



## Recycling of waste plastics into fuels. LDPE conversion in FCC

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### ABSTRACT

In order to study the tertiary recycling of waste polymers in standard FCC units low density polyethylene (LDPE) was dissolved into a commercial vacuum gas oil at 2 and 6 wt.% and converted over two equilibrium FCC catalysts of the octane-barrel and resid types in a CREC Riser Simulator laboratory reactor. The reaction temperatures were 500, 525 and 550 °C, the mass catalyst to oil relationship was 6.35 and the contact times were from 3 to 30 s. The study included the effect of the concentration of LDPE over conversion, the various product (dry gas, LPG, gasoline, LCO and coke) yields and selectivities. Results were very similar for the two concentrations. At typical conversions of 70 wt.%, dry gas and gasoline yields increased about 10 wt.%, LPG yields between 9 and 13 wt.%, LCO yields decreased more than 15 wt.% and coke yields were lower than 7.7 wt.%. The RON index of gasoline was improved slightly (up to one point), mainly due to significant increases in olefin concentrations, while the fuel quality of the LCO cut was not affected. LDPE is easily converted and seems to be subjected to primary reactions of catalytic cracking, thus increasing the yields of olefins in the LPG and gasoline boiling ranges. It was concluded that recycling waste LDPE by co-processing it as part of conventional feeds to the FCC would not interfere with the standard operation.

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### 1. Introduction

The consumption of plastic materials is vast and has been growing steadily in view of the advantages derived from their versatility, relatively low cost and durability (due to their high chemical stability and low degradability). Some of the most used plastics are polyolefins such as polyethylene and polypropylene, which have a massive production and consumption in many applications such as packaging, building, electricity and electronics, agriculture, health care, etc. [1]. In turn, the property of high durability makes the disposal of waste plastics a very serious environmental problem, landfilling being the most used disposal route.

In order to mitigate their impact on the environment, the recycling of polymers constitutes a valid alternative [2]. Among recycling options, the mechanical reprocessing (named primary recycling, which can be applied up to a certain limit) and the controlled incineration (named secondary recycling, aimed at recovering energy), are very well known choices, with clear advantages and disadvantages. The so called tertiary recycling processes, either thermal or catalytic, are attractive, since they produce chemicals or fuels [3], and has been attempted under different approaches when applied to polyolefins (particularly polyethylene) [4,5]. While the catalytic recycling, which necessarily involves cracking, allows for some degree of control of the product distribution, the thermal

conversion processes, which occur through the radical random-chain scission mechanism generate gas and liquid products in a wide range of molecular weights [6]. Another important issue is that the catalytic recycling of polymers requires lower temperatures, from 350 to 550 °C. Plastics other than polyolefins, such as PVC, alone or mixed with polyethylene or polypropylene, dissolved into vacuum gas oil, were also investigated in tertiary recycling [7].

Examples can be found in the literature in relation to the catalytic degradation of both low (LDPE) and high density (HDPE) polyethylene over acidic (BETA, H-ZSM-5, HMOR, HUSY [8–14]) or metal exchanged [15] zeolites, amorphous silica–aluminas [16] and crystalline mesoporous materials [10]. Most of these studies [11,15–17] were conducted with laboratory techniques and reactors where the plastic was contacted with the catalyst in a closed environment, the mixture was heated up to reaction temperature, a certain reaction time was allowed and finally products were separated and analyzed. Melted polyethylene was fed continuously over a bed of catalysts in other cases [18]. It is obvious that it would be necessary to develop processes in a commercial scale based on these approaches that, while feasible, are far from being put into practice.

A more attractive approach for the tertiary recycling of waste polymers would be that of co-processing them as part of the feedstocks to existing refinery processes, either catalytic or thermal, taking advantage of the facts that many of the polymers dissolve into hydrocarbon mixtures, that they are indeed high molecular weight hydrocarbons and that those processes are fully established and would not require important technical modifications

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[19]. The versatile catalytic cracking of hydrocarbons (FCC) would be a proper choice [20]; waste polyolefins could be dissolved into the usual feedstock for the process (vacuum gas oils, VGO), and in this way cracked and converted into a mixture of hydrocarbon compounds. FCC is a central conversion process in modern refineries, because it is not only the main producer of liquid fuels but also an important supplier of raw materials for a number of derived and associated processes [21]. Due to the large volumes processed, even small positive changes in its economy (raw materials, catalyst performance, product distributions) have a strong impact on the overall performance and subsequent benefits of the commercial units, thus justifying continuous efforts to optimize their operation.

