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COST BENEFIT ANALYSIS OF WASTE PLASTIC PYROLYSIS PLANT FOR BIODIESEL RECOVERY, UMUDIKE ABIA STATE NIGERIA

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Abstract: The study was focused on evaluating the cost-benefit analysis of a pyrolysis plant for converting waste plastics into diesel oil. The start-up capital for a 2kg/hr., capacity yielded low residue. Hence, it is essential to test the viability of the plant economically. The cost-benefit analysis methodology was applied, emphasizing the system payback period and the yearly internal rate of return (IRR). These indices were done using Excel. Earlier experimental results had indicated that for a 1000-hour annual operation, 1000 liters of diesel is expected at 2000 kg of waste plastic, with a corresponding revenue benefit of $1120. For the system's total life cycle, up to 10,000 litres of diesel can be produced, resulting in about $11,200. The cost-benefit analysis showed that the system has a payback period of just two years compared to its 10-year life span. It is beneficial from an economic viewpoint and is estimated to generate a net income of up to $700 for each thousand-hour operation. Furthermore, the results demonstrate that the pyrolysis plant gave an IRR of 48 % when the cost of plastic was neglected. An IRR of 48 % indicates that the plant is expected to generate a rate of return of 48 %.

When the cost of plastic is accounted for, the system's IRR is reduced to 33 % annually and is still feasible from an economic viewpoint. Therefore, pyrolysis is economically viable for scaled-up operations.

Keywords: *Waste plastics, pyrolysis plant, cost-benefit analysis, internal rate of return, payback period, net present value.*

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INTRODUCTION

Plastic waste constitutes a large part of the municipal solid waste in many countries including Nigeria [3,19,18,20]. Plastic waste contaminates water sources, clogs drain and damages the environment [20,11]. Tourism is hampered by the abundance of plastic debris on beaches, especially for coastal towns whose economies depend on tourism [19]. Plastic waste also jams ocean bottoms, endangers the lives of divers and marine animals, and impedes effective submarine operations [8]. Several countries have banned the use of plastics due to the problems caused by plastic waste. Bangladesh in 2003, followed by India and recently Tanzania, has been quoted as the 35th African country to implement the ban on plastics [8,10]. China has blocked its borders to the entry of plastics after years of importing discarded plastics [4]. China has advanced the technology for recovering plastics but can still not handle the massive waste coming into the port’s terminals [6]. One of the primary reasons for the ban is the inability of these countries to develop recycling technology; hence, most waste plastics end up in landfills because waste plastics are non-biodegradable [6].

However, since waste plastics have a high volume-to-weight ratio, appropriate landfill space is becoming scary and expensive [1,15]. Additionally, waste plastics cannot be quickly returned to their natural carbon state because the bacteria responsible for its decomposition cannot easily break the carbon-carbon bonds of waste plastics since no metabolic pathways are found [15,17]. The carbon-carbon bonds in polypropylene require vast energy to form together during the polymerization process [12,9]. Waste plastics' tensile strength is high, so the bacteria cannot penetrate to induce natural decomposition [2]. Countries with improved plastics recycling technology reap rich revenue from them and can maintain tidy environments and attractive coastlines [21,14]. Plastics can be recycled to produce parent products such as textiles, footwear, toilet facilities and floor tiles [5]. It can be part of composites for footpaths, roads and garden implements. Some waste plastics are melted to produce crude oil, and some are still used for water pipelines [17]. A waste plastics pyrolysis plant was designed and fabricated to convert these thermoplastics to diesel oil at an elevated temperature of 360^{o}C. In this paper, a cost-benefit analysis of the pyrolysis plant was investigated to determine the payback period (PBP), the net present value (NPV) and the internal rate of return (IRR) of the plant.

Cost-benefit analysis (CBA) is a simple method in which all expenses and incomes of an activity are a cash balance [19]. The method allows for determining whether an activity can promote economic profits, or which solutions generate the most profit [3]. This study applies this method to analyze the differences in financial benefits in the chosen pathway for realizing crude from waste plastic [18].

In this context, CBA is simplified, and the total expenses are mainly based on the price of the process energy requirement and equipment cost. The benefit of the recovery centres comes from the sale of recycled materials to consumers as substitute petroleum products [3,19,18,20].

