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Yuliana Rodriguez Lamar

USFQ: Universidad San Francisco de Quito

José Noboa

USFQ: Universidad San Francisco de Quito

Andrés S. Torres Miranda

USFQ: Universidad San Francisco de Quito

Daniela Almeida Streitwieser (✉ dalmeida@usfq.edu.ec)

USFQ: Universidad San Francisco de Quito <https://orcid.org/0000-0001-7024-421X>

Research Article

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Conversion of PP, HDPE and LDPE plastics into liquid fuels and chemical precursors by thermal cracking

Yuliana Rodríguez Lamar[†], José Noboa[‡], Andrés S. Torres Miranda[‡], Daniela Almeida Streitwieser^{†,}*

[†] Institute for Development of Alternative Energies and Materials IDEMA, Department of Chemical Engineering, Universidad San Francisco de Quito USFQ, EC 170901 Quito, Ecuador

ABSTRACT

The inappropriate disposal of plastic waste cause serious environmental problems. Nowadays, alternative processes are being studied for the sustainable reutilization of plastics. One of these options is the cracking into shorter liquid hydrocarbon fractions, while maintaining its basic chemical structure. The energetic potential from the original plastics structure remains and the fractions can be used as fuels and chemical precursors. This research addresses the kinetic study of thermal cracking of polypropylene (PP) and high- and low-density polyethylene (HDPE and LDPE) in a batch reactor. The kinetics of the reaction can be described as a first-order rate with the lowest activation energy using PP, followed by HDPE and LDPE with values of 367.28 kJ/mol, 453.37 kJ/mol and 457.96 kJ/mol, respectively. The yield obtained for the liquid fraction is highest for LDPE, with a value of 72% at 390°C, followed by HDPE and LDPE with 69% and 62% at 375°C. The liquid fractions obtained from the process were

characterized according to ASTM standards, obtaining that LDPE and HDPE fractions have similar properties to diesel, while PP is closer to gasoline. The fractions were also analyzed by means of gas chromatography identifying the main products of the reaction and establishing a possible reaction mechanism.

KEYWORDS: Plastic waste valorization, polypropylene, high density polyethylene, low density polyethylene, thermal cracking, kinetic study.

INTRODUCTION

Plastic products have multiple applications and they have become essential elements in modern life, but their short life cycle and inappropriate disposal are causing serious environmental, social and economic problems [1]. In the last decades, the production of disposable polymers and the resulting solid waste generation has increased dramatically. In 1950, global plastic production was 2 million tons, since then, annual production has increased almost 200 times, reaching 360 million tons in 2018 [2]. This value is equivalent to approximately two-thirds of the world's population [3]. In 2018, the plastics with highest production were polypropylene (PP), low-density polyethylene (LDPE) and high-density polyethylene (HDPE) with 10, 9 and 6 million tons, respectively [4, 5].

This situation causes an uprising environmental concern due to the lack of efficient methods for plastic waste disposal. Among the produced plastic, only 9% is recycled, 12% is incinerated and 79% is released into oceans and landfills [6]. The main difficulty with recycling, meaning the recasting of plastic into new products, is the intensive work required to classify the type of polymer and their transparency and color [7]. Also, some plastics cannot be recycled due to their structure and the amount of additives contained. In most of the cases the additives are

toxic, and they may hinder the separation of the main polymer and harm the quality of the new plastic products [8]. Another important method for plastic disposal is incineration, which is a thermal process that generates energy from plastic waste using steam turbines. Even if this process is the most widely used nowadays [9], it generates acid gases, carcinogenic dioxins and it releases heavy metals, causing problems in the ecosystem and people's health [10]. Also in this case only its high heating value can be exploited, while its chemical structure is being destroyed [11].

As observed, recycling and incineration technologies are insufficient to manage the total production of plastic waste. According to statistics, by 2025 there will be 250 million tons of plastic in the oceans and landfills [12]. The plastic waste present in the marine environment not only affects fauna and flora, it also endangers people's health by threatening the security of human food chain [13]. Therefore, a circular economy of plastics has been encouraged, where the responsibility of the producer extends to the post-consumption stage of the product's useful life; namely, the producer controls the environmental impact of his product, preventing plastics from ending up as waste [14]. Although incineration of plastic waste has increased [14], the aim is to use plastic waste as a secondary resource. Therefore, more sustainable and reliable methods for the revalorization of plastic residue must be developed [15]. Some research has focused on recovering the energetic potential of plastics, for example by thermal or catalytic cracking reactions, taking advantage of the high heat capacity containing in their structure [16–18].

Thermal cracking is the breakdown of long chains of polymer molecules into smaller and less complex units through heat and pressure [19]. Plastic residues are classified as secondary raw materials with great potential for thermal or catalytic cracking due to the long chain hydrocarbons in their structure. In addition, unlike biomass, plastics do not contain oxygen, so higher carbon efficiency is expected [20]. Thermal cracking can produce 80 wt% of a liquid

hydrocarbon and this yield can be optimized by varying the parameters of the cracking process [21, 22]. Operating conditions, such as temperature, pressure, residence time, heating rates, feedstock composition and presence of moisture or toxic elements have the highest impact on the reaction rate and they influence the composition of the gaseous, liquid and waste fractions produced during cracking [23]. These parameters can be varied depending on the desired product. For example, more gas fractions are obtained with temperatures over 500°C, while between 300°C and 500°C, a higher amount of liquid hydrocarbons are obtained [22].

In this work, liquid hydrocarbon products from the thermal cracking of PP, HDPE and LDPE are investigated using a laboratory batch reactor. The experimental data was used to perform a kinetic study and a comparison of the thermal reaction performance between the different plastic pellets. The products obtained from the cracking reaction were characterized according to ASTM standards for liquid fuels, as well as gas chromatography. Additionally, a possible reaction mechanism was presented to understand the decomposition of each polymer and its products.

EXPERIMENTAL METHODS

Sample Collection. The plastic pellets used in the study for the thermal cracking were primary plastic pellets of polypropylene (PP, type 412MK49) from SABIC, high-density polyethylene (HDPE, type HS5502) from Braskem and low-density polyethylene (LDPE, type 2601) from Dow Chemical Company. The reason for using primary pellets in this investigation is to define the kinetic parameters for the thermal cracking reaction without the effect of plastic aging or contaminants.

Experimental Setup. The equipment used for the thermal cracking of plastics was a Precision Scientific Petroleum Herzog distiller with a maximum power of 1100W. A detail description

of the setup can be found at Vargas et al [24]. For each experiment, 40 g of plastic pellets (i.e. PP, HDPE and LDPE) were placed into the reactor. At the start, the power was set to 550W for 5 minutes and then increased steadily with a ramp of 55W every 5 minutes until the desired power was reached. The reaction time of thermal cracking was 150 minutes, once the desired temperature was constant. Three experimental conditions were used for the PP plastics: 770W/360°C, 825W/370°C, 858W/375°C, while four temperatures were studied for HDPE and LDPE: 858W/375°C, 880W/380°C, 935W/390°C, 990W/400°C.

Figure 1 shows the relationship between the power of the batch reactor and the reactor temperature.

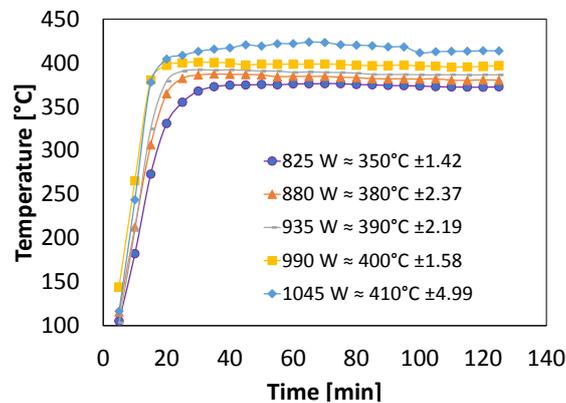


Figure 1. Temperature profile of reactor.

During the experiments, the vapors generated by the thermal cracking reaction exit the reactor through a condenser before entering a liquid-vapor separator. The gas fractions were collected from the top of the separator in a Tedlar plastic bag and the liquid fractions were collected at the bottom of a graduated cylinder, both the gaseous and liquid products were weighed. The volume of liquid products, V_L , was registered as function of time and transformed to mass of liquid products, m_L , using the density of the final product.

The mass of gaseous products as function of the reaction time, $m_G(t)$, was obtained by multiplying the mass of liquid at the same time, $m_L(t)$, by the ratio between the final weight

of gas, m_{Gf} , and the final weight of liquid, m_{Lf} , produced from thermal cracking, as described in Equation 1.

$$m_G(t) = m_L(t) \times \frac{m_{Gf}}{m_{Lf}} \quad (1)$$

Finally, the mass of reactant, m_A , at any moment was determined using mass conservation laws. This is used to calculate conversion and yield at the different reaction temperatures.

Characterization Methods. The plastic pellets were characterized with a *Cary 630 FTIR Spectrometer from Agilent Technologies* which allows the identification of the common functional group composition. 5 grams of pellet sample were used for moisture and ashes analyses. These processes were carried out in a drying oven (ECOSHEL, model FA-45B) at 70°C for 48 hours and a high temperature furnace (HYSC, model MF-03) at 550°C for 24 hours, respectively. The characterization methods used to analyze the liquid products are based on different ASTM methods. The methods and standards for the characterization are presented in **Table 1**.

Table 1. Characterization methods for liquid products.

Property	Method	Standard
Density	Standard Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method	ASTM D-1298 [25]
Kinematic Viscosity	Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)	ASTM D-445 [26]
Fire Point	Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester	ASTM D-92 [27]

A Thermo Scientific model TRACE 1310 Gas Chromatograph with an ISQ 7000 Mass Spectrometer (GC-MS) was used to identify the carbon number of the liquid products. The

software used was Chromeleon Chromatography Studio software with the NIST MS library. A TG-5MS column (30 m x 0.24 mm; 0.25 μ m) was used for the analyses. The GC oven temperature began at 50 °C held for 1 min, followed by a 4°C/min ramp up to 280°C and kept constant for 10 min. A helium flow rate of 1.2 mL/min, an injector temperature of 320°C, a purge flow of 5 mL/min and a split flow of 100 mL/min were used. The MS works with an electron ionization (EI) system in the range of full scan. The ion source was kept at 230 °C, while the MS transfer line was kept at 320 °C. The gaseous product was characterized using a Thermo Scientific Gas Chromatograph (GC) model TRACE 1310 with a Flame Ionization Detector (FID). A TG Bond Q Thermo Scientific (15m x 0.53 m; 0.20 μ m) column was used. The GC oven temperature began at 30 °C followed by a 10°C/min ramp up to 200°C and held for 8 min. A helium flow rate of 2.1 mL/min, an injector temperature of 250°C, a purge flow of 5 mL/min and a split flow of 21 mL/min were used. The temperature in the detector (FID) was set at 200°C. The gases were identified by comparison with the standards gases of chromatograms Scott Cat. No. 22566 and Scott Cat. No. 501662.

Kinetic Analysis. The thermal cracking reaction of plastic pellets is described in Equation 1. The pellets (**A**) produce the desired liquid (**B**) and gaseous (**C**) products.



The model used for the kinetic study of cracking reactions of plastic pellets is based on the mass balance of a batch reactor and it is presented in Equation 2, where the reaction rate is a function of the mass of reactant.

$$R_A = \frac{dm_A}{dt} \quad (3)$$

The rate of consumption of the plastic pellets, R_A , is represented by the power law expression, as presented in Equation 3; by applying the logarithm, it can be linearized to obtain the kinetic parameters.

$$R_A = -k \cdot m_A^n \quad (4)$$

Where the kinetic constant (k) and the reaction order (n) were determined using the integral and differential methods [28], respectively. The activation energy (E_a) and pre-exponential factor (k_o), are obtained by the linear expression of the Arrhenius law as presented in Equation 5.

$$\ln(k) = \ln(k_o) - \frac{E_a}{RT} \quad (5)$$

RESULTS AND DISCUSSIONS

Characterization of Raw Materials. FTIR was performed to determine the purity of the raw materials and the potential of conversion of plastics into liquid fuel. According to the structure of each polymer, the peaks of the infrared spectra are found in specific ranges of wavenumber, which identify the main functional groups. The PP, HDPE and LDPE infrared spectra within a wavenumber range $600 - 4000 \text{ cm}^{-1}$ are observed in **Figure 2**. The peaks between 3100 and 2600 cm^{-1} infer the presence of aliphatic hydrocarbons ($\text{C} - \text{H}_{stretch}$) such as methyl (2957 and 2870 cm^{-1}) and methylene (2922 cm^{-1}) [29]. The peaks at 1600 and 1100 cm^{-1} can be identified as alkenes ($\text{C} = \text{C}_{stretch}$) which confirm the presence of olefins and the peaks between 1100 and 600 cm^{-1} can correspond to alkenes and aromatics ($\text{C} - \text{H}_{bend}$) [30]. As observed, the long chains of polymers are the raw material with a great potential to break down into simpler molecules such as liquid fuel.

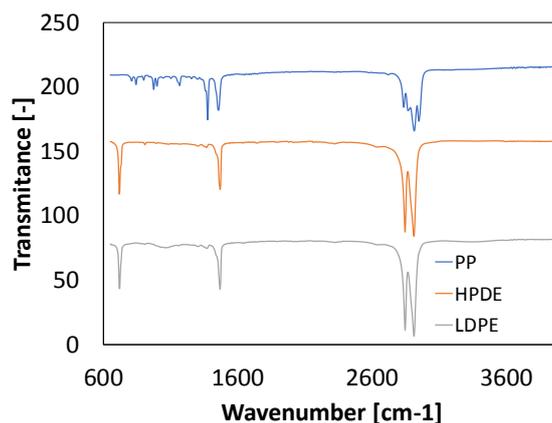


Figure 2. Infrared spectra of primary PP, HDPE and LDPE plastic pellets.

Also, moisture and ash content were analyzed to establish the physical properties of the plastics. **Table 2** indicates the percentage of each parameter for the plastics used in the thermal cracking reaction.

Table 2. Ash and moisture content of primary PP, HDPE and LDPE plastics

Plastic Type	Ash [%]	Moisture [%]
PP	0.084	0.039
HDPE	0.073	0.045
LDPE	0.097	0.069

Investigation of Temperature on Cracking Process. In this section the dependence of the product distribution with the cracking temperature are presented. The experimental data are available in the Supporting Information. **Figure 3** shows the distribution of the mass of reactant, m_A , as a function of time at different reaction temperatures for each plastic.

Figure 3 a), represents the behavior of PP. At cracking temperature of 360°C, the reaction rate is small, and no significant liquid and gaseous products can be observed, while at a cracking temperature of 370 - 375°C, the mass of reactant decreases substantially with time, while the desired products are obtained.

Figure 3 b) and **c)** show that for HDPE and LDPE plastics conversions between 70% - 85% are reached at cracking temperatures in the range between 390 - 400°C and 380 - 390°C,

respectively. Unlike PP and LDPE, HDPE requires a higher temperature for the cracking reaction. This behavior of HDPE plastics is due to the resistance of the carbon bonds in its macromolecular structure. HDPE is a long-chain polymer with low ramifications in its structure and a high degree of crystallinity. Therefore, it has high resistance to thermal degradation [31, 32]. LDPE, on the other hand, has a branched structure and low crystallinity, so its bonds are easily broken by heat. As well as PP, as it has a ($-CH_3$) group and low crystallinity, which requires lower temperature to break and a shorter reaction time [30].