Waste polyolefin co-processing has been tested with different polymers and laboratory conditions. Polystyrene and polybutadiene-polystyrene were converted in a CREC Riser Simulator reactor under conditions similar to those of the commercial process, to observe positive contributions from the standpoint of the composition of the gasoline cuts [22,23]. Ng [24] used a MAT reactor to convert polyethylene-VGO mixtures and concluded that an increase in gasoline yield was observed only when more than 10% of plastic was dissolved into VGO. Marcilla et al. (2008) [25] converted LDPE/VGO mixtures with different proportions of plastic over equilibrium FCC catalysts in a fluidized bed reactor and observed high selectivities to C4–C5 isoparaffins in gases and aromatic compounds in liquids. Siddiqui and Redhwi, 2009 [26] co-processed mixtures of LDPE, HDPE, polystyrene and polypropylene with VGO over various catalysts in batch reactors and observed high yield of liquid products. Interestingly, equilibrium FCC catalysts showed the best performance among other catalysts (ZSM-5, mordenite, promoted zirconia) in the conversion of polyolefins in terms of the yields of hydrocarbons in the boiling range of gasoline [27]. Alternatively, waxes from the pyrolysis of waste polyolefins have been studied as co-feeds in FCC [28,29]. Considering that the FCC process follows a delicate heat-balanced operation based on the equilibrium between the heat generation from coke combustion in the regenerator and heat consumption by cracking reactions in the riser reactor, the magnitude of the yield of coke from the plastics could rule the implementation of this option.

It is the objective of this work to evaluate the changes in the FCC process performance, such as those expected in the product slate, the additional coke yield or the light olefin yield, induced by the addition of polyethylene to the usual feedstocks, following a realistic approach (that is, using process conditions and LDPE, VGO and equilibrium FCC catalysts from commercial sources, with a reasonable incorporation of plastics), on a CREC Riser Simulator laboratory reactor [30].

## 2. Experimental

Two equilibrium commercial FCC catalysts from running refineries (E-cat M, of the octane-barrel type, and E-cat R, of the resid conversion type), were used. Their main properties are shown in Table 1. The feedstock was a commercial paraffinic VGO with a typical commercial LDPE [31] dissolved at 2 and 6 wt.% The plastic was dissolved with stirring during 2 h at 115 °C. Other works used LDPE concentrations up to 10 wt.% [32]. The VGO was also used “pure” in experiments performed in order to generate reference information. Its main properties are shown in Table 2. Concerning the CCR (Conradson carbon residue), it increased from 0.11 wt.% in the case of the VGO to 0.20 wt.% for the 2 wt.% solution to 0.34 wt.% for the 6 wt.% solution.

The experiments were performed in a CREC Riser Simulator laboratory reactor [30] at 500, 525 and 550 °C, with a catalyst to oil relationship (C/O) of 6.35 and reaction times from 3 to 30 s. The basic design concept of the laboratory unit considers that a slice of

**Table 1**  
Properties of the catalysts used.

	E-cat M	E-cat R
UCS (nm) <sup>a</sup>	2.426	2.427
REO (wt.%)	1.19	2.94
Zeolite (wt.%) <sup>b</sup>	18.0	14.8
Specific surface area (m <sup>2</sup> g <sup>-1</sup> ) <sup>c</sup>	158.0	125.0
Micropore volume (cm <sup>3</sup> g <sup>-1</sup> ) <sup>d</sup>	0.046	0.043
Fe (wt.%)	0.35	0.42
Ni (wt.%)	0.06	0.51
V (wt.%)	–	0.58
Catalyst type	Octane-barrel	Resid

<sup>a</sup> ASTM D-3942-85.

<sup>b</sup> Johnson's method [64] with N<sub>2</sub> adsorption.

<sup>c</sup> BET method, with N<sub>2</sub> adsorption.

<sup>d</sup> *t*-plot method.

**Table 2**  
Properties of the VGO used.

Property	Value
Density 20/4 °C (g cm <sup>-3</sup> )	0.9162
Distillation (°C)	
10 vol%	361
30 vol%	408
50 vol%	432
90 vol%	494
CCR (wt.%)	0.12
Viscosity (cP)	40.0
Aniline Point (°C)	80.1
Fe (ppm)	2.36
Cu (ppm)	<0.02
Na (ppm)	0.38
V (ppm)	0.73
Ni (ppm)	0.1
Sulfur (wt.%)	2.03
Total nitrogen (ppm)	1441
Character	Paraffinic

the environment of an ideal riser reactor, involving certain mass of catalyst and gases and moving along it during a given residence time, is located into this batch reactor; then, the reaction time evolved in the CREC Riser Simulator is equivalent to contact time, and motion, along the ideal riser [30]. The reactor has a turbine on top of a chamber that holds the catalyst bed between porous metal plates. The turbine rotates at 7500 rpm, thus inducing a low pressure area in the upper central zone in the reactor that makes gases recirculate in the upwards direction through the chamber, thus fluidizing the catalyst bed. When the reactor is at the desired experimental conditions, the reactant is fed with a syringe through an injection port and vaporizes instantly, thus setting the initial time. After the desired reaction time is reached, the gaseous mixture is evacuated immediately and products can be sent to analysis. A schematic representation of this description is shown in Fig. 1. Additional details can be found in, e.g., references [33,34]. The reactor was previously used in the study of various subjects such as catalyst evaluation [35], kinetic and diffusive modelling [36,37], and studies of new operative modes [38–40].

Reaction products were analyzed by on-line conventional capillary gas chromatography in a HP6890Plus chromatograph, equipped with a 30 m length, 0.25 mm i.d. and 0.25 μm phase thickness HP-1 column. The amount of coke on the catalysts was assessed by means of a procedure with temperature-programmed oxidation and further methanation of the carbon oxides. Mass balances (recovery) closed to more than 94% in all the cases.

Conversion was defined as the addition of the yields of dry gas (C1–C2, hydrogen excluded), LPG (C3–C4), gasoline (C5–216 °C), LCO (216–344 °C) and coke product groups. Selectivities were assessed as the relationship between the yield of a given group and