MATERIALS AND METHODS

Materials

The research materials are obtained from an existing pyrolysis plant with the accompanying operating parameters: the plant costing in Table 1, the 2kg waste plastics, and the software application (Engineering Equation Solver EES). The plant has the following components, as shown in Fig. 1.

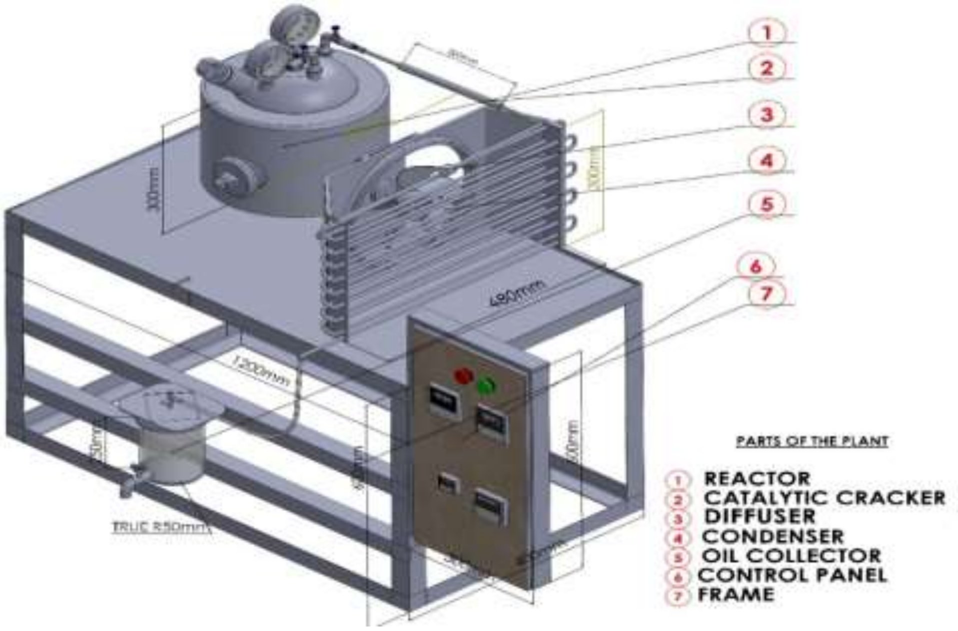


Fig. 1. 3D solid view of the local waste plastics plant

The pyrolysis plant operation

The production method for converting plastics to liquid fuel is based on the pyrolysis of the plastics and the condensation of the resulting hydrocarbons. The plastic waste is first shredded into sizes and removed off any moisture content. The mixture of waste plastics and catalyst (quatze sand, and iron) are then introduced into the reactor, to enhance degradation of oil vapour from higher molecular weight to lower molecular weight and is called primary cracking process. The waste plastics is heated and melted at temperature range of 150-180^{0}C. The melted liquid plastics will be decomposed or vaporize at inlet reactor temperature range of 250ºC – 500ºC, at point 1, in the thermodynamics state point and evaporate at point 2, at the state point. The evaporated oil was further subjected into secondary cracking process in the catalytic cracker at points 3 and 4.

The evaporated oil vapour was also degraded due to impact on the catalyst (quartz sand and iron chips) at elevated temperature.

The pressure and the flow rate of the light oil were reduced or dropped in the diffuser component to enable fluid spend more time in the condenser for condensation to occur, at points 5 and 6 at the thermodynamics state point.
The waste plastics vapour were condensed in the air-cool condenser. Heat from the waste plastics vapour was rejected to the surroundings at points 7 and 8 in the state points. The blowing fan channeled a steady flowing air to the condenser to remove heat from the oil gas between points 9 and 10 in the state point. The liquid hydrocarbons were then collected in a storage tank through a receiver tank. Gaseous hydrocarbons such as methane, ethane, propylene and butanes cannot be condensed and were therefore incinerated in a flare stack or stalled for cooking gas purposes.