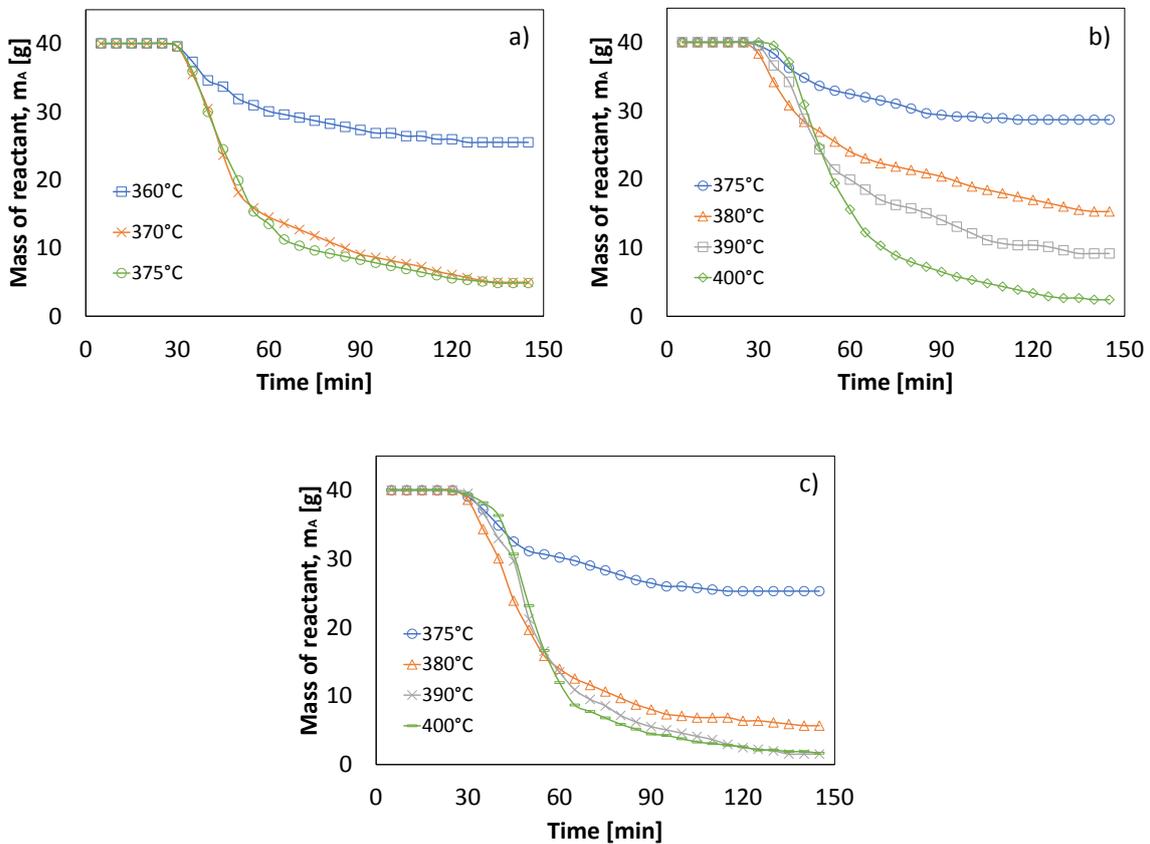


Figure 3. Mass of reactant consumed during the thermal cracking reaction: (a) PP, (b) HDPE, (c) LDPE.

Figure 4 shows the yield of the liquid fraction as it increases linearly at higher temperatures. In the case of PP, the yield increases from 26 to 62% as the temperature was increased from

360 to 375°C. Similarly, the yield increases from 13 to 69% in HDPE and from 29 to 72% in LDPE as the temperatures is raised from 375 to 400°C.

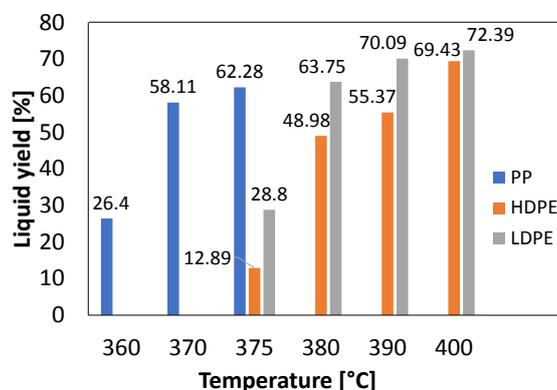


Figure 4. Reaction yield of liquid products for the three plastics as a function of temperature.

The mass balances of the different plastics were established at the optimal reaction temperatures of 375, 400 and 390°C for PP, HDPE and LDPE, respectively. The optimal temperatures were defined as the ones where approximately 70% of yield was reached after 120 minutes for each plastic. The weight percentages obtained from the mass balances of the different cracking processes are shown in **Table 3**. The temperature has not affected the selectivity of the desired liquid products, therefore its effects are negligible [33]. The results show that the thermal cracking of LDPE has the highest yield for the desired liquid products.

Table 3. Mass balance obtained for the cracking reactions of plastic pellets.

Plastic Type	Liquid fraction [%]	Gaseous fraction [%]	Residue [%]	Losses [%]
PP	68.83	0.65	22.47	8.05
HDPE	73.47	0.025	11.22	15.29
LDPE	77.77	1.02	10.12	11.09

Kinetic Analysis. The kinetic rate law of the thermal cracking was estimated using the data from three different temperatures for PP (i.e. 360, 370, 375°C) and four for HDPE and LDPE (i.e. 375, 380, 390, 400°C). **Figure 5** a) shows the linearized differential model of the power law kinetic expression of PP in a batch system, where a first order reaction was found. This order was then applied for the definition of the kinetic constant using the linearized integral method as shown in **Figure 5** b). These values are used in the Arrhenius equation to determine the activation energy, E_a , and the pre-exponential factor, k_0 as shown in **Figure 5** c). The same process was performed for HDPE and LDPE plastic pellets and the results are presented in the Supplemental Information.

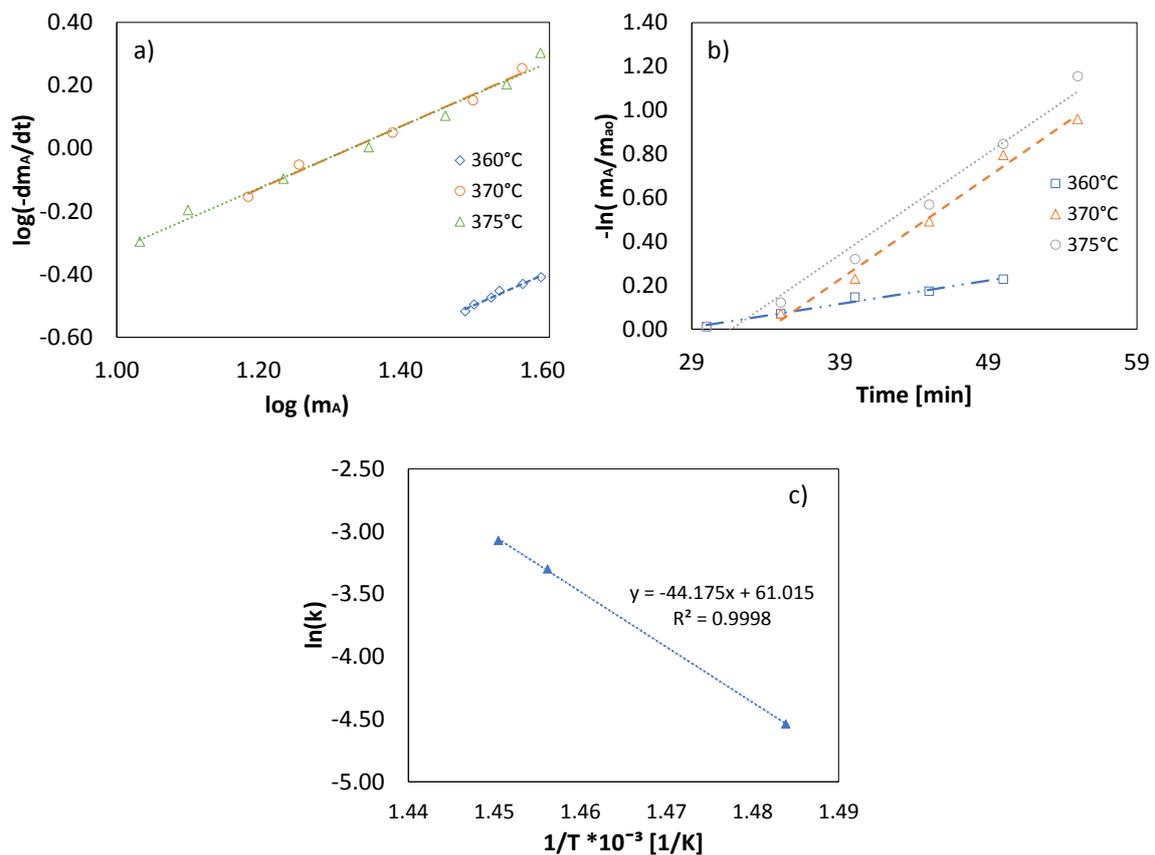


Figure 5. Graphical methods for the kinetic analysis of the thermal cracking of PP determining: (a) reaction order by differential method, (b) kinetic constant by integral method, and (c) activation energy and pre-exponential factor by the linearized Arrhenius law