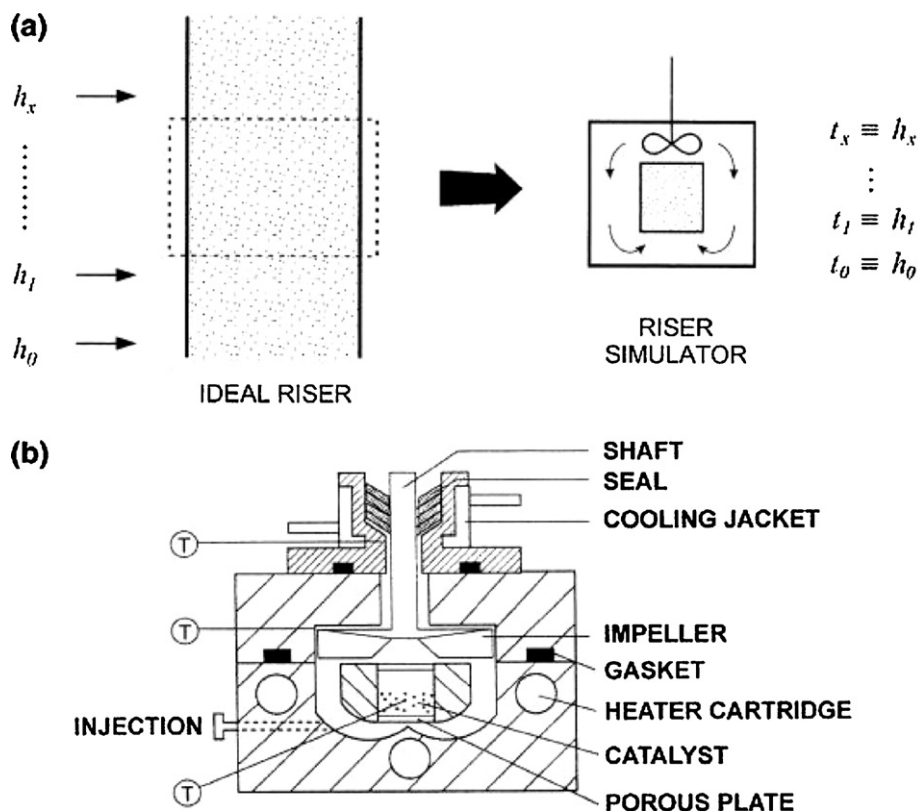


Fig. 1. CREC Riser Simulator reactor: (a) basic design concept, (b) schematic representation.

conversion. Analysis can also be performed on individual product yields. The error in the yield curves was determined using the approach by Wallenstein and Alkemade (1996) [41] (optimum performance envelope OPE curves); the standard deviation values were 0.1 wt.%, 0.2 wt.%, 0.3 wt.%, 0.3 wt.% and 0.2 wt.% for dry gas, LPG, gasoline, LCO and coke, respectively. The quality of the gasoline cut was assessed by means of a modified Anderson method [42].

### 3. Results and discussion

#### 3.1. Conversions

Conversions as a function of reaction time for the three feedstocks (pure VGO and 2 and 6 wt.% LDPE added) over the two catalysts and three temperatures are shown in Fig. 2. As expected for a closed, batch reacting system, in all the cases conversion increases steadily as a function of reaction time. For the case of the pure VGO it can be seen that above 10 s reaction time the conversions reached are in the range which is typical of commercial units [43], with catalyst E-cat M having values that were three to four percentage points higher than those from E-cat R. This is not surprising since catalyst E-cat M is the one used in combination with this base VGO in the same refinery (custom-made catalyst). The ease of conversion of plastics over acidic catalysts at high temperature had been observed in different experimental setups [11,44,45].

It is important to note that, overall, the dissolution of LDPE into VGO does not induce significant changes in conversion as compared to the base case (pure VGO), and that no significant differences were noticed between the two LDPE concentrations used. This suggests that, at least under these conditions, the basic yield scheme of a given FCC unit would not be strongly affected if polymers are added to the feedstock.

However, it can be seen that the LDPE–VGO mixtures behave differently according to the reaction temperature. In effect, over both catalysts, at the lowest temperature of 500 °C, the conversions of the mixtures are slightly lower than that of the pure VGO; at 525 °C, all the conversion profiles are similar, and at the highest temperature of 550 °C the LDPE–VGO mixtures show higher conversions than the pure VGO. These evidences suggest, in a general sense, that the cracking of polyethylene has a higher energy of activation than the cracking of the VGO, which translate into this behaviour.