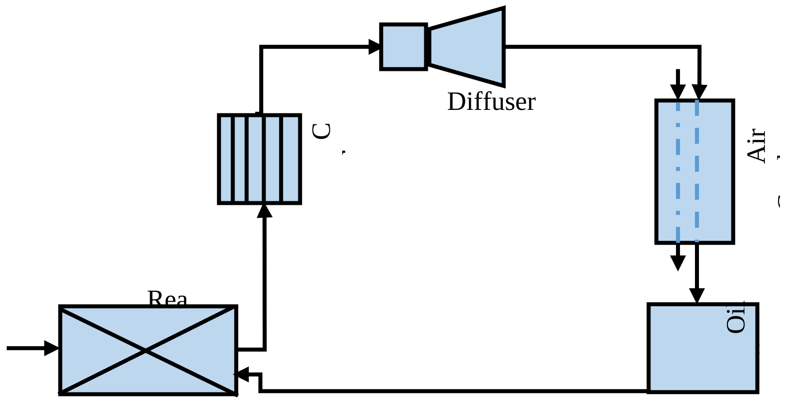


Fig. 2. State points of the local waste plastics plant

State points 1, 3, 5, 7, and 9 represent the inlet temperature and pressure of the plant components, while state points 2, 4, 6, 8 and 10 represent the outlet temperature and pressure of the various parts.

The waste plastics experimental procedure

The pilot test of the waste plastic pyrolysis plant in the Michael Okpara University of Agriculture Umudike was carried out using shredded 2 kg of mixed waste plastics (PP, PE and PS), measured in the weighing machine. The empty reactor was also measured in the weighing machine. 2 kg of mixed waste plastics and 1.0 kg of catalyst were fed inside the reactor and weighed in the weighing machine. Thermocouples were fitted at the reactor base to regulate inlet temperature from the 3kW heater placed at the bottom of the reactor. The inlet reactor temperatures used to produce one liter of petroleum products were 310, 360, 400, 460 and 500^{o}C at the residence time of 60, 54, 50, 46 and 43 minutes, respectively. The waste plastics pyrolysis plant was powered electrically to produce five different samples of liquid products, and the oil samples were taken to the Principal Laboratory Technologist at the National Root Crops Research Institute Umudike for characterization.

The results from the laboratory revealed that liquid oil with a reactor inlet temperature of 310,360,400 and 460°C has close results with standard diesel oil.

However, it was stressed that the diesel oil (AGO) with a reactor inlet temperature of 360°C was the best and had the same oil quality as regular diesel oil. The reactor was finally weighed in the weighing machine after the experiment. The mass left (residue) and decomposed masses in the reactor were calculated to determine the plant's product yield.

Methodology for cost-benefit analysis

The following financial analysis tools were used for economic evaluation: the cash flow, the payback period (PBP), the net present value (NPV) and the internal rate of return [3,19,18,20]. The following equations define the PBP, NPV and IRR indices:

$$PBT = \frac{C_0}{C_t} \qquad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$NPV = \sum_{t=1}^{N} \left| \frac{C_t}{(1+i)^t} - C_0 \right| \qquad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$C_0 - \sum_{t=1}^{N} \left| \frac{C_t}{(1+i)^t} \right| = 0 \qquad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where:

- C_0 is the initial investment cost (Naira);
- N is the lifetime of the investment (years);
- i is the Weighted Average Cost of Capital (WACC);
- C_t is the yearly revenue (Naira/year)

The yearly revenue for the system is computed as:

$$C_t = \left(a.p_{Eoutput} + b.p_{Eself.consumption}\right).CF.t_{year} - c_{fix}.C_0 - c_{var} \quad \ldots\ldots\ldots. \ (4)$$

Where:

- a – the share of crude product from the plant (selling product);
- $p_{Eoutput}$ – the price feed-in tariff for the plant product;
- b – the share of energy input for self-consumption;
- $p_{Eself.consumption}$ – the average price of the energy used by the pyrolysis plant;
- CF – the usage factor of the installed capacity (%);
- t_{year} – the duration of year (hours/year);
- c_{fix} – fixed costs of operation and maintenance (%/year);
- c_{var} – variable operating costs.

RESULTS AND DISCUSSION

System cost-benefit analysis

The cost-benefit analysis was performed using the cash flow, the payback period (PBP), the net present value (NPV) and the internal rate of return (IRR) for the system as indicated in the methodology.

A summary of the cost components of the system is shown in Table 1. The cost parameters include the capita cost of the components, the operating cost, and the maintenance cost. The costs have also been annualized per hour based on a 1000-hour yearly operating time.

Therefore, the system's hourly operation rate was 2.28 USD. The estimated plant life span is 10 years, while the CBA parameters are computed using the parameters in Table 1. With an estimated 1000 hours of annual operation, the system expected a diesel yield of 1000 liters in addition to flared methane gas.

System estimated yield and accruing revenue.

