



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-2146

ANALYSIS OF ECONOMIC AND FINANCIAL VIABILITY OF THE IMPLANTATION OF A PLASTIC MATERIAL REUSE SYSTEM FOR GENERATING ELECTRICAL ENERGY

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Abstract. *This paper proposes a project to generate electricity from the pyrolysis of plastic and analyzes its economic viability in the industrial system. Initially, it proposed the necessary equipment, capacities, energy consumption, and all the necessary human resources for the operation of the enterprise. The energetic capacities of plastic were based on literature data. After data analysis, it was proved that the project is economically viable. Since the net present value is positive, and the internal rate of return is higher than the minimum attractiveness rate. The results indicate a payback period of 78 months, i.e., six years and six months, using the minimum attractiveness rate of 0.5%. Besides, this investment has an internal rate of return of 1.1923% per month, analyzing the investment time by ten years. Thus, this paper presents itself as an incentive for energy innovation and market expansion.*

Keywords: *energy, plastic, recycling, viability, pyrolysis*

1. INTRODUCTION

Energy demand increases proportionally with population growth, industrial and technological advancement, hence the importance of innovation of energy sources.

The objective of this paper is the economic and financial viability of an industrial scale project capable of generating electricity through the reuse of plastic. Plastic accumulation in landfills is a significant social problem, and recycling is a considerable solution.

Mechanical recycling is not as efficient due to the inability to mechanically recycle all types of plastics. On the other hand, there is a viable alternative in chemical recycling as it covers all types of plastics. Chemical recycling corresponds to a decomposition reaction through the action of heat, i.e., pyrolysis. Pyrolysis is the breakdown of molecules by heat in the total or partial absence of oxygen followed by combustion to transform gases to generate electricity. Also, pyrolysis forms fuel oil, which has calorific value compared to diesel oil (Carneiro and Marques, 2011).

In this context is the importance of the financial viability of the project determining the financial expenses, investments, and the medium and long term return. With this analysis, the market value and applicability of the project are verified by quantifying monetary gains and expenses, using economic feasibility analysis techniques to conclude whether or not it is feasible to implement an energy production system from pyrolysis followed by combustion of the plastic.

2. PYROLYSIS OF PLASTICS

Pyrolysis occurs in the total or partial absence of oxygen. Depending on the type of material and the temperature subjected, the end products may be solid (coal), liquid (oil) and gaseous (pyrolysis gas). Niessen (2002) shows that the parameters that interfere with the pyrolysis process of plastics are particle sizes, gas velocity, pyrolysis time, and heating rate. Therefore, many studies are showing pyrolysis performance and energy potential for each type of plastic. The main types of plastics available are polyethylene (PE), polystyrene (PS), polypropylene (PP), polyvinyl polychloride, or polyvinyl chloride (PVC) and ethylene polyethylene terephthalate (PET).

Ciliz *et al.* (2004) noted that low-temperature processes generally favor liquid products and high temperatures process gaseous products. Besides, the higher the pyrolysis, the greater the gasification of the fuel. Thus, as the main proposal of this article is the production of gases for electric power generation, the working temperature of 1000° C was adopted. Table 1 is a summary of the critical information regarding the types of plastic, properties relevant to this paper.

Table 1. Plastics properties, energy potential, and conversion of plastics in pyrolysis.

	Percentage of material	Density (g/cm ³)	Specific heat (kJ/kgC ^o)	Energetic Content (MJ/kg)	Plastic Processing		
					Gases	Liquids	Solids
PE	65 %	0.95	2.30	46.05	97.5 %	2.5 %	0 %
PS	6%	1.04	1.34	38.10	15.0 %	85.0 %	0 %
PP	23%	0.95	1.93	45.27	46.0 %	50.0 %	4 %
PET	17%	1.40	1.10	35.94	61.0 %	38,0 %	1 %
PVC	5%	1.30	1.46	19.00	84.8 %	0 %	15.2 %
Other types	2%	1.13	1.63	35.94	60.9 %	35.1 %	4.0 %
Weighted Average		1.22	2.31	42.09	72.5	25.6	1.9

According to (Harper and Petrie, 2003), (Gonçalves, 2007), (Jinno *et al.*, 2002), (Conesa *et al.*, 1997), (Kahlow, 2007), citecastro2013recuperacao, (NORMA DIN 53 479), (Figueiredo *et al.*, 2015).

3. METHODOLOGY

3.1 Project Overview

To analyze the economic viability of the project, it was necessary to assemble and idealize the system on an industrial scale, which produces electricity through pyrolysis followed by combustion to produce gases. The gases are directed to a boiler that heat the overheated steam. This overheated steam will be sent to a turbine, which is connected to a generator, reducer, and transformer for power generation. At the same time, pyrolysis produces liquid products, which is a raw material for fuel oils and has similar heat heating to diesel oil. For pyrolysis to occur efficiently, the plastic must be ground to specific particle size, hence the need for the plastic crusher.

