para os cenários 2, 3 e 4, respectivamente. Os custos por unidade de energia (GJ) do OC variam entre 40,88 e 29,67 R$/GJ. O Valor Presente Líquido (VPL) positivo para os três cenários indicam a viabilidade econômica da planta de pirólise. Os VPL aumentaram de R$ 6.72×10^6 a R$ 11.29×10^6, na ordem de 1.68 vezes maior para o cenário 4. O sistema de pirólise precisa operar entre três e quatro anos para recuperar o capital investido. Os custos do munícipio com destinação de RSU podem ser reduzidos em até 54,75%, de 139,48 a 63,12 R$/ton RSU gerado, entre o cenário de referência e o cenário 4.

Palavras-chave: Pirólise; Plásticos; Óleo combustível.

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Correspondência: