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Catalytic Pyrolysis of Waste Low-Density Polyethylene (LDPE) Carry Bags to Fuels: Experimental and Exergy Analyses

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Abstract: The present investigation reports the results of experiments related to the conversion of low-density polyethylene (LDPE) waste carry bags to fuel through an economic catalytic pyrolysis method in a batch reactor using zinc oxide (ZnO) as the catalyst. Plastics are highly beneficial for the day-to-day activities of human beings; however, their decomposition is limited due to their strong covalent bonding. Degradation of these big molecules into smaller ones or monomers has been attempted by several researchers in recent decades, with limited success. Pyrolysis is one of the ideas used to convert plastics, with the crowded structure of polymers, into fuel rather than small molecules. Among these plastics, LDPE is widely used as carry bags throughout the world, and, herein, the results of catalytic pyrolysis of the conversion of LDPE into fuel are reported. A compact laboratory-scale batch reactor, specially designed at our laboratory, was used to carry out the pyrolysis process. Different dosages of ZnO were used as a catalyst to carry out the pyrolysis at a specific temperature. The optimal dosage of ZnO for a 50 g waste LDPE batch was found to be 0.6 g to get the maximum oil yield. The yielded oil was analyzed chemically through Fourier transform infrared spectroscopy (FTIR) and a Reformulyzer M4 Hydrocarbon Group Type Analyzer. Evaluation of physical and chemical exergy along with exergetic efficiency of the process was carried out. The described experiments and the results represent a small but significant step toward curbing the menace of plastic solid wastes, which are degrading the environment and human life worryingly, and allowing them to be utilized for generating low-cost fuel for transportation and other applications.

Keywords: plastic conversion; catalytic pyrolysis; low-density polyethylene (LDPE); zinc oxide (ZnO); exergy

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1. Introduction

Plastics have an important role in everybody's life these days. Many of the household items that we come across in our daily life are made up of plastics. They are packaging materials for foods and beverages, various types of containers, toys, decorating materials, household items, automobile components, construction materials, and so on. Most of these items are disposable in nature, which means we discard these items after their intended use and these materials pile up as a major component in the municipal solid waste (MSW) stream. Annually, 2.01 billion tons of municipal solid wastes are generated, of which 33% are not managed in an environmentally safe manner [1]. Nearly 70% of MSW ends up in landfills and dump sites, 19% is recycled, and 11% is used for energy recovery [2].

Responsible use of plastics will help to preserve our environment because it takes hundreds of years for the natural degradation of these materials. All the commodity plastics can be recycled and safe disposal at designated collection bins is essential for that. The littering of plastic packaging items, especially carry bags, creates a big menace to the environment. Around 300 million plastic bags have been found in the Atlantic Ocean alone [3]. These bags are very dangerous for marine life and aquatic species, especially for

those of the mammalian variety. The most common victims are sea turtles because they eat rubbish along with jellyfish. Even if they survive after swallowing the waste plastics, their digestion system is affected, and they eventually die a slow death because of toxicity or intestinal blockage [4]. As a result, one species dies at an abnormal rate and so every other living organism in the waterway is impacted.

Another problem with the littering of waste plastic carry bags is the effect on animals in the forest. Improper digestion of plastic waste has the potential to kill an animal in the forest every three months [5]. The plastic waste accumulates in municipal sewage systems and leads to blockages in the drainage; this can, in turn, act as a breeding ground for the insects that spread infectious diseases [6].

In the Kingdom of Saudi Arabia (KSA), it has been reported that 64–72 M tons of solid waste is produced annually and this is predicted to reach 125 M by 2031 [7]. The majority of this MSW is disposed of in landfills or offsites after generous recycling by the informal sector. Two of the key performance indicators (KPIs) of Vision 2030 of KSA specifically address the need for increased recycling of MSW in the country [8].

The various strategies adopted for the proper disposal of plastics in MSW are mechanical recycling, incineration, pyrolysis, gasification, and anaerobic conversion [9]. Pyrolysis is considered an economically favorable process for converting MSW into fuels, with many operational and environmental benefits. The plastic components in the MSW stream have a rich combustible composition, which can be easily converted to carbonaceous fuels by the process of pyrolysis [10]. Pyrolysis is defined as a thermal process in which controlled thermal degradation of long-chain polymeric materials takes place in an inert atmosphere in the presence or absence of a suitable catalyst. The former process is known as thermal pyrolysis, whereas the latter is known as catalytic pyrolysis. Various catalysts, such as zeolites, red mud, silica-alumina mixture, Fe_2O_3, and Al_2O_3, have been employed in the pyrolysis of waste plastics [11–14]. Lee et al. carried out pyrolysis of scrap LDPE in the presence of H-ZSM-11 zeolite as an effective catalyst [15]. The process yielded low molecular weight aliphatic hydrocarbons in the gaseous fuel range. In another reported investigation, waste LDPE packaging materials and cement carry bags made up of polypropylene (PP) were converted to oil, with a yield in the range of 75–81%, by the pyrolysis process [16]. The pyrolytic oil was blended with diesel and used in a diesel engine and the studies demonstrated that such blending resulted in a decrease in CO and CO_2 emissions from the engine, a decrease in the overall fuel consumption, and an improved engine performance. Pradeep and Gowthaman reported the catalytic pyrolysis of waste LDPE with magnesium bentonite as a catalyst [17]. The use of 2 wt% of the catalyst resulted in a fuel with better properties, similar to those of diesel fuel. Pyrolysis of mixed plastic waste from MSW has been subjected to detailed investigation in recent decades. The pyrolysis kinetics of the major commodity plastics present in the MSW stream was reported by Wu et al. [18]. In another investigation, Williams and Williams carried out the pyrolysis of these commodity plastics in a static batch reactor under a nitrogen atmosphere [19]. The product composition and the yield of the pyrolysis were examined, and the results showed that the pyrolysis products are mainly aliphatic compounds, with aromatic compounds as a minor component. The pyrolysis behaviors of LDPE, PS, and their mixtures were investigated by Onwudili and coworkers using a closed batch reactor [20]. The major observation was that the presence of PS helped to reduce the degradation temperature of LDPE and produced more oil and fewer residues. The effect of PS on the pyrolysis product yield of PE and PP mixture was reported by the research group of Straka [21]. A comprehensive review of various strategies adopted for the conversion of waste plastics to valuable chemicals was published by Zheng et al. [22]. A reduction in the overall process energy requirements and improvements in the quality of the product fuels are the major advantages of catalytic pyrolysis [23]. The oil obtained from the pyrolysis of waste plastics can be used in combustion engines, burners, and furnaces to produce thermal energy due to its high calorific values [10,24–26]. As an alternative to the landfilling process, the pyrolysis process contributes to the reduction in carbon monoxide (CO) and carbon dioxide (CO_2) emissions. As pyrolysis takes place in

the presence of inert gases, it eliminates the formation of toxic dioxins, which are produced at high temperatures in the oxygen atmosphere [27].

In the case of energy-intensive processes, such as pyrolysis of LDPE at high temperatures, it is always necessary to develop the process that is the most energy-efficient [28]. This can be achieved by performing the exergy analysis of the process at different operating conditions. There are only a few reports available that look at the thermodynamic or exergetic efficiency of the pyrolysis processes. Chaudhary et al. investigated the effect of pyrolysis process temperature on exergy efficiency and concluded that the exergy of pyro-gas increased with the increase in temperature at a fixed amount of catalyst [29]. Their calculations revealed exergy efficiency to be in the 59–91% range with a temperature range of 300–600 °C. The energy and exergy efficiencies of rice husk pyrolysis in the temperature range of 800–1000 °C were reported by Wang et al. [30]. They estimated energy and exergy efficiencies in the ranges of 65–73% and 53–61%, respectively. Zhang et al. analyzed the exergy and exergy efficiencies of the pyrolysis of plastic waste in a rotary kiln with a heat carrier by considering the heat carrier-loading impact on the heat and mass transfer in the process [31]. The exergy and exergy efficiencies were reported to be in the ranges of 61–68% and 59–66%, respectively. Rajkumar and Somsundaram reported the kinetic parameters of the pyrolysis of residual tires at 450–500 °C without the use of any catalyst, and were able to estimate the exergy and the amount of energy required for the process [32]. Huang et al. focused on predicting the chemical exergy of six types of plastic wastes through a model with an error of less than 5% [33].

Overall, the research literature on improving LDPE catalytic pyrolysis is still evolving. Further work, such as the use of different types of catalysts to reduce pyrolysis temperature and the estimation of related energy efficiency, is highly desirable. In the present investigation, pyrolysis of waste plastic carry bags was carried out in the presence of a zinc oxide (ZnO) catalyst to study its effect on the overall process. In addition to thermal pyrolysis, three experimental runs were made with varying amounts of ZnO catalysts, that is, 0.5 g, 0.6 g, and 0.7 g. Moreover, exergy analyses for each pyrolysis case (with or without a catalyst) were conducted to determine the thermodynamic efficiency of the process. Process Simulation Software ASPEN Plus v.11.0 was used to extract and simulate the thermodynamic properties of the pyrolysis of raw material and the products.

2. Experimental Procedures

Waste plastic carry bags were collected and cut into square pieces approximately 3 cm in size and washed well in water to remove any dirt and other impurities. The washed samples were dried in a hot-air oven at 60 °C for 24 h before the pyrolysis experiments. The amount of waste carry bag material used for the pyrolysis process (batch size) was fixed at 50 g. A block flow diagram for the pyrolysis process, starting with the collection stage, is shown in Figure 1. Shredded plastic waste material was fed into a round bottom flask. Nitrogen gas was supplied to the flask at a rate of 30 mL/minute to create an inert atmosphere. The temperature chosen for the experiment was 300 °C, which was supplied with the help of an electric heater (Electrothermal, UK, power 170 W, 230 V). After melting the feed, the vapor was allowed to pass through a condenser. The condensate was collected in the oil flask. A schematic of the experimental setup is given in Figure 2.

The first trial of the experiment was carried out as thermal pyrolysis (without using a catalyst). ZnO (Analytical grade, Merck, St. Louis, MO, USA) was used as the catalyst for catalytic pyrolysis. The various catalyst dosages used for catalytic pyrolysis were 0.5 g, 0.6 g, and 0.7 g for a batch size of 50 g waste carry bags. The pyrolysis time was fixed at 2 h for all sets of experiments.

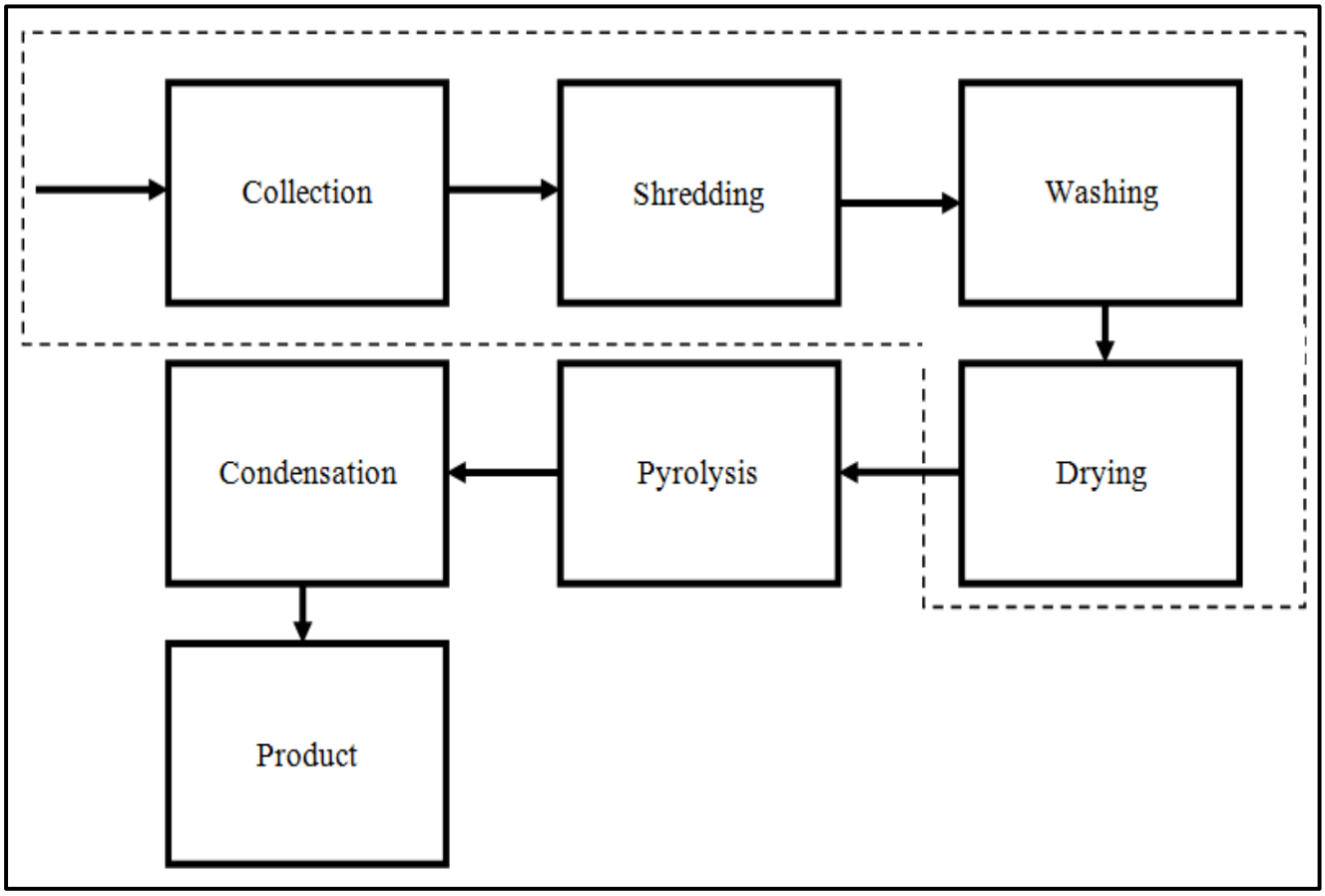

Figure 1. Block Flow Diagram of Pyrolysis Process.

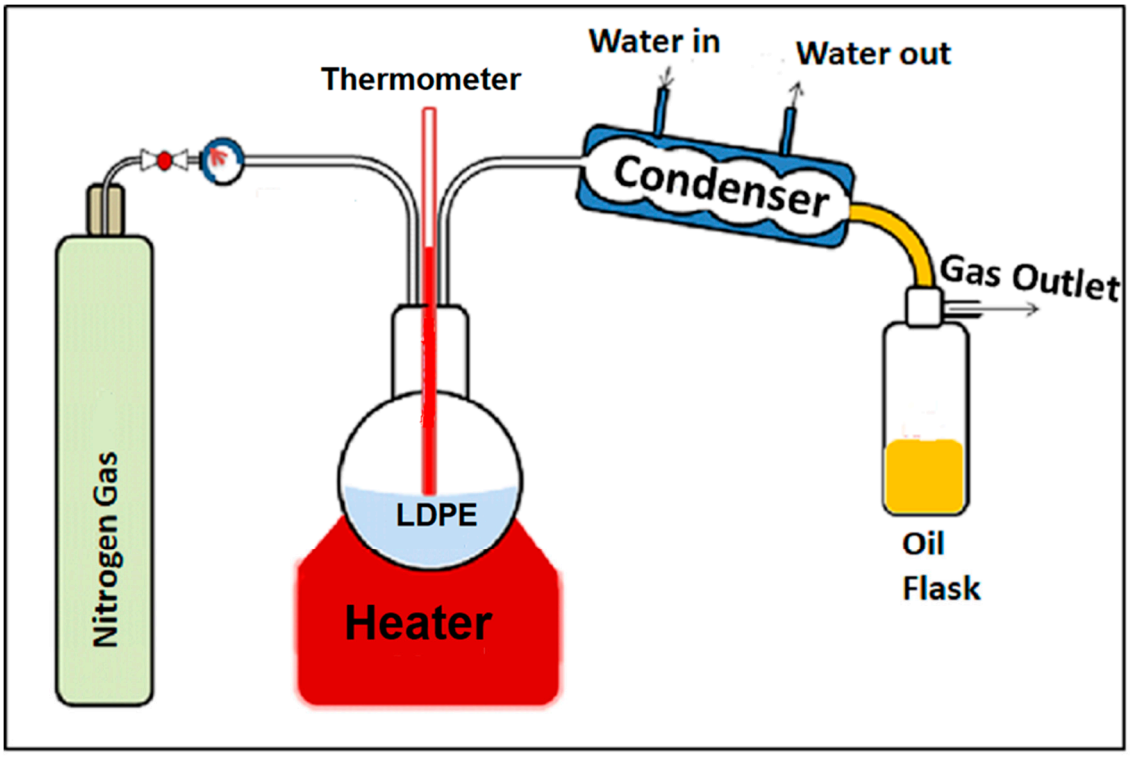

Figure 2. Schematic of the experimental set-up.