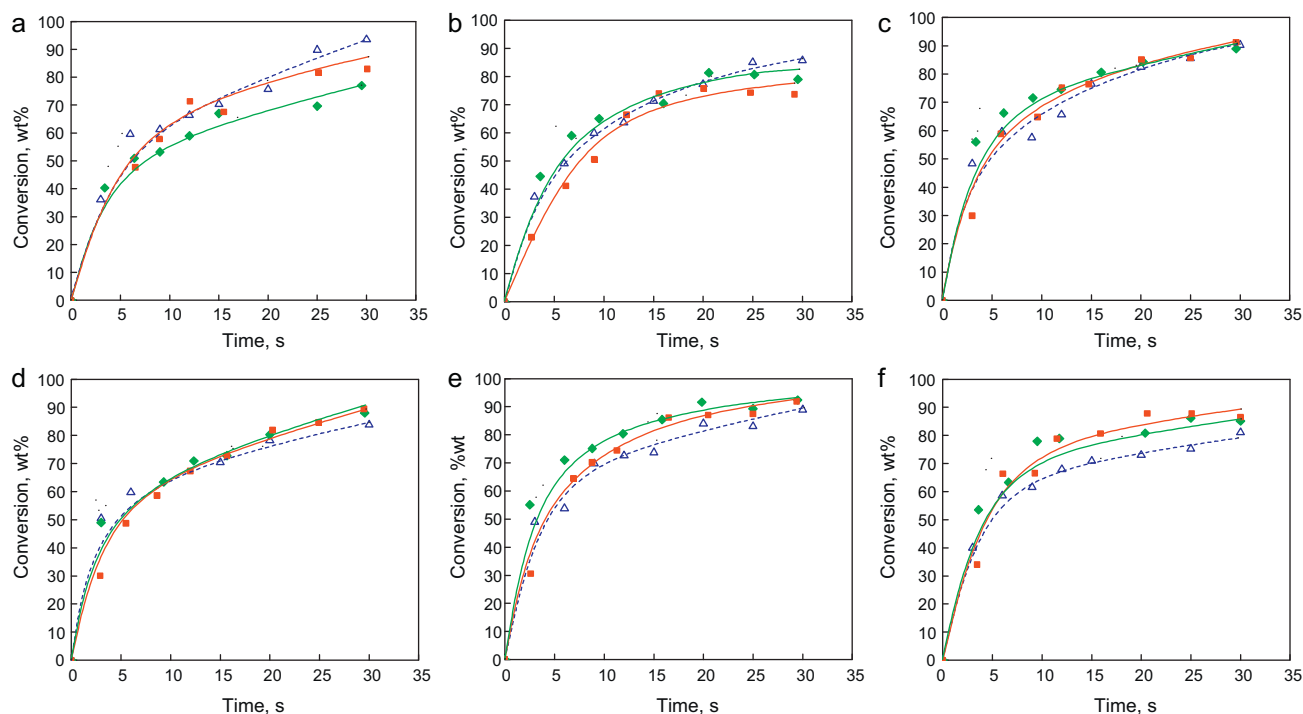
Besides the fact that it is less active, the resid catalyst E-cat R insinuates a better performance in converting the LDPE–VGO mixtures, as exposed by the higher relative increase in conversion for both LDPE concentrations, related to the standard VGO feedstock, which is observed particularly at 525 and 550 °C, in comparison to the octane-barrel catalyst E-cat M (results not shown for the sake of clarity). This could be associated to the specific architecture of a resid catalyst, which will ensure better diffusion properties in terms of accessibility [46] when facing large polymeric structures.

#### 3.2. Product yields

The distributions of products obtained with the two LDPE + VGO feedstocks is analyzed in terms of the most important FCC product groups and compared to that of the base case (pure VGO).

##### 3.2.1. Dry gas C1–C2

The dry gas fraction in FCC, which is usually about 5 vol% (gasoline and light olefin modes, [47]) comprises methane, ethane and ethylene, is typically used as fuel in the refinery and also allows separating ethylene for petrochemical purposes. Figure 3 shows the yield curves of dry gas from the two catalysts for the example of 6 wt.% LDPE + VGO at the three temperatures tested, which are compared with those from the pure VGO feedstock. As expected, the higher the temperature, the higher the yields. The group shows to



**Fig. 2.** Conversion as a function of reaction time. Temperatures and catalysts: (a) E-cat M 500 °C, (b) E-cat R 500 °C, (c) E-cat M 525 °C, (d) E-cat R 525 °C, (e) E-cat M 550 °C, (f) E-cat R 550 °C. Symbols: ( $\triangle$ ) VGO; ( $\blacklozenge$ ) VGO + 2 wt.% LDPE; ( $\blacksquare$ ) VGO + 6 wt.% LDPE.

be a primary product at 500 and 525 °C, and incorporates characteristics of secondary product at 550 °C when conversion is higher than about 50%, due to more intense cracking reactions. This behaviour is not perturbed by the addition of plastic and it can be seen in general that when LDPE is present, the yield of dry gas increases. This change is considerable in some cases (e.g. E-cat R at 550 °C), representing an increment of about 10% in the yield of dry gas at 70% conversion. Both concentrations of plastic in VGO showed these increases in the yield of dry gas, without neat differences between them (results not shown).