Figure 1 shows the flowchart of the proposed project to obtain fuel oil and electricity from the reuse of discarded plastics by pyrolysis. At the same time, the figure shows the thermodynamic cycle of water circulating in the boiler, turbine, condenser, cooling tower, and pump.

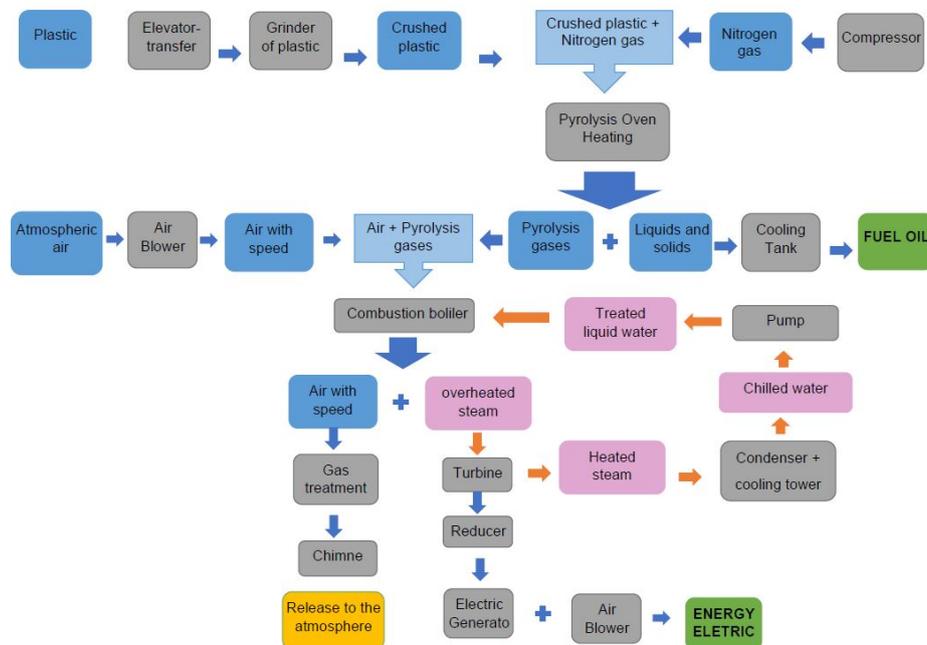


Figure 1. Production process flow diagram

To carry out the economic viability analysis of the project, it was necessary to obtain information such as: system production capacity, amount of monthly raw material as well as logistics, equipment purchase and maintenance, equipment electricity expenses and lighting location, rental of the shed for installation of the system, number of employees required, salaries, relevant taxes and monthly invoicing. Cash flow was performed with all relevant data, and through an Excel spreadsheet, all information was related to each other in order to verify that the venture is viable and profitable and in

addition to obtaining a minimum amount of plastic to be purchased monthly.

3.2 Economic and financial feasibility

According to Pilão and Hummel (2006), the Minimum acceptable rate of return (MARR) represents a minimum that the investor proposes to receive when investing. Considering that the project proposed by this article represents a trend in the generation of new energies. Also to reconciling social and environmental concerns, it can be pointed out that business liquidity is high and representative with a great opportunity in the Brazilian financial market, due to the search for alternative sources of energy. Thus it was adopted as the minimum attractiveness rate (i) of 5% per month. For the calculation of economic viability, the first method to be used as the present value method, in which all expenditures (listed in the Fig. 3) and the revenues calculated were brought to present value, i.e., $n = 0$. These calculations were performed by Eq. 1 and Eq. 2. Equipment costs are already at present value ($n = 0$).

$$R = \frac{P i}{1 - \frac{1}{(1+i)^n}} \quad (1)$$

$$P = \frac{S}{(1 + i)^n} \quad (2)$$

where R : is the Uniform Payment Series ; P : is the present value (initial investment); S : is the future value in time n ; n : is the the number of months; i : is the minimum attractiveness rate ($i = 0.5\%$ per month).

With all the present value variables, by the Net presents value method (NPV), it is possible to analyze the viability of the business, calculate the internal rate of return and the return period of the investment. The Equivalent Annual Cost Method (EAC) is the distribution of all cash flow variables represented by a single Uniform (R) series by Eq. 1. Through this method, it is also possible to analyze the viability, the internal rate of return of the investment, and the return period of the investment. Besides, it is possible to compare the effectiveness of the two methods.