Table 4 shows the results obtained for the kinetic analysis of the three plastics PP, HDPE and LDPE using both kinetic methods. As observed, the reaction order for the thermal cracking of all plastics can be defined as 1. Also, as expected, an increase in the value of the kinetic constant k can be observed with the temperature, exhibiting a linear dependence [33]. The activation energy of PP is 367.28 kJ/mol , while for HDPE and LDPE higher values of 453.37 and 457.96 kJ/mol are found, respectively. These results are comparable with the values reported in studies by Yan et al. [29] and Hazrat et al. [16], where the reported activation energies are 362.6 , 342.95 and 413 kJ/mol for PP, HDPE and LDPE, respectively. Thus, the data predicted by the model is consistent with the literature values with a percentage error equal to 1.3 , 32.2 and 10.9% for PP, HDPE and LDPE, respectively. Also, it can be established that PP is a less stable polyolefin that can be cracked at a lower initial temperature than HDPE and LDPE. The results obtained show that indeed the activation energy of virgin plastic is higher than plastic waste, this is because virgin plastic degrades at a higher initial temperature while waste plastics can easily degrade and may favor the mild condition [29].

Table 4. Kinetic parameters obtained for the experimental data.

Plastic Type	Temp [°C]	Differential analysis		Integral analysis		Kinetic parameters			
		n [-]	R^2	k [$\frac{1}{min}$]	R^2	k [$\frac{1}{min}$]	k_o [$(\frac{mol}{mL}) min^{-1}$]	E_a [$\frac{kJ}{mol}$]	R^2
PP	360	0.9895	0.9782	0.0107	0.9816	$3.13E-2 \pm 0.02$	$3.15E+26$	367.28	0.9998
	370	0.9917	0.9888	0.0369	0.9898				
	375	0.9780	0.9861	0.0464	0.9861				
HDPE	375	0.9449	0.9949	0.0042	0.9954	$2.24E-2 \pm 0.02$	$3.14E+31$	453.37	0.9014
	380	0.9602	0.9882	0.0129	0.9882				
	390	1.3161	0.9920	0.0295	0.9902				
	400	0.9859	0.9872	0.0431	0.9855				
LDPE	375	0.9786	0.9915	0.0118	0.9909	$1.95E-1 \pm 0.30$	$1.48E+32$	457.96	0.9934
	380	1.0119	0.9946	0.0406	0.9935				
	390	0.9807	0.9960	0.0472	0.9853				
	400	1.0733	0.9932	0.6815	0.9960				

Characterization of Cracking Products. The liquid and gaseous products of the cracking process at the optimal condition were characterized for PP (858W/375°C), HDPE (990W/400°C) and LDPE (935W/390°C). The physical properties using ASTM methods [25–27] of liquid product are shown and compared with diesel and gasoline standards in **Table 5**. As seen, the density, API degree and flash point of PP product are in the gasoline range. While the kinematic viscosity, density, API degree and flash point of HDPE and LDPE are close to diesel range.

Table 5. Characterization of liquid cracking products.

	Density [g/cm ³]	API degree [deg]	Kinematic viscosity [cSt]	Flash point [°C]
PP - Product	0.75	57.28	1.06	<24.00
HDPE - Product	0.78	50.45	2.66	55.33
LDPE - Product	0.79	47.20	2.73	64.67
Gasoline	0.74-0.75	57.48-59.54	0.54-0.59	-40
Diesel	0.85-0.87	29.70-33.40	2.0-5.0	>51

The composition of the liquid product was also analyzed qualitatively using a GC-MS and compared with chromatograms from gasoline and diesel standards. The standard's chromatograms are presented for gasoline in **Figure 6 a)** and for diesel in **Figure 6 c)**.

Figure 6 b), shows the liquid products obtained from PP, where short chains of hydrocarbons between $C_9 - C_{19}$ are identified. This range is also observed in the chromatogram of gasoline standard. In previous studies of the thermal cracking of virgin polypropylene, a similar distribution of carbon number among $C_6 - C_{12}$ was identified, indicating a significant presence of alkenes [29]. The greater number of carbons with double bonds is due to the presence of the $CH_3 -$ group in the PP structure [29].

On the other hand, **Figure 6 d)** and **e)** present the chromatograms of HDPE and LDPE liquid products with hydrocarbon chains between $C_9 - C_{27}$ and $C_8 - C_{27}$, respectively. The results obtained are in a similar range of the diesel's chromatogram and show the same sort of bell

distribution. Some investigations indicate that the hydrocarbon distribution of HDPE and LDPE are found among $C_5 - C_{32}$ and $C_6 - C_{30}$, respectively [29, 34, 35]. Additionally, the distribution of double peaks throughout the chromatogram indicates the presence of n-alkane and n-alkene (1-olefins) [36]. These results confirm that from the thermal cracking of PP lighter fractions corresponding to gasoline are obtained, unlike HDPE and LDPE where heavy fractions such as diesel are obtained.