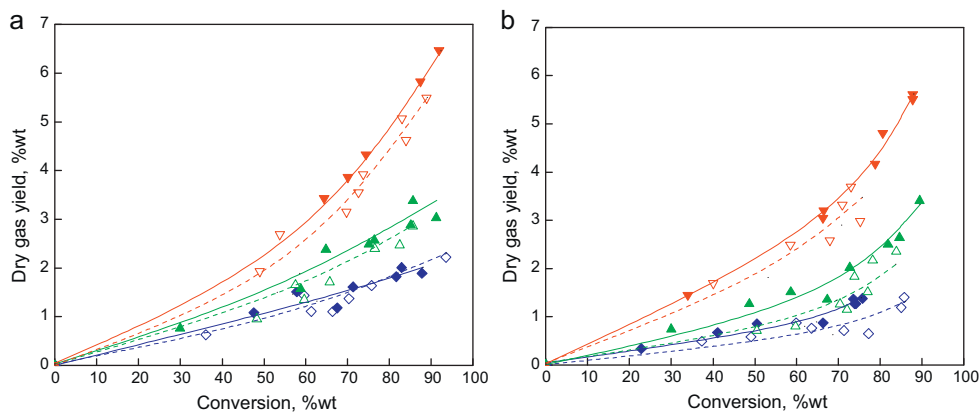
### 3.2.2. LPG C3-C4

The liquefied petroleum gas fraction includes very high value C3-C4 hydrocarbons, such as propylene, isobutane and C4 olefins, which are raw materials for the petrochemical industry. Fig. 4 shows the yield curves of LPG from the two catalysts for the example of 6 wt.% LDPE + VGO at the three temperatures tested, which are compared with the pure VGO feedstock. The group shows an

essentially primary product character at 500 and 525 °C and some slightly characteristics of secondary product at 550 °C. It can be seen that in all the cases the catalyst E-cat M produces more LPG than the catalyst E-cat R, consistently with its higher activity and, independently of the addition of plastic, the LPG yields increased importantly as a function of the reaction temperature, values at 550 °C being about 30% higher than at 500 °C.

When plastic was added, the LPG yields overall increased; for example, for catalyst E-cat M at 70% conversion, the rise was approximately 9% at 525 °C and 13% at 550 °C. For given reaction temperature, catalyst and conversion level, no significant differences could be observed for the two different concentrations of plastic added.

Isobutane, which is an important petrochemical feedstock, can be considered as an example of the fact that individual hydrocarbon yields can be analyzed following this scheme. Its yield and proportion in LPG, which is shown in Table 3 as a function of the different conditions, have been given relevant mechanistic



**Fig. 3.** Dry gas yield as a function of conversion. Temperatures: ( $\blacklozenge$ ) 500, ( $\blacktriangle$ ) 525 and ( $\blacktriangledown$ ) 550 °C. (a) E-cat M; (b) E-cat R. Symbols: open, VGO; closed, VGO + 6 wt.% LDPE.

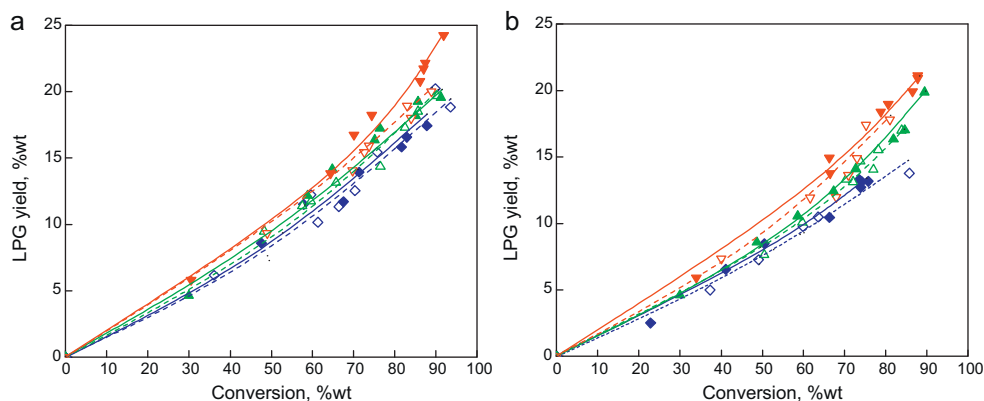


Fig. 4. LPG yield as a function of conversion. (a) E-cat M; (b) E-cat R. Symbols as Fig. 3.