3.3 Human Resources

Table 2. Specification payroll

Function	Number of employees	Base salary (R\$)	Health care (R\$)	Food voucher (R\$)	Transportation vouchers (R\$)	Additio- nal night (R\$)	Vacation (R\$)	Thirteen first salary (R\$)	FGTS (R\$)
Manager	1	2,200.00	120.00	120.00	120.00	-	733.33	2,200.00	176.00
Administrative Assistant	1	1,200.00	120.00	120.00	120.00	-	400.00	1,200.00	96.00
Engineer (production and maintenance)	2	3,800.00	120.00	120.00	120.00	-	1,266.67	3,800.00	304.00
Technician (morning and afternoon)	2	1,500.00	120.00	120.00	120.00	-	500.00	1,500.00	120.00
Technician (night)	1	1,500.00	120.00	120.00	120.00	300.00	500.00	1,500.00	120.00
Industrial Operators (morning and afternoon)	4	1,200.00	120.00	120.00	120.00	-	400.00	1,200.00	96.00
Industrial Operators (night)	1	1,200.00	120.00	120.00	120.00	240.00	400.00	1,200.00	96.00

The Severance Pay Fund (FGTS) is not paid directly to the employee.

In the employee hiring section, 44 working hours per week are stipulated for all employees. Table 2 shows the necessary and sufficient employees for the operation of the company. Of the five foreseen operators, three are scheduled as fixed one for each shift, and two are sufficient for time off and holidays of technicians and operators. Besides, one-month vacations are planned for all employees, organized suggestively as Engineers (March and September), Manager

(November), Administrative Assistant (May), Operational Technicians (June, September, October), Operators (February, April, May, July, August).

Table 2 shows with the salary charges of all employees predicting thirteenth, vacation, FGTS (Government Severance Indemnity Fund for Employees), health care, food voucher, and transportation voucher. Table 3 shows the company's monthly payroll expenses for all employees.

Table 3. Payroll Expenses for Employee Salaries

Month	January	February	March	April	May	June
Monthly spend	R\$ 28,080.00	R\$ 28,480.00	R\$ 29,346.67	R\$ 28,480.00	R\$ 28,880.00	R\$ 28,580.00
Month	July	August	September	October	November	December
Monthly spend	R\$ 28,880.00	R\$ 30,146.67	R\$ 28,580.00	R\$ 28,580.00	R\$ 28,813.33	R\$ 50,080.00

3.4 Operation Sector

The system proposed in this article can operate 24 hours a day, t , with rotation among employees in the three work shifts. However, it was considered only 22 hours of productivity per day for calculating system productivity and profit. In order to obtain a safety margin of 60 hours of downtime per month for any equipment breakdowns and failures and any maintenance. Besides, it is planned that once a year all production will be interrupted for 15 days to perform the necessary annual maintenance of all equipment.

3.5 Industrial equipment

The quotation of the equipment took into consideration the production capacity and the operating synergy between them. The performance and maximum production capacity of each equipment are required for the calculation of productivity, some of which were specified by the manufacturers and the others adopted. The following will list the equipment and its specifications according to the flow chart shown in Fig. 1.

The function of the industrial elevator supplies the grinder of plastic with plastic. The model that meets the production costs R\$ 18,000.00 and has a power of 2 kW. The grinder of plastic adopted was the model JLSS400 with the power of 5.25 kW and offered a grain size of 25-100 mm (being adjustable with the correct purchase of blades). The investment of this equipment is R\$ 20,000.00, and it adopts a performance, $\eta = 0.998$, for any plastic waste. The cost of the blade sharpener for the shredder is R\$ 1500.00 and must be paid in the first year with 12 installments of R\$ 125.00. The power of this equipment is 1 kW.

A specific flow of crushed plastic feeds the pyrolysis oven through a particle injector. The particle injection system is a long 100 mm diameter tube coupled to two Altech vibrators (Vibro-Graver) to prevent clogging of this tube (Gonçalves, 2007). Besides, the pyrolysis oven needs 150 mm diameter liquid collection tube; piping of pyrolysis gases that will be directed to a combustion boiler; pressure gauges and thermocouples installed for internal pressure and temperature control; safety valve; exhaust valve; 160 mm diameter nitrogen inlet tube and finally a liquid settling reservoir: this reservoir will have a yield of 70%, ie, only 70% of the liquids produced by pyrolysis will produce fuel oil.

Through Kahlow (2007) experiments, was determined the stoichiometric ratio (SR) of the plastic mass and nitrogen mass, which corresponds to $SR = 510.90$. Besides, it was adopted as pyrolysis oven firing performance with $\eta_{furnace} = 0.85$.

The pyrolysis oven is the only equipment that is not available on the market, so it is necessary to design and subsequently manufacture it. There are some works in the literature with prototype furnace pyrolysis furnaces already adequately constructed. Although the purpose of this work is not to design this pyrolysis oven, a simplified sizing was performed in order to obtain an estimate of the power used to make this oven perform pyrolysis.