The cost-benefit analysis from annual product yield and corresponding revenue are shown in Figure 3. The system's output for a one-hour batch operation results in one liter of diesel. Thus, for a 1000-hour annual operation, 1000 liters of diesel is expected as shown, with a corresponding revenue benefit of USD 1120. For the system's total life cycle, up to 10,000 litres of diesel can be produced, resulting in about USD 11,200. The comparison of the accrued revenue and the cost of operation is highlighted in the next section.

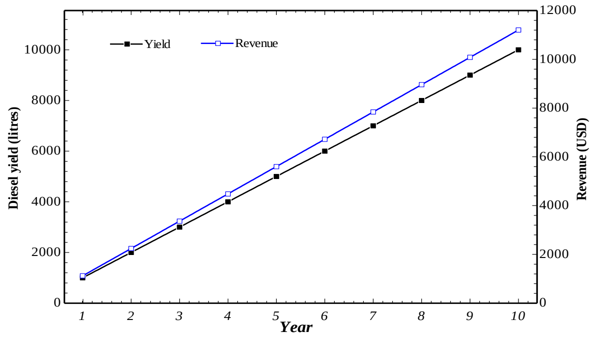


Fig. 3. Yearly diesel yield and estimated revenue from the pyrolysis plant

System Payback Period

The system's payback period is obtained from the cost considerations in Figure 4 based on the yearly revenue accrued and the yearly operational cost. The system has a payback period of just two years compared to its 10-year life span. Thus, it is beneficial from an economic viewpoint and is estimated to generate a net income of up to 700 USD for a thousand-hour operation.

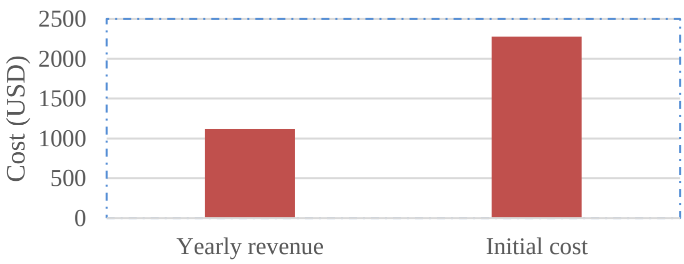
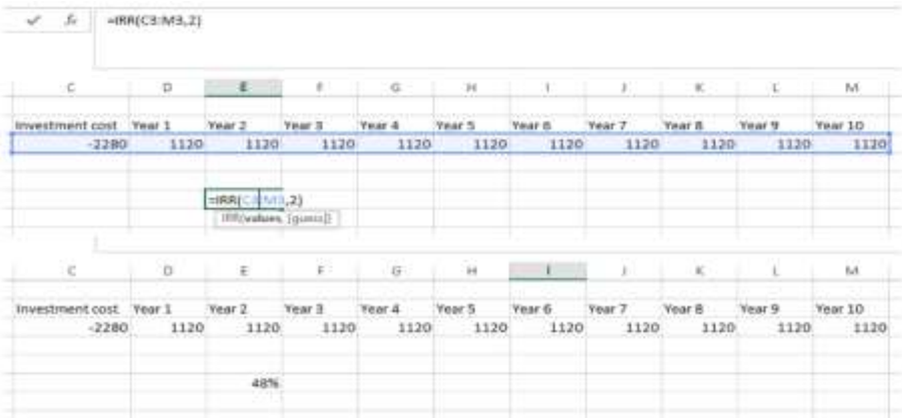


Fig. 4. Yearly revenue and system initial cost

System internal rate of return

The internal rate of return (IRR) was used to estimate the profitability of the investments in the pyrolysis plant and was computed using the expression obtained in the methods. The IRR provided a comprehensive understanding of the potential return on investment and aids in project selection, as well as compared investment opportunities and measured performance. The computation of the IRR was done using Excel (Fig. 5) with an annual revenue yield of $1120 over the 10-year lifespan period from the diesel products. The investment cost, including the cost of waste plastic, was used as indicated in Tab. 1. The pyrolysis plant gave an IRR of 48 % when the cost of plastic was neglected.