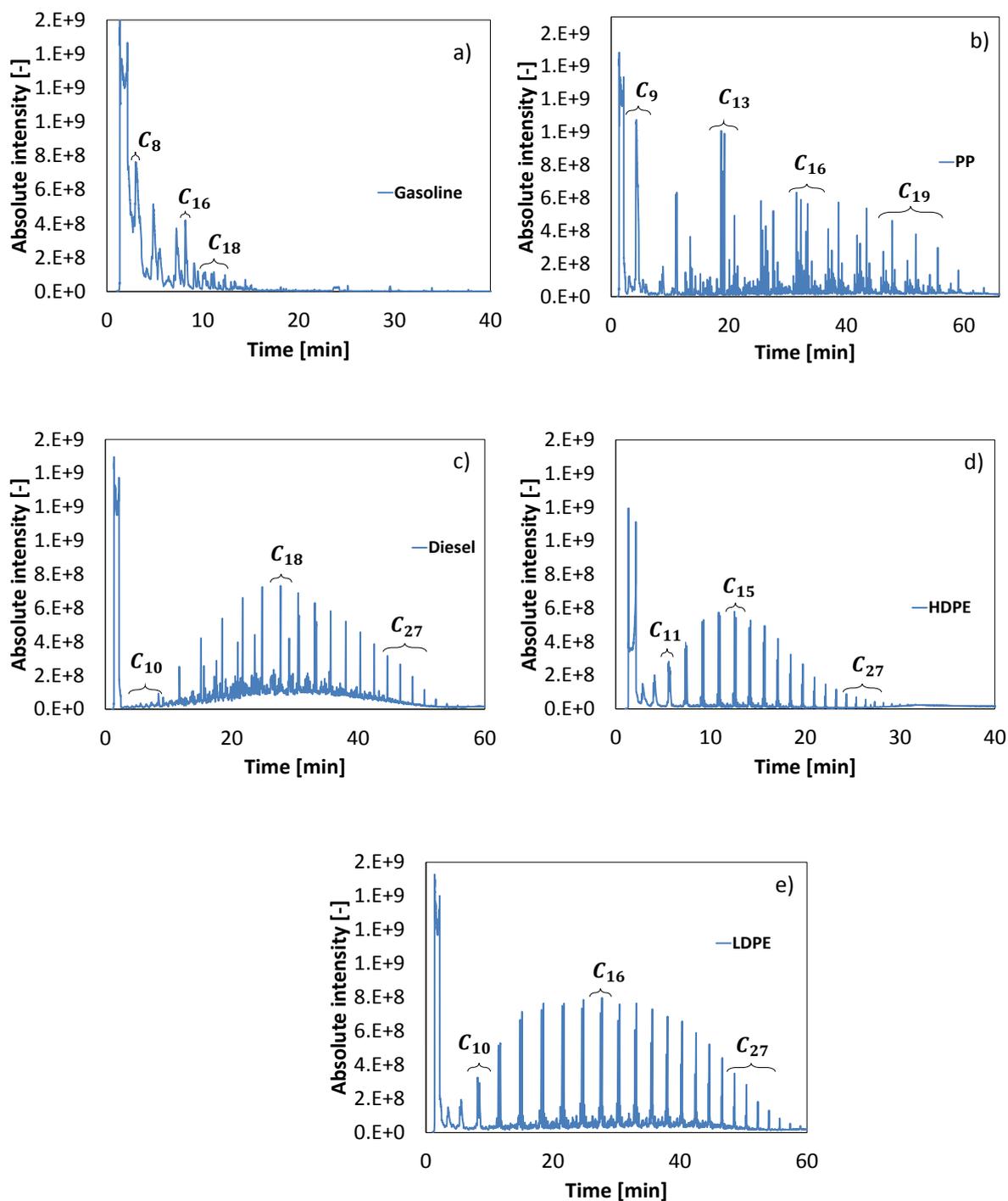


Figure 6. GS-MS chromatograms of (a) gasoline, (b) liquid fractions of PP, (c) diesel, (d) liquid fractions of HDPE, (e) liquid fractions of LDPE.

The gaseous products were analyzed by GC – FID detector. The chromatograms of PP and LDPE are observed in **Figure 7**, the compounds were determined based on retention time. In all the samples, three peaks are identified between the retention time from 1 to 8 minutes

corresponding to $C_1 - C_2$ compounds such as methane, ethane, ethylene and acetylene. On the other hand, peaks 4 to 7 are represented by $C_3 - C_4$ bonds such as propane, propylene and n-butane in retention times of 10 to 15 minutes. HDPE gas samples were not analyzed since the gas could not be collected. This is confirmed by the low yield presented in the mass balance of HDPE in **Table 3** where it is lower than 0.5%.

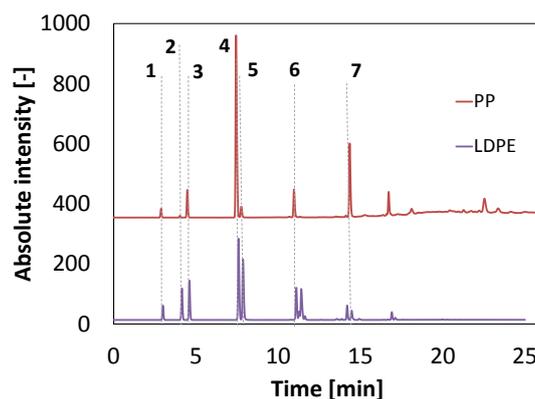


Figure 7. Chromatogram of the gas fractions of PP and LDPE. Peaks: 1 Methane, 2 Ethane, 3 Ethylene, 4 Acetylene, 5 Propane, 6 Propylene, 7 n-Butane.

Reaction Mechanism. The mechanism of thermal decomposition of polymers is arbitrary, the probability of breaking under the influence of heat is very similar for any bond in the molecule. Therefore, the polymers decompose into a large number of paraffinic and olefinic compounds. The analysis of the gaseous and liquid products agrees with the radical chain mechanism proposed by Yan et al [29, 37].

In the initiation phase, two free radicals are formed due to the breaking of the chain. The cracking may occur either at the ends of the chain or in the middle. Therefore, these products could include free methyl radicals. The propagation phase consists of a sequence of H-abstractions and β scissions. The H-abstraction can be intermolecular, where a free radical takes a hydrogen from a different molecule, or intramolecular, where the hydrogen abstraction occurs inside in the same radical followed by β -scission which originates an alkene and a free radical.

Finally, the termination phase occurs through the combination of two radicals [35–40]. The proposed reaction mechanism for PP, HDPE and LDPE are presented in **Figure 8**.

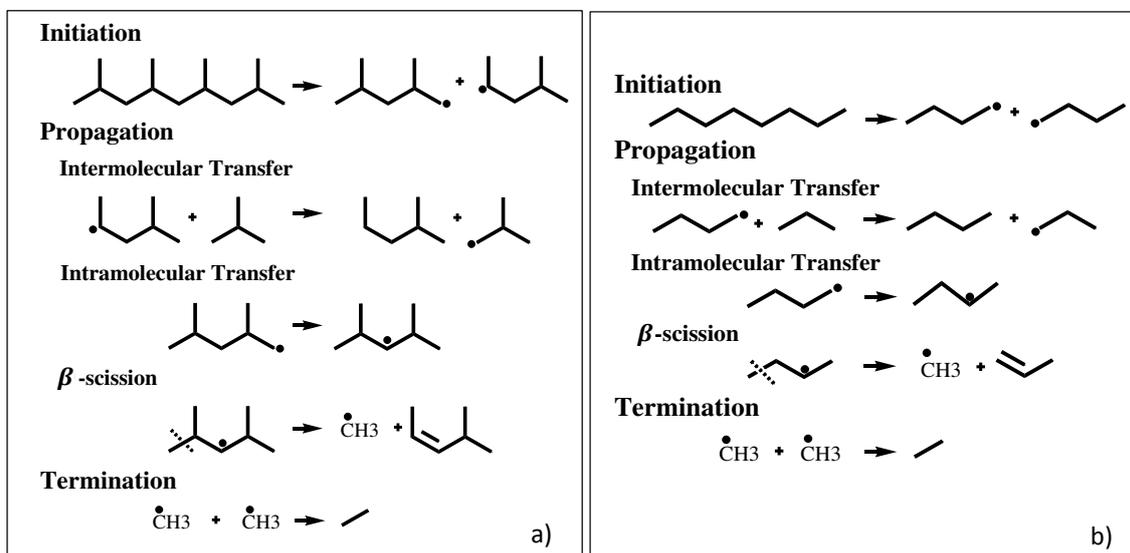


Figure 8. Reaction mechanism of thermal cracking (a) PP and (b) HDPE/LDPE

All cracking reactions start with the initiation reaction and finish with the termination. The product distribution depends on the pathway followed for the propagation reaction. The research of Levine et al [39] and Gao et al [38] indicate that β -scission is a dominant reaction to form alkenes and the intermolecular hydrogen abstraction to form alkanes. As mentioned, a major presence of alkenes was identified in the liquid products obtained from the PP, establishing intramolecular transfer followed by β -scission as the main reaction for PP cracking. On the other hand, the presence of alkanes and olefins in the liquid product of HDPE and LDPE, can be explained by two competing reaction pathways, namely the same intramolecular transfer followed by β -scission and the intermolecular hydrogen transfer responsible for the alkanes production [29]. Finally, the composition of the gaseous products can be explained by β -scission forming the alkenes ethylene and propylene, while H-abstraction favor aliphatic compounds such as methane, ethane, propane and n-butane [29].

Using this simplified reaction mechanism consisting of 5 steps, the product distribution of the thermal cracking reaction of PP, HDPE and LDPE can be explained.

CONCLUSION

In this investigation, the thermal cracking of primary plastic pellets of PP, HDPE, and LDPE was studied at different reaction temperatures. The results show that the highest cracking yield of 72% is obtained with LDPE at 390°C. The yield obtained for PP is 62% at 375°C, while HDPE requires the highest temperature and reaches a yield of 69% at 400°C. The physical properties of the final products obtained by the cracking processes of the different plastics shows that with a further post-treatment step PP can meet the necessary requirements for gasoline, while HDPE and LDPE products show similar characteristics to diesel.