For simplified pyrolysis oven sizing the working temperature of 1000 °C was considered, the structural sizing, useful furnace capacity, furnace production capacity, and finally estimation of furnace power. The material chosen for this pyrolysis furnace was Alumina ($\sigma_{permissible} = 155MPa$) because it withstands high temperatures and is subject to lower oxidation rates than, for example, stainless steels. Besides, an maximum internal pressure of $P_{max} = p = 25MP$ and the safety factor $S = 2$ was considered. The estimated furnace parameters found by Eq. 3, Eq. 4 and Eq. 5, given that $t = 182$ mm, $r_{mean} = 560$ mm, $D_{in} = 939.4$ mm, $D_{out} = 1300.6$ mm, $h = 1950$ mm and $V = 1351.53$ Liters.

$$\sigma_c = \frac{p r_{mean}}{t} \quad (3)$$

$$\sigma_l = \frac{p r_{mean}}{2t} \quad (4)$$

$$S = \frac{\sigma_{permissible}}{\sigma_c} \quad (5)$$

where σ_c is the circumferential stress of the cylinder (Mpa); σ_l is the cylinder longitudinal tension (Mpa); p is the the maximum pressure inside the oven (Mpa); r_{mean} is the average radius between outer and inner radius (mm); t is the oven wall thickness (mm); $\sigma_{permissible}$ represents the tensile stress of alumina [Mpa]; and S is the safety coefficient.

The mass of plastic that enters the oven in each cycle is calculated as a function of the system's production capacity, oven capacity and power, and the raw material purchasing and logistics. Being then, variables that depend on each other. This variable could only be obtained by collecting all the data. For didactic reasons, it is known that the optimal value found for $\dot{m}_{p(in)oven}$ is 486.551 Kg.

For safety reasons in a pyrolysis oven sizing was considered a vacuum ratio of 10 %, ie, 10 % of the pyrolysis furnace volume will not be filled with plastic or nitrogen gas. The maximum capacity considered for this pyrolysis oven is 100 kg/h ($\dot{m}_{p(max)oven}$). For this calculation, the useful internal volume of the pyrolysis oven, the stoichiometric ratio of pyrolysis, the density of the plastic and the gaseous nitrogen were considered. The pyrolysis cycle time was calculated by Eq.(6). Also, then the total time for each pyrolysis cycle is calculated by Eq.(7).

$$\Delta t_{ciclo} = \frac{m_{p(in)oven}}{\dot{m}_{p(max)oven}} \quad (6)$$

$$\Delta t_{total_{pyrolysis}} = \Delta t_{ciclo} + \Delta t_e + \Delta t_h \quad (7)$$

where Δt_{cycle} is the effective pyrolysis time, $m_{p(in)oven}$ is the plastic mass that goes into the oven each cycle [Kg], $\dot{m}_{p(max)oven}$ is the maximum plastic capacity of the pyrolysis oven [Kg/h], $\Delta t_{total_{pyrolysis}}$ is the total pyrolysis cycle time, Δt_e , is the time the oven empties (3 min) Δt_h is the oven warm-up time (5 min).

Therefore, the effective pyrolysis time for each cycle in the oven is $\Delta t_{ciclo} = 4.86h = 292min$. Moreover, in turn, the total time is $\Delta t_{total_{pyrolysis}} = 299min$. Gonçalves (2007) found that for a 0.181 l oven, the pyrolysis time is 240 milliseconds. Proportionally the pyrolysis time to 1351.53 liters would give a pyrolysis time of 1548 seconds, i.e., 30.13 minutes. Therefore for a non-experimental analysis, this statement shows that the pyrolysis time (292 minutes) adopted is reasonable.

In the estimation of the potency of the pyrolysis oven, it was considered the conduction of the plastic and the nitrogen gas and convection of the plastic and the nitrogen gas.

$$Q_{p_cond} = \dot{m}_{p(in)oven} c_p \Delta T \quad (8)$$

$$Q_{N_2_cond} = m_{N_2} c_{N_2} \Delta T \quad (9)$$

$$Q_{N_2_conv} = h_{N_2} A \Delta T \quad (10)$$

where Q_{p_cond} is the heat energy required to heat the plastic by conducting each cycle [J]; $\dot{m}_{p(in)oven}$ is the oven plastic mass [kg]; c_p is the plastic specific heat [$\frac{Cal}{gC^\circ}$]; ΔT is the difference between ambient air temperature and the desired heating temperature [C°]. $Q_{N_2_cond}$ is the heat energy needed to heat N_2 driving each cycle [J]; m_{N_2} is the mass of N_2 in the furnace structure [g]; c_{N_2} is the N_2 specific heat [$Cal g^{-1} C^\circ^{-1}$]; $Q_{N_2_conv}$ is the heat required for convection heating of N_2 at each cycle [W]; h_{N_2} is the heat transfer coefficient of N_2 [$W m^{-2} K^{-1}$]; A_o is the heat transfer area perpendicular to the heat flux [m^{-2}].

The mass of the nitrogen gas is calculated by Eq. (11)

$$SR = \frac{m_{p(in)oven}}{m_{N_2(in)oven}} \quad (11)$$

where SR is the toichiometric ratio; $m_{p(in)oven}$ is the plastic mass that goes into the oven each cycle; and $m_{N_2(in)-oven}$ is the nitrogen gas mass that goes into the oven each cycle.