2.1. Characterization

A Fourier Transform Infrared spectrometer (FTIR, Nicolet iS5, Thermo Scientific, Waltham, MA, USA) was used to characterize the waste carry bags and the oil obtained after pyrolysis. A total of 32 scans were done with a resolution of 4 cm^{-1}. The hydrocarbon products with five or more C atoms (C_{5+}) remained liquid in the collecting vessel of the cold trap. Afterward, the liquid organic phase was analyzed in a Reformulyzer M4 (PAC) GC (PIONA method). By the standards ISO 22854:2021 and ASTM D6839, the PIONA method provides information on the proportions of naphthenes, *n*-paraffins, *iso*-paraffins, cyclic olefins, *n*-olefins, *iso*-olefins, and aromatics in the chain length range C_5–C_{11} with high reproducibility [34,35]. In addition, the fraction of the product group C_{12+} was determined. A clear distinction between kinds of paraffin and olefins wass not possible for the C_{12+} product group, so a distinction could only be drawn between non-aromatics and aromatics.

2.2. Exergy Analysis

Exergy analysis is a tool that can be used to isolate and improve process conditions that contribute to lower efficiency. In this method, together with energy and mass balances, the exergy destruction or loss of work potential is determined across a system [36–38]. The higher the exergy destruction the lower the thermodynamic efficiency of the system or process. Thus, if the system's actual exergy decrease is much higher than the thermodynamic exergy decrease, then there is room for improvement.

Exergy can be evaluated by doing exergy balance on a given process, which may be continuous, semi-continuous, or batch. In our case the pyrolysis of LDPE was semi-continuous. Hence the exergy balance, around the flask as a control volume, can be written as:

$$\frac{\Delta \xi}{\Delta t} = -\xi_{out} - \xi_{destroyed} \quad (1)$$

where ξ is the exergy in Joules. The extra destruction term is because, in contrast to entropy, the exergy is always destroyed during the process.

The term on the left-hand side indicates the change in the exergy of the system with time. In our case, the time of exergy change lasted for 30 min when the LDPE was put in the flask and heated for 30 min. It should be noted that the exergy change of the system is due to heat transfer from the electric heater (130 W) and the exergy of the LDPE. The exergy due to heat transfer is determined by the following formula:

$$\xi_{heat_transfer} = \left(1 - \frac{T_o}{T}\right) Q \quad (2)$$

where T_o is the environment temperature and T is the temperature of the heating source.

Now the first term on the right-hand side is the exergy of the pyrolysis products leaving the flask and the second term on the right-hand side is the exergy destroyed during the process. In the pyrolysis process, where nuclear, magnetic, and surface tension effects are unavailable, the exergy associated with mass 'ξ' is usually taken as the sum of kinetic, potential, physical, mixing, and chemical exergies [39].

$$\xi = \xi^{ke} + \xi^{pe} + \xi^{ph} + \xi^{ch} + \xi^{M} \quad (3)$$

In LDPE pyrolysis the changes in kinetic, potential, and mixing exergies can also be ignored [40]. The contributions of physical and chemical exergies are important.

2.2.1. Physical Exergy (ξ^{ph})

The physical exergy is written as the exergy due to temperature and pressure effects and is determined as follows:

$$\xi^{ph}_{T,P} = (h - h_d) - (s - s_d)T_d \quad (4)$$

where h is the enthalpy, s is the entropy, and d represents the dead state of 25 °C and 1 atm.

2.2.2. Chemical Exergy (ξ^{ch})

The exergy of chemical compounds according to their standard states, or the most stable states available, is defined as the chemical exergy. Here the stable states are referred to as species available at normal temperature and pressure in air, seawater, or lithospheric solids [41]. In a reaction, if the affinity of reactants and products are known and it is done under standard conditions, the calculation of chemical exergy is easy. If the chemical exergy of a chemical species is calculated under standard conditions, it can be utilized to calculate the chemical exergy at other temperatures and pressures. The chemical exergy of organic molecules, as is the case in LDPE pyrolysis, can be estimated by using the correlations available in the literature [42]. We used the correlation developed by Rant [43].

2.2.3. Process Exergetic/Thermodynamic Efficiency

Exergetic efficiency is dependent on raw materials, fuel, and product exergies [44]. The fuel exergy is important, and it is the measure of product exergy. It includes heat transfer, thereby helping to increase the temperature of the system studied. On the other hand, product exergy comprises exergies associated with all the streams leaving the system, such as gas, oil, wax, and carbon residue. Thus, we write exergy efficiency, or second law efficiency, as follows [45]:

$$\lambda_{II} = \frac{\text{Exergy Recovered}}{\text{Exergy Expended}} = \frac{\text{Exergy of Products}}{\text{Exergy (Raw Material + Heat)}} = 1 - \frac{\text{Exergy Destroyed}}{\text{Exergy Expended}}$$

3. Results and Discussion

The pyrolysis process was carried out with and without a catalyst. Initially, the thermal pyrolysis of 50.0 g of the waste LDPE yielded about 20.0 g of pyrolysis oil, 9.10 g of wax, and about 7.0 g of residue. This shows that about 14.0 g were the losses, which was the gaseous product (not collected) of the pyrolysis. To understand the effect of ZnO as a catalyst for the pyrolysis process, experiments were carried out under conditions similar to thermal pyrolysis, with three different catalyst dosages (0.5 g, 0.6 g, and 0.7 g). The thermal process was compared with the catalytic process and the products obtained as a percentage are given in Table 1. It can be seen that the highest yield of pyrolysis oil (67.3%) was obtained with a catalyst dosage of 0.6 g with no wax formation. As the catalyst dosage was increased to 0.7 g, the gas and oil product percentages decreased, whereas there was an increase in the residue. This suggests that 0.6 g of catalyst is the optimum dosage for converting 50 g of waste LDPE to fuel oil with the highest yield. Similar results with no wax formation are also reported by others.