=IRR(C3:M3,2)

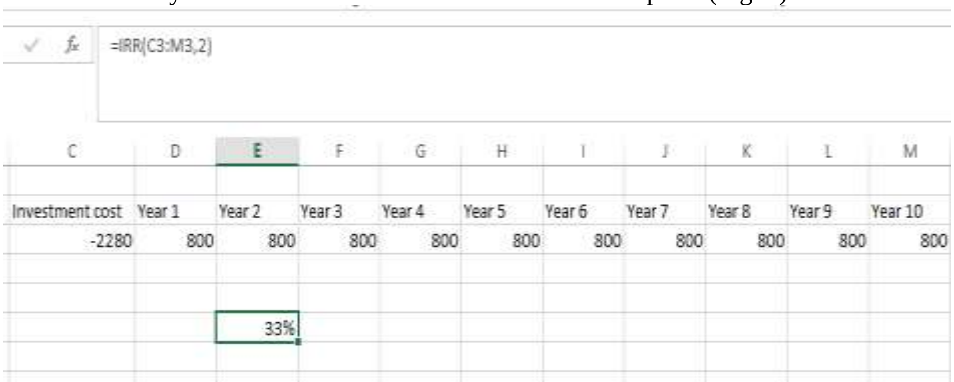
C	D	E	F	G	H	I	J	K	L	M
Investment cost	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
-2280	1120	1120	1120	1120	1120	1120	1120	1120	1120	1120
		=IRR(C3:M3,2)								

C	D	E	F	G	H	I	J	K	L	M
Investment cost	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
-2280	1120	1120	1120	1120	1120	1120	1120	1120	1120	1120
		48%								

Fig. 5. Result on the IRR of the pyrolysis plant with free waste plastic

An IRR of 48 % indicates that the plant is expected to generate a rate of return of 48 %. This means that the cash inflows from the investment are projected to be substantial enough to yield a return on investment of 48 % per year. In other words, the plant is expected to be highly profitable, especially when plastic waste is sourced freely.

Additionally, when the cost of plastic is accounted for, the system's IRR is reduced to 33 % annually and is still feasible from an economic viewpoint (Fig. 6).



=IRR(C3:M3,2)

C	D	E	F	G	H	I	J	K	L	M
Investment cost	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
-2280	800	800	800	800	800	800	800	800	800	800
		33%								

Fig. 6. Result on the IRR of the pyrolysis plant with regards to cost of waste plastic

Tab. 1. Breakdown of the cost of the fabricated waste plastics pyrolysis plant

S/N	Components	Capital cost Z_{cl} ($)	Operating cost Z_{om} ($)	Z_{Lp} ($)	Total annual operating hours(h)	Z_{cl} ($/h)	Z_{om} ($/h)	Z_{Lp} ($/h)
1	Reactor	1,000	100		1000	1	0.1	
2	Cracker	300	30		1000	0.3	0.03	
3	Expansion	350	30		1000	0.35	0.03	
4	Condenser	400	70		1000	0.4	0.07	
5	Total cost on each column	2050	230	$2,280	1000	2.05	0.23	2.28
	Total plant cost	$2050 + $230 = $2,280						

Tab. 2. Characterization of the petroleum products from the plant

Test property	Unit	Test method	Diesel	Standard Limits	Standard Limits
Flash point	°C	ASTM D93	76	>55	45.5 – 46.5
Pour point	°C	ASTM D97	-10.80	-32	-49
Boiling point	°C	Oil weathering system	358	369	200 - 260
Self-ignition temp	°C	ASTM D97	711	725	640
Lower heating value	MJ/kg	ASTM D240	44.8	45.9	45.6
Density at 40 °C	kg/m^3	ASTM D4052	837	810 – 890	760
Viscosity at 40 °C	N.s/m^2	ASTM D445	3.6	2.0 -.4.5	1.6 – 1.8
Sulfur content	%	ASTM D5453	0.23	0.16	0.04
Saturates content Vol.	%	ASTM D2007	77.3	75.3 – 79.3	79.0 – 82.0
Specific gravity at 15 °C	-	ASTM4052	0.88	0.82 -0.95	0.90 -0.98
Ash content mass	%	ASTM D482	0.007	MAX 0.01	0.01
Water content volume	%	ASTM D95	0.20	0 – 0.50	0 – 0.40

The characterizations of petroleum products from waste plastics plant

The fuel samples were tested to determine the fuel characterization according to the ASTM 675 and AFNOR m 15-009 Biodiesel and light fuel oil quality Assurance standard test.