And then, equation (12) shows the pyrolysis oven power.

$$P_{oven} = Q_{N_2_conv} + \frac{Q_{plastic_cond}}{\Delta t_{pyrolysis}} + \frac{Q_{N_2_cond}}{\Delta t_{pyrolysis}} \quad (12)$$

where P_{oven} is the pyrolysis oven power.

Thus, the useful power obtained by Eq. (Ref Pforno) was 70.02 kW. In turn, the total power is calculated by Eq. (Ref oven) knowing that $\eta_{(oven)} = 90\%$, thus obtaining $P_t = 78kW$. Also, for the calculation of production, the pyrolysis performance considered was 85 % As the pyrolysis oven has not yet been produced, it is an estimated idealization that the price as market value is R\$ 150,000.00.

$$\eta_{(oven)} = \frac{P_u}{P_t} \quad (13)$$

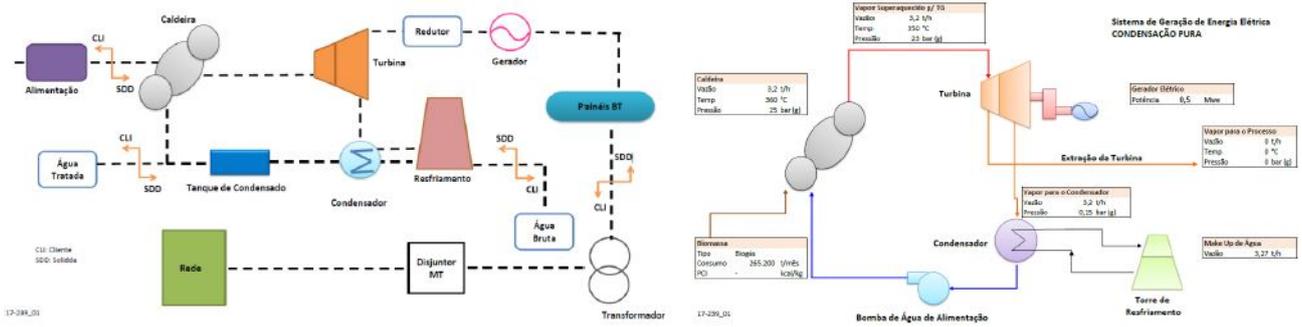


Figure 2. Basic flowchart of electric power generation/cogeneration

where η_{oven} is the performance of pyrolysis oven; P_u is the useful power P_t is the total power.

One company will provide the equipment shown in Eq. (Ref equipment2) with a budget of r\$ 3,760,000. The advantage of this purchase is the guaranteed timing and perfect functionality of the equipment.

In the boiler, pyrolysis gases are burned with atmospherical air. The boiler is a water-tube type and has a flow rate of 3.2 t/h, steam pressure of 25 bar, the steam temperature of 360 (C°) and a burn rate of 86%. The boiler's fuel consumption (air) in the equipment documents is 265 200 m^3 / month. Besides, the boiler is a biogas type, but due to the burning of pyrolysis gases, some grid retrofitting would be required. For example, (which is explicitly designed for boiler fuel), a budget of R\$ 50,000 has been added to the project. Also, it is recommended to have external heating elements in the boiler in order to maintain the temperature around 1000 (C°).

The boiler works synchronously with the pyrolysis oven, i.e., they have the same cycle. The stoichiometric burn ratio between the plastic mass and the air mass is used from the citep Golçalves experiments are two. Moreover, the air mass entering the boiler is calculated at each cycle, and it has been found that the specified boiler meets the demand.

Also, the boiler power was also estimated in a simplified manner taking into account air conduction and convection by Eq. 14, Eq. 15 and Eq. ?? just considering the boiler.

$$Q_{air_cond} = m_{air} c_{air} \Delta T \quad (14)$$

$$Q_{air_conv} = h_{air} A_b \Delta T \quad (15)$$

$$P_{boiler} = Q_{air_conv} + \frac{Q_{air_cond}}{\Delta t_{pyrolysis}} \quad (16)$$

where Q_{air_cond} is the heat energy needed to heat N_2 driving each cycle [J]; m_{air} is the mass of N_2 in the furnace structure [g]; c_{air} is the N_2 specific heat [$Cal g^{-1} C^\circ^{-1}$]; ΔT is the difference between ambient air temperature and the desired heating temperature [C°]. Q_{air_conv} is the heat required for convection heating of N_2 at each cycle [W]; h_{air} is the heat transfer coefficient of N_2 [$Wm^{-2}K^{-1}$]; A_b is the heat transfer area perpendicular to the heat flux and [m^{-2}]; P_{boiler} is the boiler power [W].