The kinetic study shows that reactions of the three types of plastics are first order. In addition, the lowest activation energy belongs to PP with a value of 367.28 *kJ/mol*, followed by HDPE with 453.37 *kJ/mol* and LDPE with 457.96 *kJ/mol*. Finally, the reaction mechanisms of thermal decomposition of polymers are based on chain reactions with radical formation, where β – scission is the main reaction to form alkene compounds and intermolecular hydrogen abstraction to form alkane compounds in the final products.

The results obtained from the thermal cracking of the most abundant plastics, namely PP, HDPE and LDPE, show very promising results in their capability to form alternative liquid fuels. To be able to incorporate the products in commercial blends, further investigations on post-treatments, heat value and stability are necessary. Also, the gaseous and liquid products of the cracking reaction can be used as chemical precursors or reincorporated into refining processes to valorize this residue as secondary chemicals.

▪ **AUTHOR INFORMATION**

Corresponding Author

Daniela Almeida Streitwieser – Institute for the Development of Alternative Energies and Materials IDEMA, Department of Chemical Engineering, Universidad San Francisco de Quito USFQ, EC 170901 Quito, Ecuador

*E-mail: dalmeida@usfq.edu.ec.

▪ **AUTHOR CONTRIBUTIONS**

Conceptualization: [Daniela Almeida Streitwieser]; Methodology: [Yuliana Rodríguez Lamar], [José Noboa]. Formal analysis and investigation: [Yuliana Rodríguez Lamar], [Andrés S. Torres Miranda]. Writing - original draft preparation: [Yuliana Rodríguez Lamar], [José Noboa], [Andrés S. Torres Miranda]. Writing - review and editing: [[Yuliana Rodríguez Lamar], [José Noboa], [Daniela Almeida Streitwieser]. Funding acquisition: [Daniela Almeida Streitwieser]. Resources: [Yuliana Rodríguez Lamar], [José Noboa], [Daniela Almeida Streitwieser]. Supervision: [Daniela Almeida Streitwieser], [José Noboa].

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▪ **SUPPORTING INFORMATION**

Supporting information corresponds to the experimental data and its application for determining the differential and integral methods as well as the Arrhenius analysis for HDPE and LDPE.

▪ **DECLARATIONS**

All authors confirm that they don't have any conflict of interests regarding sources of funding, financial or non-financial interests. This research did not involve humans and/or animals, nor required consent of involved human participants,

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Figures

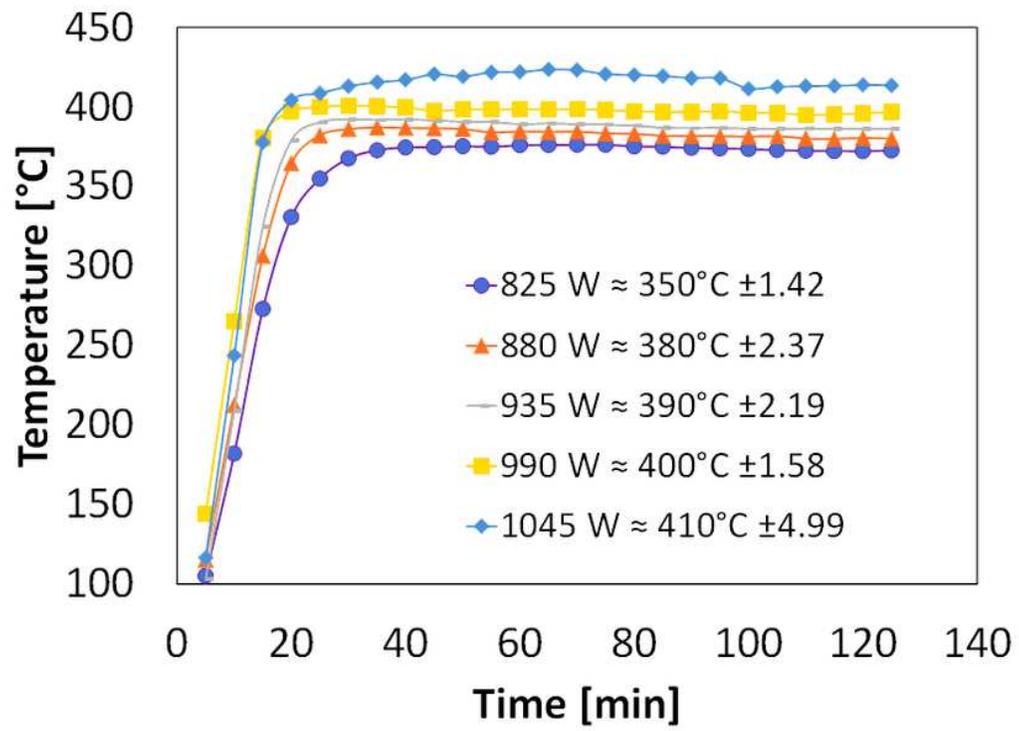


Figure 1

Temperature profile of reactor.

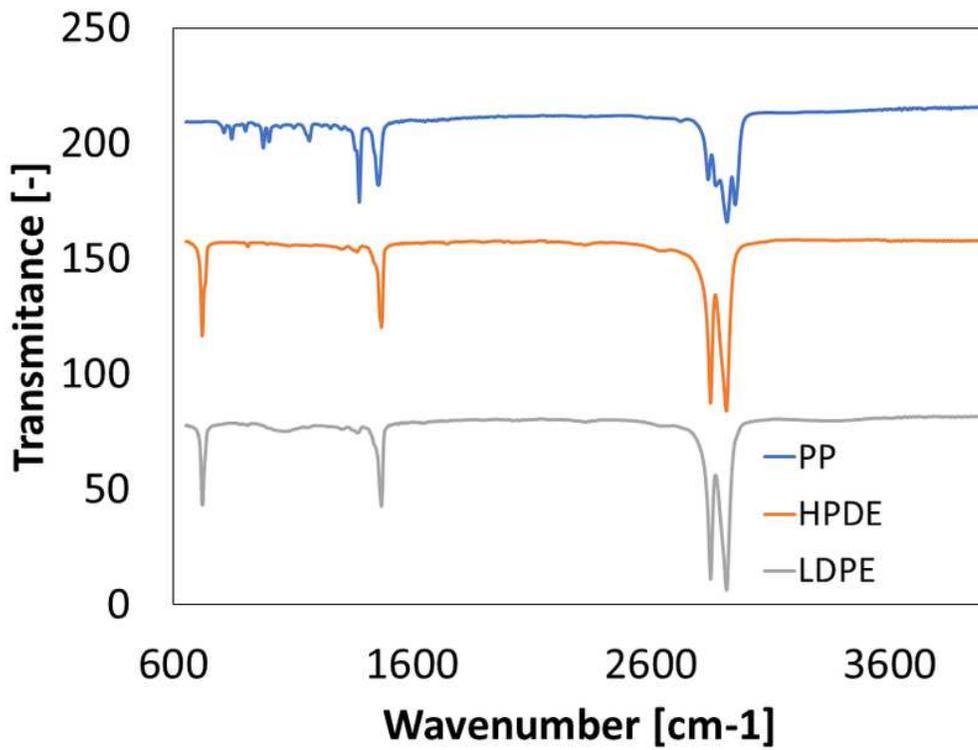


Figure 2

Infrared spectra of primary PP, HDPE and LDPE plastic pellets.