Colour does not directly influence an engine's functioning but indicates the quality of samples, as shown in Tab. 2. Density is a fundamental physical property that can be used (in addition to other properties) to characterize light and heavy fuel fractions. A density in the range 810<d<890 (kg/m^3) for diesel ensures good engine running in this study. It was found that the density of diesel oils was within limitation standards. One property to consider in assessing the overall risk of fuel flammability is the flash point. This is the highest temperature at which a fuel can be handled without risk of explosion. However, the flash points observed for diesel fuels meet the ASTM specifications for all biodiesel products. So, as fuel, they are all expected to be safe during transport and storage. The pour point of fuel is the lowest temperature at which fuel freezes. This value determines the fuel heating conditions for cold weather using appropriate additives. Viscosity was performed at 40 ºC to conform to the national standard ASTM D415 requirement for diesel fuel oil grade D2. The kinetic viscosity of the diesel fuel is slightly higher than that of the main diesel fuel at the same temperature, but this is without harmful consequences to the engine because the value obtained is found to be within acceptable limits (2-best).

CONCLUSION

Due to the need to contribute to reducing environmental pollution from improper disposal of waste plastics, the study performed the economic feasibility of a pilot pyrolysis plant using the cost-benefit analysis (CBA) methodology. The payback period and initial internal return (IRR) were the two CBA performance indices used with consideration given to the system’s total operating cost and initial capital. Additionally, the cost of plastic waste for the duration of the plant was factored in CBA. The following significant conclusions are made: 1000 liters of diesel are expected for a 1000-hour annual operation, with a corresponding revenue benefit of USD 1,120. For the system’s total life cycle, up to 10,000 liters of diesel can be produced, resulting in about USD 11,200.

The system's payback period is just two years compared to its 10-year life span. Thus, it is economically beneficial and is estimated to generate a net income of up to 700 USD for a thousand-hour operation.

The pyrolysis plant's IRR was 48 % when the cost of plastic was neglected. An IRR of 48 % indicates that the plant is expected to generate a rate of return of 48 %.

When the cost of plastic is accounted for, the system’s IRR is reduced to 33 % annually, but it is still feasible from an economic viewpoint.

RECOMMENDATION

Following the CBA results, the pilot system is recommended for use as it adds value to the environment and is economically feasible to operate.

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ANALIZA TROŠKOVA I BENEFITA POSTROJENJA ZA PIROLIZU OTPADNE PLASTIKE KOD PROIZVODNJE BIODIZELA, DRŽAVA UMUDIKE ABIA, NIGERIJA

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Apstrakt. Studija je bila usmerena na procenu cene i koristi analize postrojenja za pirolizu za pretvaranje (konverziju) otpadne plastike u dizel ulje/pogonsko gorivo. Početni kapital za kapacitet od 2 kg/čas plastike je dao mali dobitak.

Zato je od suštinske važnosti da se ekonomično testira održivost ovog sistema (postrojenja, fabrike).

Primenjena je metodologija analize troškova i koristi, sa naglaskom na period otplate sistema i godišnju internu stopu prinosa (IRR eng. internal rate of return). Ovi indeksi su analizirani za godišnji rad od 1000 časova i očekuje se 1000 litara dizela za 2000 kg otpadne plastike, uz odgovarajuću korist od ukupno 1120 $.

Za ukupan životni ciklus sistema/postrojenja, može se proizvesti do 10.000 litara dizela, što rezultira korist od 11.200 $.

Analiza troškova i koristi je pokazala da sistem ima period povrata sredstava od samo dve godine u poređenju sa eksploatacionim vekom od 10 godina.

To je korisno sa ekonomskog stanovišta i procenjuje se da generiše netto prihod do 700 $ za svaku operaciju u trajanju od 1000 časova.

Pored toga, rezultati pokazuju da je postrojenje za pirolizu dalo od 48 % kada je zanemarena cena plastike. IRR od 48 % ukazuje da se očekuje da postrojenje ostvari stopu prinosa od 48 %.

Kada se uzmu u obzir troškovi plastike, IRR sistema se smanjuje za 33% godišnje i još uvek je izvodljiv sa ekonomske tačke gledišta.

Stoga je piroliza plastike ekonomski isplativa za operacije iskorišćenja otpadne plastike za dizel gorivo.

Ključne reči: *Otpadna plastika, postrojenje za pirolizu, analiza troškova i koristi, interna stopa prinosa, period otplate, neto sadašnja vrednost*.

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