Therefore, useful boiler power is 10.15 kW. Adopting a boiler thermal efficiency of 0.9, the total boiler power adopted in this article was 12 kW.

Also, for the system to work, it is necessary to purchase a compressor to inject nitrogen gas into the pyrolysis oven and an air compressor to the boiler. The nitrogen gas flow in the pyrolysis oven corresponds to $m_{N_2} = 34.41 \frac{m^3}{h}$, with an estimated time of 2 min. The compressor that meets this specification has a rated power of 0.05 kW and has a cost of R\$ 7300.00.

The mass flow of atmospheric air injected into the boiler is $m_{ar} = 288,78 \frac{m^3}{h}$, having a time limit of 8 min. The compressor that meets this demand has a maximum pressure flow of 294 m^3/h , 1000 Pa working pressure and 1 kW rated power. The price of this equipment is R\$ 7700.00. Therefore, the total cost of the blowers would be R\$ 15,000.00.

The chimney is essential for the treatment of gases from pyrolysis. According to cite golcalves the leading gases are light hydrocarbons, CO, CO_2 , O_2 , N_2 , PAH and soot, and particulates. For the treatment of CO_2 and methane gas, electrostatic precipitator activated carbon filter (for gas purification), and biofilters may be used.

The boiler is connected with the turbine. The turbine of this system is powered by the superheated steam generated by the heat transfer from the flaring gases to the boiler liquid water, so this equipment transforms the thermal energy of the superheated steam into shaft energy, i.e., into mechanical energy. The turbine datasheet mains information provided by the supplier is minimum generation power: 475 kW, performance of 90%, maximum steam consumption, 3.52 $\frac{t}{h}$, spindle power of 500kW and maximum steam admission of 3.2 $\frac{t}{h}$.

The reducer is a mechanical device located between the turbine and the generator and has the function of reducing the rotation speed of the turbine driver at 60 Hz. The leading information of datasheet this equipment is 500 kW power, 98% overall output, 12000 rpm high-speed power, and 1800 rpm low-speed power.

The electric generator transforms the electric power from kW to kVA. This equipment operates at 60 Hz and has the following components included: AVR, Brushless Synchronous, and Self-excited. The leading information of datasheet of this electric generator is 500kW net power, 625 kVA power, 0.8 power factor, 380V voltage, 1800 rpm speed, and 96% overall output.

The function of the transformer is raising the voltage 380 V voltage that leaves the generator to the 13.8 kV voltage, which is indicated for use in the public network. The primary information provided by the datasheet is a power of 625 KVA, lower voltage, 380 V, and higher voltage 13.8 kV.

At the same time, there is the thermodynamic cycle of water that is composed of the boiler, turbine, condenser, and the cooling tower.

According to Depreciation and amortization rates for tax purposes (IRS), all the equipment in the system the amortization rate is ten years. The initial investment for the purchase of equipment is R\$ 4,014,500. By the equation (1) it is possible to calculate the value of the installments to be paid for the purchase of the equipment over ten years.

3.6 Equipment Maintenance and Physical space of the industrial system

Maintenance is divided into three types: predictive, preventive, and corrective and preferably the maintenance predictive, preventive of equipment are scheduled once a year, where the total production will be stopped for 15 days during January. Maintenance costs were considered 1 % of the initial purchase price of the equipment for each month of the year. Also, the budget takes into account corrective and preventive maintenance throughout the year. Therefore, a monthly amount of R\$ 32 116.00 is reserved for equipment maintenance.

Besides, it considered as an alternative to rent a warehouse in the Industrial region of Uberlandia with 200 m^2 and a ceiling height of 5 m, with the amount to be paid monthly of R\$ 2500.00.

3.7 Energy Eletric

In the lighting of the shed 16 LED lamps of 9 W of power are provided. The lifetime of these lamps is 35,000 hours or approximately 49 months. The price of each lamp is around R\$ 6.69 (Free Market), totaling an expense of R\$ 107.04 every 49 months. The electrical energy expenses of the equipment were calculated according to its power and the working time each one.

The pyrolysis oven and the boiler are equipment that works the entire production process because it takes more energy to reconnect them than to leave them connected during the whole service time. On the other hand, other equipment has a much higher operating capacity than the minimum demand. Thus, by Eq. 17 and Eq. 18 it is possible to estimate the electrical energy expenses of all other equipment as a function of working time.

$$Factor_{work} = \frac{Cap_{production}}{Cap_{maximum}} * 100 \quad (17)$$

$$Hour_{work} = Factor_{work} Time_{production} \quad (18)$$

where $Factor_{work}$ is to the effective percentage of equipment work during the production process [%]; $Cap_{production}$ is to the production demand required of the equipment [kg/h]; $Cap_{maximum}$ is to the maximum production capacity of the equipment [kg/h]; $Hour_{work}$ is the current working time [h]; $Time_{production}$ is the working time of all monthly production [h].

The proposed system requires 59941.6 kW of electricity, considering 22 working hours per day of equipment per month.