Table 3

Proportion of isobutane in LPG. Average values at the different conditions.

	E-cat M			E-cat R		
	0% LDPE	2% LDPE	6% LDPE	0% LDPE	2% LDPE	6% LDPE
500 °C	0.37	0.39	0.34	0.33	0.29	0.28
525 °C	0.37	0.33	0.31	0.28	0.26	0.26
550 °C	0.29	0.30	0.27	0.25	0.23	0.22

significance [48,49]. It can be seen that, according to the higher cracking and hydrogen transfer activity in catalyst E-cat M [50], the concentration of isobutane is higher with this catalyst at every condition. Catalyst E-cat M has a lower content of rare earths, but it must be considered that if the load is above approximately 3 wt.%, like in the case of catalyst E-cat R, rare earth ions may form OH bridges between them, leading to a decrease in the catalyst acidity, below that expected from the hydrolysis of the individual cations [51].

In general, over the two catalysts at a given reaction temperature, the addition of plastic seems to decrease the proportion of isobutane among products, suggesting a higher incidence of primary cracking reactions leading to olefins [52]. The higher yields of propylene when plastic is added can be observed in Fig. 5, confirming previous conclusions about the specific contribution from the conversion of plastics on equilibrium FCC catalysts [31]. Moreover, the well known fact that olefins are produced more significantly at

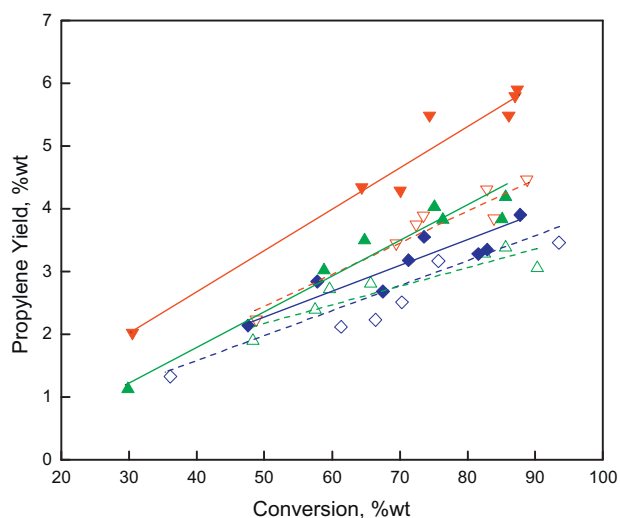


Fig. 5. Propylene yield as a function of conversion. Catalyst E-cat M. Symbols as Fig. 3.

higher temperatures [53] is observed not only in the base case but also with the addition of plastic at different concentrations.

### 3.2.3. Gasoline C5–216 °C

Fig. 6 shows the yield curves of gasoline from the two catalysts for the example of 6 wt.% LDPE + VGO at the three temperatures tested, which are compared with the pure VGO feedstock. It can be seen that all the yield curves are linear, showing gasoline to be a primary product. This behaviour constitutes an important advantageous characteristic of the CREC Riser Simulator reactor that defines constant gasoline selectivities, as opposed to results from MAT-type or FFB reactors that require complex analysis models [54].

It is clear for both catalysts that the higher the temperature the lower the gasoline selectivity, due to the more important influence of cracking reactions (see results for the pure VGO feedstock), also reflected in higher dry gas or LPG yields, as shown in Figs 3 and 4. At typical conversion levels of about 70%, the yields of gasoline observed are similar to those in commercial units [43].

The addition of plastic to the VGO brings on an increase in the yield of gasoline in most of the cases. In effect, if comparisons are done at typical 70% conversions, the increase for catalyst E-cat M can be of more than 9% at 525 °C. These results evidence a significant effect of a low content of polyethylene in the feed, which suggests certain synergism in the cracking mechanism. The increase in gasoline yield seems to be more important when the temperature is higher, as can be noticed on catalyst E-cat M; particularly for catalyst E-cat R it is more notorious at the highest reaction temperature.