Table 1. Effect of catalyst on the pyrolysis product.

Weight of Catalyst (g)	Gas (wt %)	Oil (wt %)	Wax (wt %)	Residue (wt %)
0	27.90	40.00	18.20	13.90
0.5	20.00	54.40	0.85	24.75
0.6	9.55	67.30	0	23.15
0.7	9.30	65.00	0	25.70

Uthpalani et al. used recycled LDPE and PP and converted them into oil through a batch reactor [46]. They reported that LDPE produced a small amount of wax whereas PP resulted in no wax formation. Another recent report also showed the elimination of wax formation while using a catalyst for the conversion of waste plastics to oil through pyrolysis [47].

3.1. FTIR Spectroscopy

FTIR is a powerful characteristic tool to understand the functional groups present in plastics as well as the oil produced from them. The IR spectra for the waste plastic carry bags and the oil produced at a catalyst dosage of 0.6 g are shown in Figure 3. The spectra show the characteristic peaks for polyethylene such as asymmetric C-H stretch of methylene groups at 2910 cm^{-1} and symmetric stretch of methylene groups at 2850 cm^{-1}. The peak corresponding to CH_2 rocking can be seen at 710 cm^{-1}, whereas the peak at 1471 cm^{-1} can be attributed to the bending vibrations of the methylene group in polyethylene.

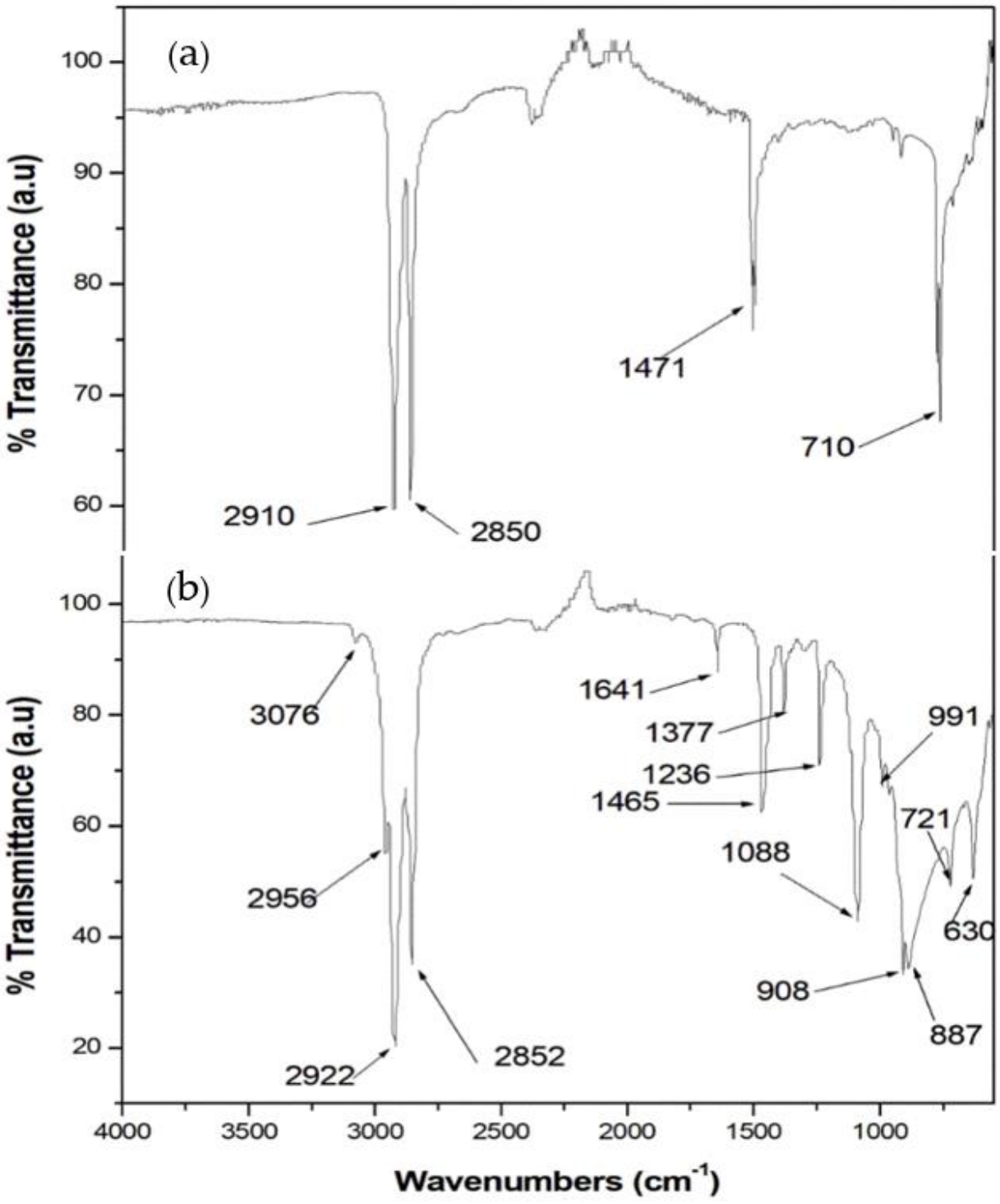

Figure 3. FTIR spectra of (**a**) LDPE waste carry bags, (**b**) oil obtained from pyrolysis with 0.6 g of catalyst.