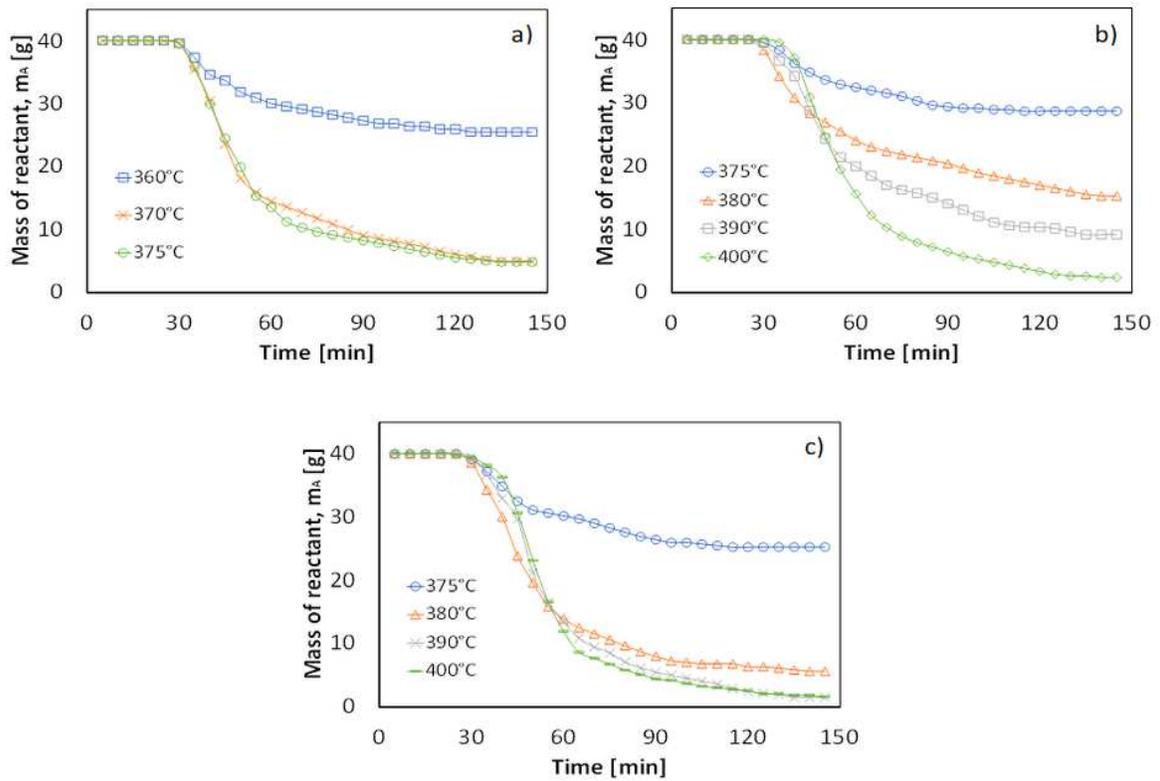


Figure 3

Mass of reactant consumed during the thermal cracking reaction: (a) PP, (b) HDPE, (c) LDPE.

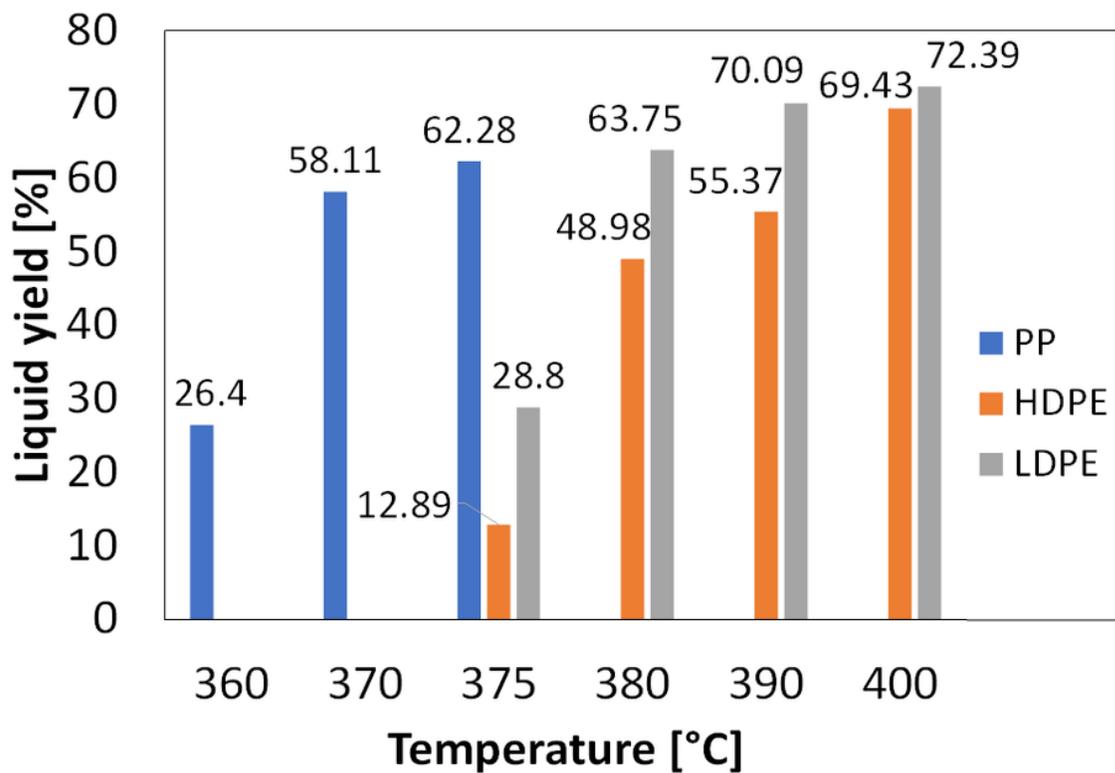


Figure 4

Reaction yield of liquid products for the three plastics as a function of temperature.

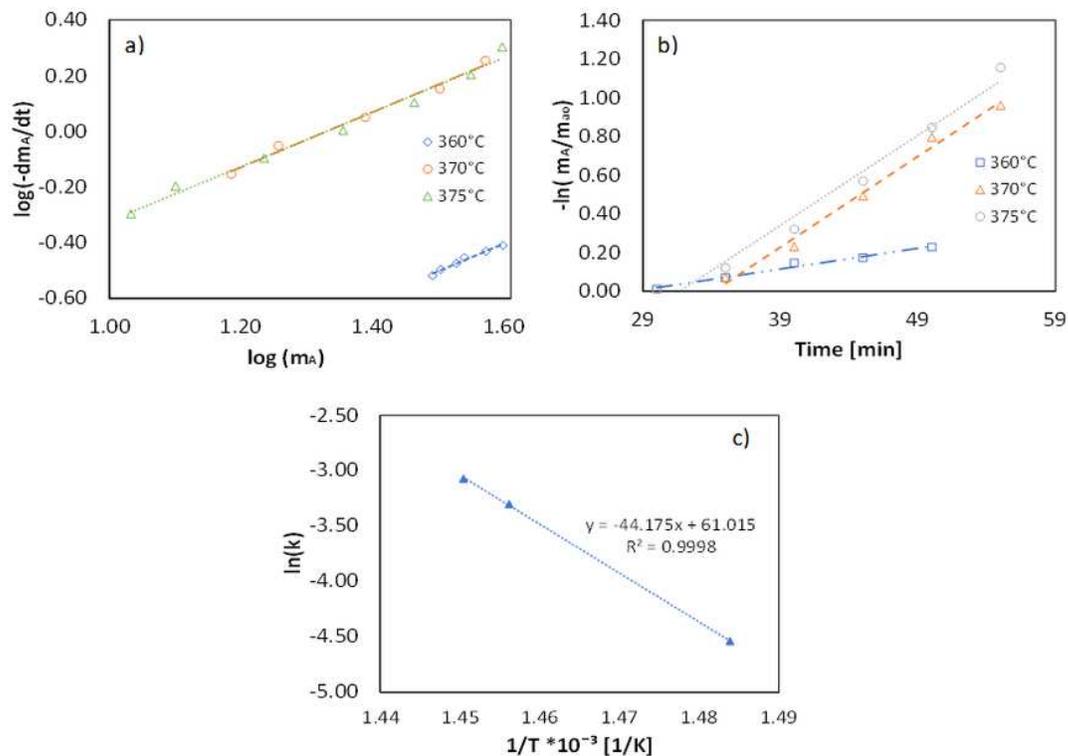


Figure 5

Graphical methods for the kinetic analysis of the thermal cracking of PP determining: (a) reaction order by differential method, (b) kinetic constant by integral method, and (c) activation energy and pre-exponential factor by the linearized Arrhenius law