3.8 Raw Material

The raw materials required for power generation are plastic and nitrogen. The amount of plastic consumed monthly is estimated based on its logistics (purchase and delivery) and the system's production capacity (limited by the oven's production capacity). This value is known to correspond to 64983 kG, and this section will show the methodology adopted to arrive at this value. The average price per kilo of plastic is R\$ 0.35.

According to the estimated amount of plastic needed throughout the process, the nitrogen gas mass is calculated by Eq. 11 and after the number of cylinders required. The company of nitrogen gas cylinder is responsible for the delivery of them. The estimated cost with nitrogen cylinders is R\$ 8693.65. Third-party truck companies can deliver the plastics.

Considering the round trip of the truck equal to 80 min and the loading and unloading time approximately to 40 min. Thus the T_{total} is approximately 120 min. Thus, for an 8 hour working day, the driver would be able to fill the truck four times. A small truck carries 4061.44 kg of plastic per trip.

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plastic. In this case, it was decided to rent the truck along with the driver for R\$ 500.00 per day. For the demand for the initial purchase of plastics that corresponds to 64983 Kg, it is necessary to rent this truck for four days.

$$Raw_{material} = cost_{transport} + m_{plastic} + m_{nitrogen} \quad (19)$$

All these expenses by the Eq. 19: add up to an expense on raw material equivalent to R\$ 33,437.70.

4. RESULTS

4.1 Calculation of production

The production of energy electricity and fuel oil is related to equipment performance and the energy potential of plastics. With the equipment's performance already specified in this paper, it is possible to calculate the input and output of each equipment by Eq. 20.

$$\eta = \frac{m_{input}}{m_{output}} \quad (20)$$

In the pyrolysis oven, there is a conversion of mass (kg) to energy (J). For this the authors adopted a η pyrolysis = 0.85, also, already specified in the paper. Besides, the relation between energy potential and gas is given in Table 1.

The turbine is responsible for transforming the energy in $[\frac{MJ}{Kg}]$ to kW. Thus, with the transformer output per hour calculated (650.8725 kW), it is possible to calculate the monthly production of energy electric.

$$Monthly\ energy\ production = output_{transf} \times work_hours \times working_days = 429.576MW \quad (21)$$

Part of the electricity produced monthly is used for the operation of the equipment. Therefore the net electric energy produced monthly by the system corresponds to the difference of the gross production with the energy demand in KW of the equipment. Thus, the net energy produced by the system corresponds to 369,634 MW (*Monthly energy production*).

In parallel, the oil production per hour is calculated through the conversion of liquids in the pyrolysis, shown in Tab. 1. Thus, it is possible to calculate the mass of plastic (liquid form) that enters the oil cooler. Thus, through the density and the adopted performance of 70 %, the volume of oil produced monthly in the oil cooler is calculated by Eq. 23. The calorific value of the oil is equivalent to the diesel oil and can be used for the manufacture of other fuel oils.

$$Monthly\ oil\ production = output_{oil} \times work_hours \times working_days = 405984m^3. \quad (22)$$

4.2 Bilings and Taxes

The price considered for the sale of the energy KW was R\$ 0.42, and the fuel oil price was R\$ 1.20 per liter. Revenues expected are fixed all the months and proportional to production. January is the only month in which revenues change due to reduced production because of maintenance. Therefore the company's monthly turnover R\$ 192 403.19. Moreover, in January it is R\$ 171 460.91. Thus the monthly profit of this enterprise is calculated by Eq. 23.

$$Monthly\ profit = oil\ production \times Price\ oil + Monthly\ energy\ production \times Price\ energy \quad (23)$$

Thus, the company's annual revenues correspond to R\$ 1 911 772.52.

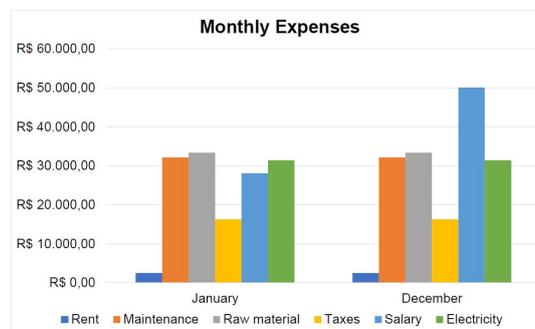


Figure 3. Monthly expenses

With the national simple tax current system, the tax calculation is calculated by Eq. 24 and Eq.25. This regime includes all other relevant taxes, such as IPI, CPP, Pis /Pasep, ISS, ICMS, among others.

$$i_e = \frac{(B_a \times i_n) - D}{B_a} \quad (24)$$

$$T = B_a \times i_e \quad (25)$$

where B_a is to the Annual billing [R\$]; i_n is to the nominal tax rate [%]; i_e is to the effective tax rate [%]; D is to the installment to be deducted [R\$].