The different peaks and functional groups from FTIR spectra are given in Table 2. The results showed strong peaks at wavelengths around 2956, 2852, 2922, and 2954 cm^{-1} due to C–H stretching belonging to alkanes. The bands around 1465 cm^{-1} correspond to the C–H bending vibration of the methyl groups present in alkanes. The presence of aromatic compounds is confirmed by the appearance of the absorption bands at 630 cm^{-1}, 721 cm^{-1}, and 887 cm^{-1}, which can be attributed to C–H out-of-plane bending vibrations [47]. C–H out-of-plane bending vibration of vinyl groups or alkenes is shown at 908 cm^{-1} [48]. From the peak assignment, it is clear that the product obtained by the pyrolysis consists of low molecular weight alkanes, most probably in the diesel and gasoline range with some alkenes and aromatic compounds.

Table 2. IR Peak Assignment.

Wave Number (cm^{-1})	Type of Vibration	Nature of Functional Group
3076	=C-H stretching	Aromatics
2956, 2954	-C-H stretching	Alkane
2922	-C-H stretching	Alkane
2852	-C-H stretching	Alkane
1641	-C=C stretching	Alkene/fingerprint region for phenyl ring substitution overtone
1465	-C=C stretching	Alkanes with methyl groups with C-H bending vibration
1377	-C-H scissoring and bending	Alkane
1236	-CH_2 group bending	Alkane
1088	In-plane deformation	Aromatics
991	-C-H out-of-plane vibration	Alkane
908	=C-H bending	Alkene
887	-C-H out of plane bending	Alkene
721	-C-H rock	Alkene
630	-CH=CH_2 twisting vibration	Alkene

3.2. Oil Parameters

The key findings from hydrocarbon group-type analysis (as per Test Methods ASTM D5443, ASTM D6839) for the pyrolysis oil with 0.6 g catalyst are given in Table 3. The calorific value of the pyrolysis oil obtained in the present investigation (43.15 MJ/kg) closely matches the value reported by other research groups [49,50]. The carbon and hydrogen ratios of the oil are 86.80 and 13.30%, respectively. Al-Salem et al. reported recently that the pyrolysis of LDPE at around 600 °C yields similar results [51]. In the present investigation, the experiments were done at a relatively low temperature. The research octane number (RON) and motor octane number (MON) of the pyrolysis oil were 80.40 and 66.80, respectively. From the FTIR studies, it can be concluded that the majority of the compounds obtained were linear saturated materials. Therefore, the reported values of RON and MON match.

Table 3. Properties of the pyrolysis oil with 0.6 g catalyst.

Oil Property	Value
Calorific Value	43.15 MJ/kg
Carbon ratio	86.80%
Hydrogen ratio	13.30%
Research Octane No.	80.40
Motor Octane No.	66.80

The composition summary of various hydrocarbons present in the oil, as per the hydrocarbon group-type analysis using Reformulyzer M4, is given in Table 4. The selected method provided benzene, saturates, olefins, and aromatics as components. The obtained oil contains a small fraction of benzene. The saturates and aromatics are almost equal in

weight percentages. The saturates generally include aliphatic and cyclic hydrocarbons. The aromatic components may be limited to di and polysubstituted phenyl groups as monosubstituted phenyl groups are absent as per the FTIR data. If they are present, a band at 695 cm^{-1} should have been there, but in this case that particular band is missing. Some of the aromatics, such as naphthalene and derivatives of napthalenes, may contain polycyclic rings. It is also noteworthy that there is a certain percentage of olefins present in the oil. Determination of the exact nature and the different constituents of these fractions is beyond the scope of this preliminary study and more advanced techniques such as GC-MS need to be employed to get a clear picture.

Table 4. Composition of the liquid product from pyrolysis.

Component	% (*w*/*w*)	% (*v*/*v*)
Benzene	0.10	0.10
Saturates	41.40	43.50
Olefins	18.70	20.30
Aromatics	40	36.20

The analysis shows that saturates and aromatics are the major components present in the oil product obtained from pyrolysis.

3.3. Exergy Analysis

ASPEN Plus v.11 was used to calculate the physical exergy of the raw material LDPE and the products LPG, oil, wax, and carbon residue. The thermodynamic method used was Peng–Robinson. The selection of the Peng–Robinson equation of state was made based on the fact that it accurately predicts the thermodynamic properties of hydrocarbons. In ASPEN Plus, stand-alone streams cannot be processed without linking them to equipment. To circumvent this issue, we connected the streams to a splitter with 0 split fraction so that the input and one of the output streams remained the same (Figure 4). Therefore, the use of a splitter did not affect the exergy values, as both inputs and output streams were the same. The ASPEN software then generated the values of the exergy of the stream. The model accuracy was checked by looking at the mass and energy balances around the splitter and was found to be correct.

The calculated physical and chemical exergies for each component at different catalyst amounts are given in Table 5. As far as chemical exergy is concerned, we used the correlations developed by Rant [43]. The correlation developed by Rant was used because it specifically calculates the chemical exergy of fuels, which closely matches with our components. He correlated chemical exergy to the lower heating value (LHV) of the compound. It should be noted that the physical exergy and the chemical exergy values of LDPE and the electric heater remained fixed and were estimated to be 1.65 J, 2.23×10^6, and 0.15×10^6 J, respectively. The exergy values for the catalyst have been ignored.

Table 5. Exergy analysis of the conversion of LDPE to oil with varying amounts of ZnO catalyst.