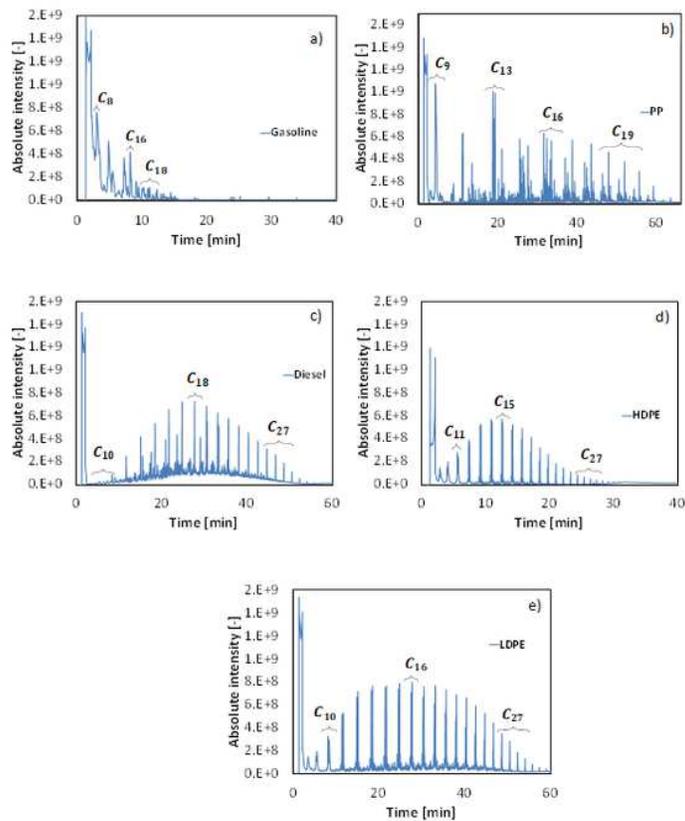


Figure 6

GS-MS chromatograms of (a) gasoline, (b) liquid fractions of PP, (c) diesel, (d) liquid fractions of HDPE, (e) liquid fractions of LDPE.

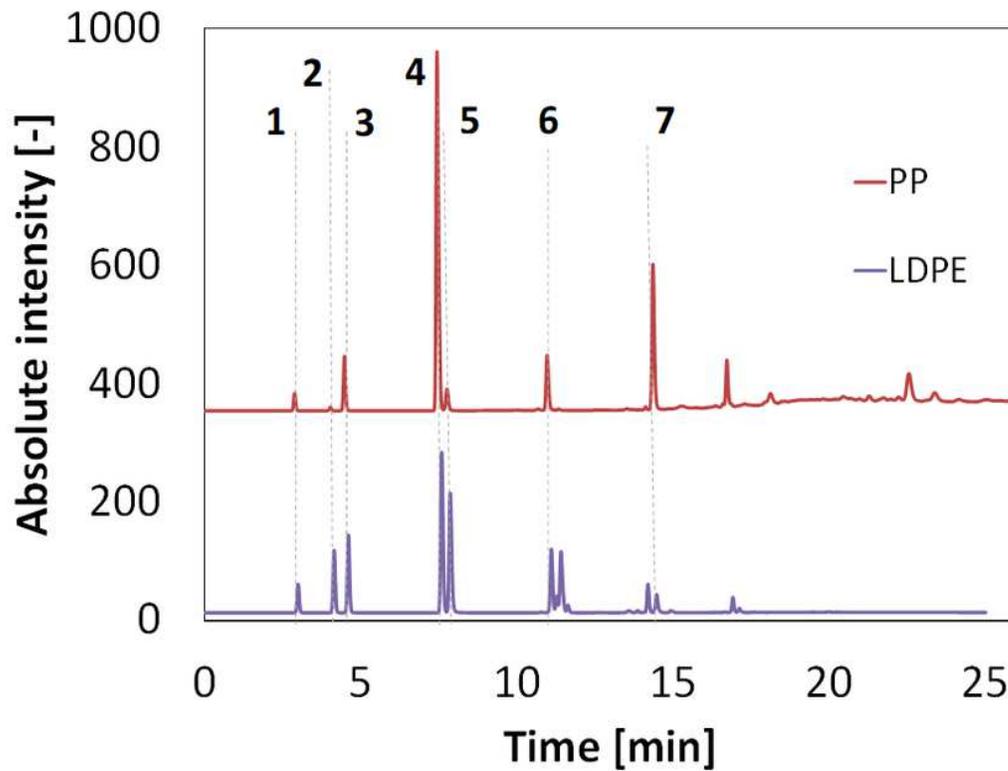


Figure 7

Chromatogram of the gas fractions of PP and LDPE. Peaks: 1 Methane, 2 Ethane, 3 Ethylene, 4 Acetylene, 5 Propane, 6 Propylene, 7 n-Butane.

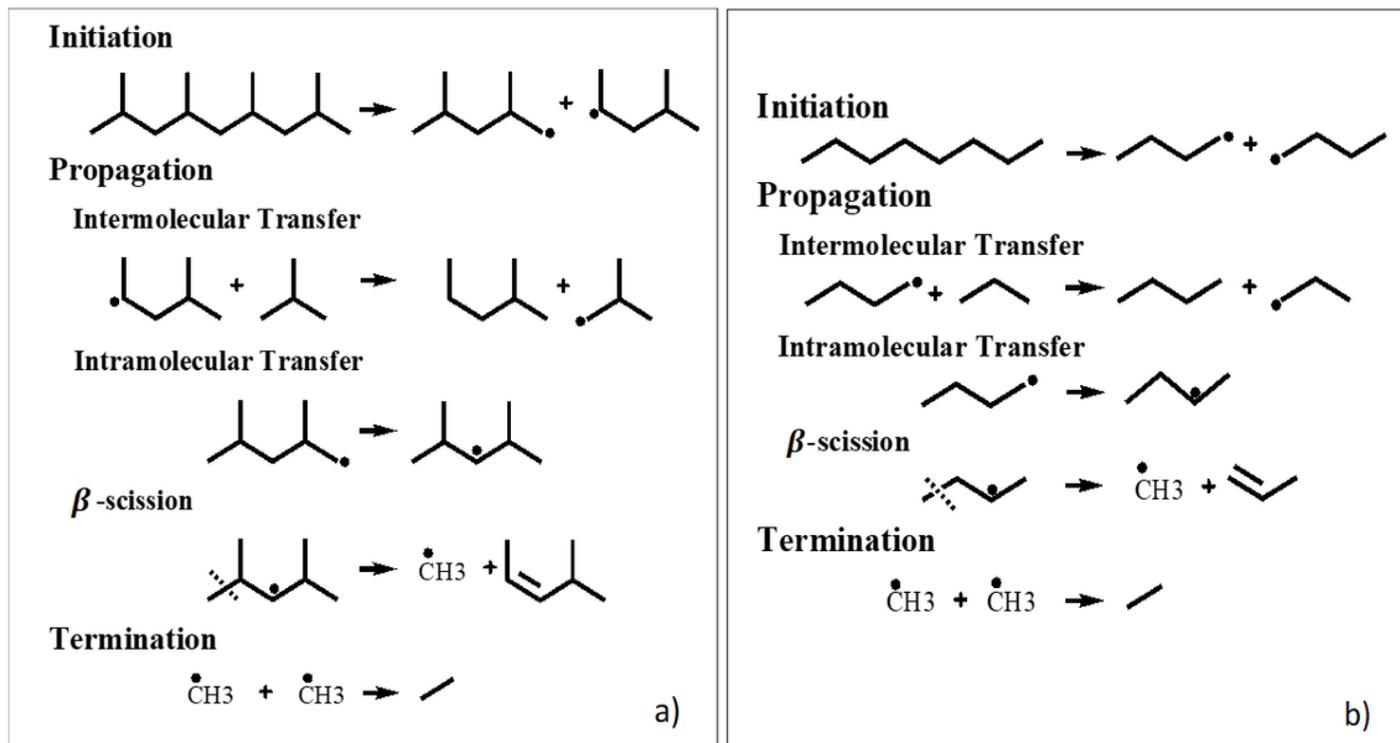


Figure 8

Reaction mechanism of thermal cracking (a) PP and (b) HDPE/LDPE