Considering the company billing range of R\$ 1,800.00 to R\$ 3,600.00 for factories and industries, the i_n is to 14.7 % and D is to R\$ 85,500.00. Therefore the annual tax expense corresponds to R\$ 195,530.00.

Figure 3 shows all expenses involved in the project in January and December. In all months of the year, the expenses are considered to be the same, and the variant expense corresponds to the employee's payroll, as shown in Tab. 3.

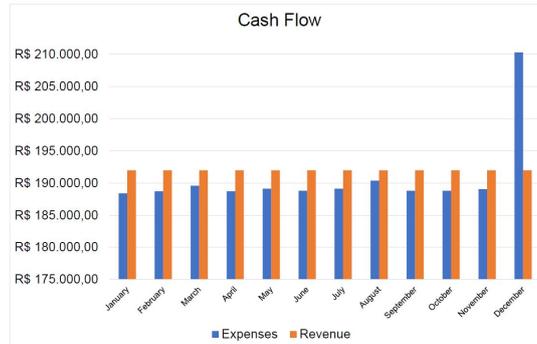


Figure 4. Cash Flow

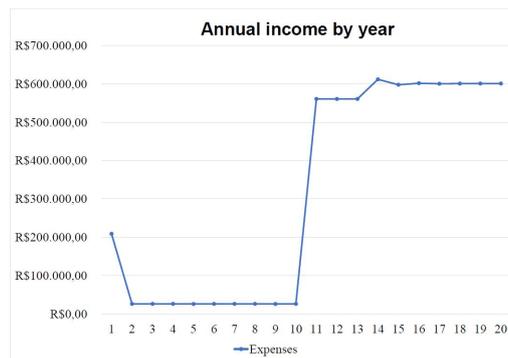


Figure 5. Annual profits by year

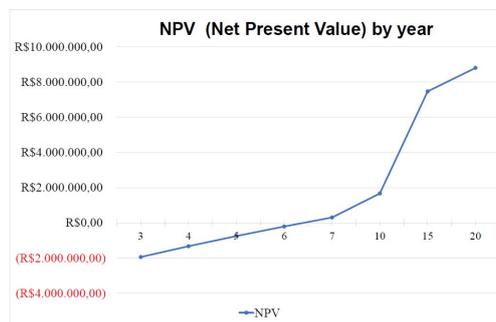


Figure 6. NPV (Net Present Value) by year

The calculation of monthly income depends on all on revenues and expenses. Fig. 4 shows the chart of the summary of monthly spending for the first year. Figure 5 shows the company's annual profit for 20 years. Figure 6 shows the company's revenue through the present value method, and Fig. 7 by the uniform cost method. Both graphs show the payback period for a minimum attractiveness rate of 0.5% per month. For both NPV and EAC, the payback period is 6.5 years.

5. CONCLUSIONS

For a 20-year analysis, which corresponds to the estimated lifetime of the equipment, were found a positive net present value (NPV) and a real uniform annual cost (EAC). Therefore, the investment is considered viable. It is possible to observe

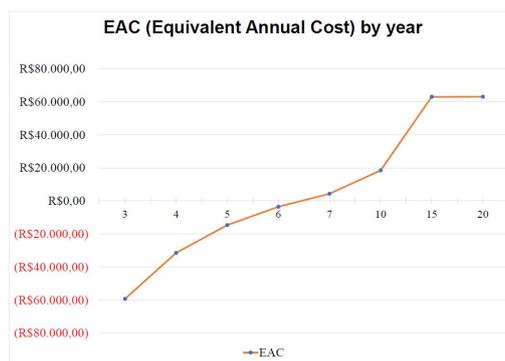


Figure 7. EAC (Equivalent Annual Cost) by year

that the payback period is between the sixth and the seventh year since year 6 has an NPV <0 and the year 7 NPV > 0. It is known that the return period of the investment is seventy-eight months, corresponding to six years and five months. A minimum attractiveness rate established per month ($i = 0.5\%$ per month) was found, emphasizing that this scenario is modifiable as it depends on the amount of energy to be generated. For the chosen scenario of $m_{p,lastic} = 98.24 \frac{Kg}{h}$, the equipment is not in its maximum operating capacity.

Besides, it was possible to find the internal rate of return, which corresponds to a NPV or EAC for 10 years, as it corresponds to the amortization time of the equipment. Therefore, when performing the relevant project data calculations, the system's internal rate of return for 10 years is 1.1923 % per month. Remembering that this time is not the lifetime of equipment that, according to manufacturers, is at least 20 years.

As a result, the financial and economic viability of the investment was verified through the net present Value and / or Uniform Annual Cost Method, as well as estimated the return period being reasonably short, and presenting an internal rate of return above market rates.

6. ACKNOWLEDGEMENTS

The authors are thankful Faculty of Mechanical Engineering, Federal University of Uberlandia.

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8. RESPONSIBILITY NOTICE

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