	Physical Exergy (kJ)				**Chemical Exergy (kJ)**				**Total Exergy (kJ)**			
	Catalyst Loading (g)				**Catalyst Loading (g)**				**Catalyst Loading (g)**			
	0	0.5	0.6	0.7	0	0.5	0.6	0.7	0	0.5	0.6	0.7
Gas	2.7	1.9	0.9	0.9	605.2	432.3	205.3	201.0	607.9	434.2	206.3	201.9
Oil	6.1	8.3	10.3	10.0	846.3	1153.1	1423.9	1390.0	852.4	1161.0	1434.2	1400.1
Wax	1.9	0.1	0	0	302.9	14.4	0	0	304.9	14.5	0	0
Carbon	5.3	9.4	8.9	9.8	197.4	349.9	329.4	364.9	202.7	359.3	338.3	374.8

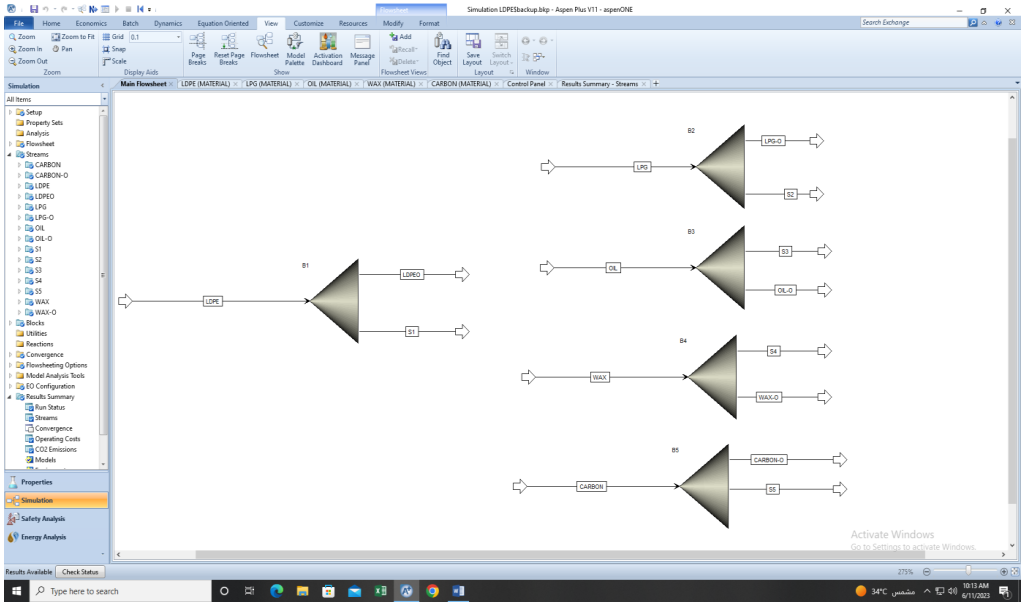

Figure 4. Aspen Plus v.11 flowsheet simulations to extract physical exergies of components.

The product distribution concerning catalyst amount at 300 °C is shown in Figure 5. It can be seen that higher amount of catalyst ZnO favors the formation of oil and residue whereas the production of wax and gas decreases. There is a significant increase in oil production with the catalytic pyrolysis technique rather than with simple pyrolysis, as can be evidenced from the figure. Among the different dosages, 0.6 g gives the optimum results for oil production. Based on these results, a pilot plant for the production of oil from LDPE waste carry bags will be designed and further studies will be conducted. Figure 6 shows exergy destruction as a function of catalyst weight. A slight increase in the exergy efficiency as catalyst weight is increased should be noted. This may be because, at higher catalyst amounts, products with higher exergy values are formed. Our calculations show exergy efficiency to be around 83%, compared to the 60% reported by Chaudhary et al. [29] at 300 °C (see Figure 7). This might be due to the different catalysts used. This indicates that ZnO is more energy efficient than MgO, ZSM-5, and activated charcoal. However, further experiments at different temperatures are needed to validate our argument.

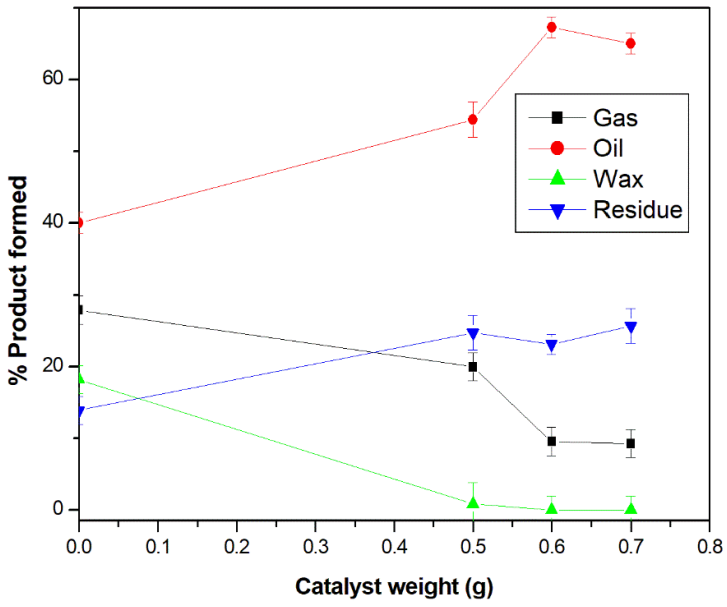

Figure 5. Product distribution as a function of catalyst weight.

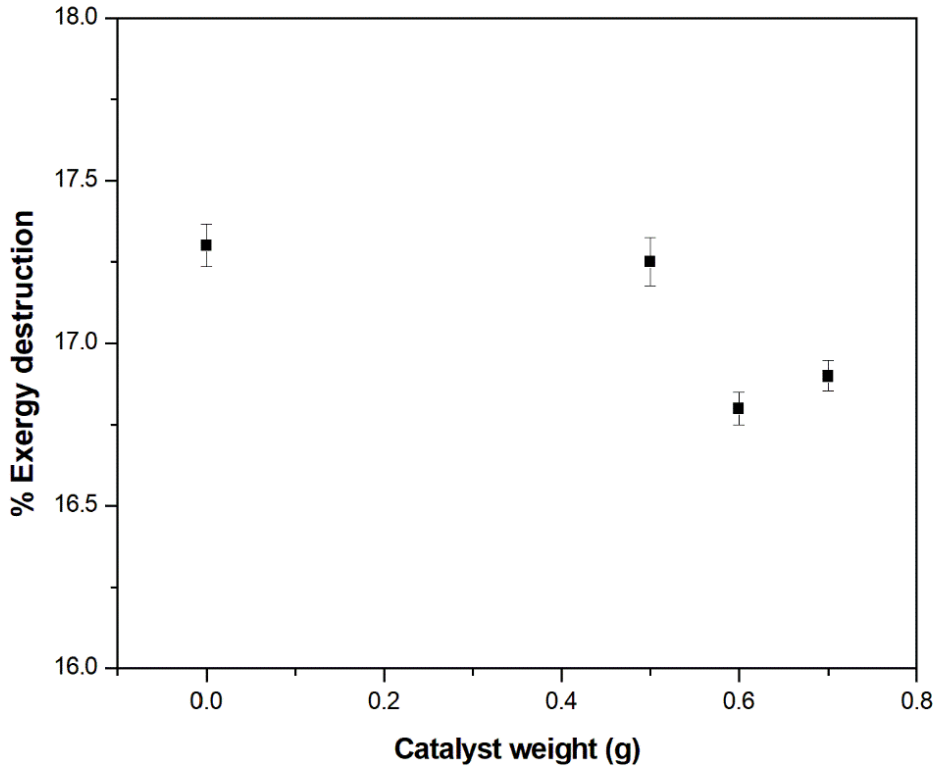

Figure 6. Exergy destruction as a function of catalyst weight.

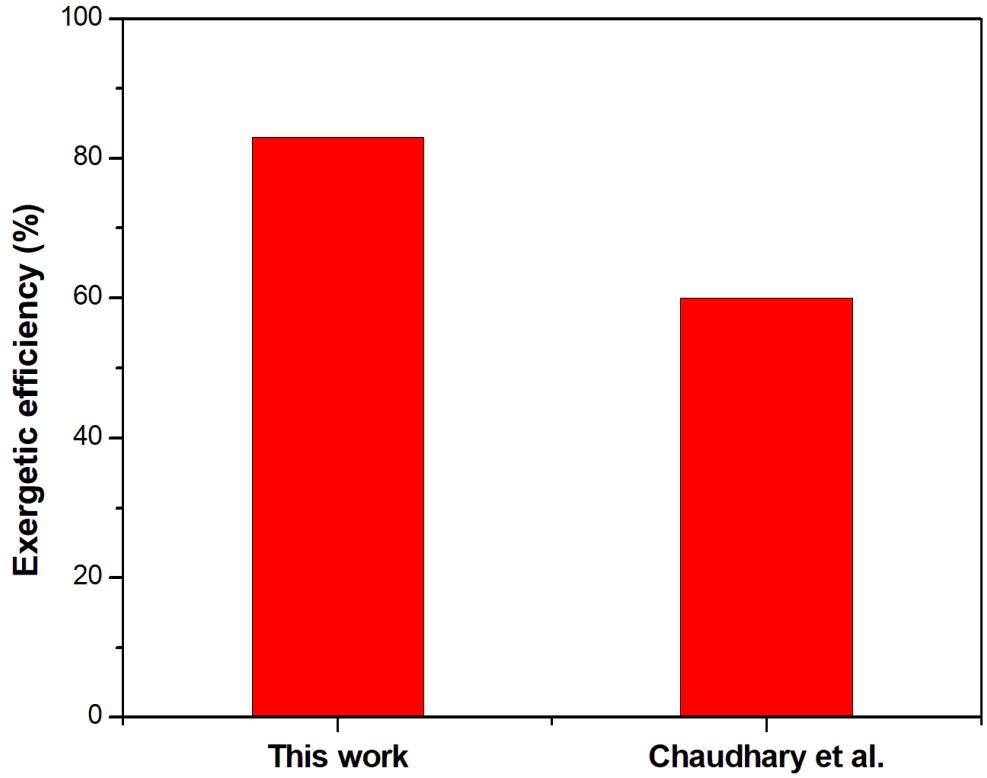

Figure 7. Exergetic efficiency of ZnO (this work) with other catalysts in the literature [29].

4. Conclusions

The reverse of polymerization is a challenging area of research and, so far, no noteworthy results have been reported by the scientific community. This work adopted a catalytic pyrolysis technique using zinc oxide for the decomposition of low-density polyethylene

into small fractions. LDPE-based materials are extensively utilized all over the world as carry bags and a huge amount of waste is created from it. Therefore, any method to convert it into useful products such as oil or fuel will be useful for mankind. Pyrolysis of LDPE into oil has been an active research area for many years. Compared with thermal pyrolysis, the catalytic pyrolysis process resulted in an improved yield of oil product; specifically, 0.6 g of catalyst (ZnO) was found to be the optimum dosage for pyrolysis of waste LDPE with a batch size of 50 g. The catalyst used is economically viable and has been readily available as an activator in elastomer compounds for many years. The obtained products were characterized by various techniques such as FTIR spectroscopy and composition analysis. The process achieved the conversion of 67.30% of the plastic into oil.

This preliminary investigation led to the conclusion that LDPE-based waste carry bags can be easily converted to oil through catalytic pyrolysis using a cheap material as a catalyst at a relatively lower temperature. The process has to be streamlined to limit the production of wax and gas so that the efficiency can be increased to 90% or so. The purification strategies of pyrolysis oil, the efficiency of the oil in internal combustion engines, and other characteristics are yet to be determined. The exact chemical components present in the different fractions of oil obtained need to be analyzed systematically, which will help us to identify potential applications in the future. The exergy analysis revealed that, compared to other catalysts, ZnO shows improved process efficiency. However, further experiments at different temperatures are required to validate our claim.

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