Previous studies [31] showed that the specific contribution of the conversion of LDPE over FCC catalysts was concentrated mainly in the gasoline fraction, increasing it slightly.

Given its impact on fuel quality, it is interesting to observe changes in the composition of the gasoline cut. Average values of RON calculated with a modified Anderson's method, which are in line with typical refinery's values [54,55], are shown in Table 4. They confirm the very important and well known effect of temperature in increasing the RON, a fact that can be associated to the higher formation and conservation of olefins due to the lower incidence of hydrogen transfer reactions as compared to cracking [56]. It can

Table 4

Average RON in gasoline cuts.

Feedstock	E-cat M			E-cat R		
	0% LDPE	2% LDPE	6% LDPE	0% LDPE	2% LDPE	6% LDPE
500 °C	93.6	94.1	94.6	94.1	94.4	94.8
525 °C	95.0	95.7	96.0	94.9	95.6	96.1
550 °C	97.3	97.6	97.8	97.4	97.0	97.7

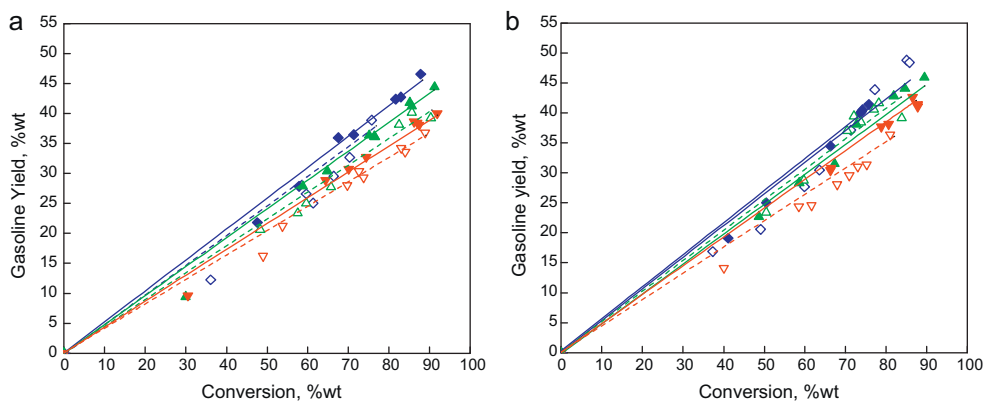


Fig. 6. Gasoline yield as a function of conversion. (a) E-cat M; (b) E-cat R. Symbols as Fig. 3.

**Table 5**  
Concentration (wt.%) of main hydrocarbon groups in gasoline. Average values.

	LDPE (%)	E-cat M			E-cat R		
		500 °C	525 °C	550 °C	500 °C	525 °C	550 °C
Aromatics	0	36.4	40.9	40.8	41.9	38.0	43.4
	6	37.0	39.1	42.0	37.4	38.8	40.6
n-Paraffins	0	5.1	4.6	4.9	4.8	4.2	4.8
	6	4.2	4.7	4.9	4.4	4.7	4.9
i-Paraffins	0	40.7	38.3	31.9	34.5	34.4	29.4
	6	36.8	33.0	28.5	32.2	30.1	26.1
Olefins	0	10.7	10.1	16.6	10.5	15.2	16.5
	6	14.1	17.1	19.5	18.1	19.7	22.9
Naphthenics	0	7.2	6.0	5.7	8.3	8.1	6.0
	6	7.1	5.8	5.1	7.9	6.8	5.9

be seen that the two catalysts produce very similar RONs in the gasoline cut.

The slight positive impact of the addition of plastics on the RON values can be noted over both catalysts. This positive effect on the quality of the gasoline can be associated to the increase in the concentration of olefins, due to a higher incidence of primary cracking products, and the slight variations in the concentration of aromatics, as can be seen in Table 5, and it is also consistent with the observation about LPG olefinicity in Section LPG. Depending on catalysts and experimental approach, some works on the conversion of plastics reported low aromaticity in gasoline range products (e.g., [12,6,57]), while others stated the opposite (e.g., [58]).

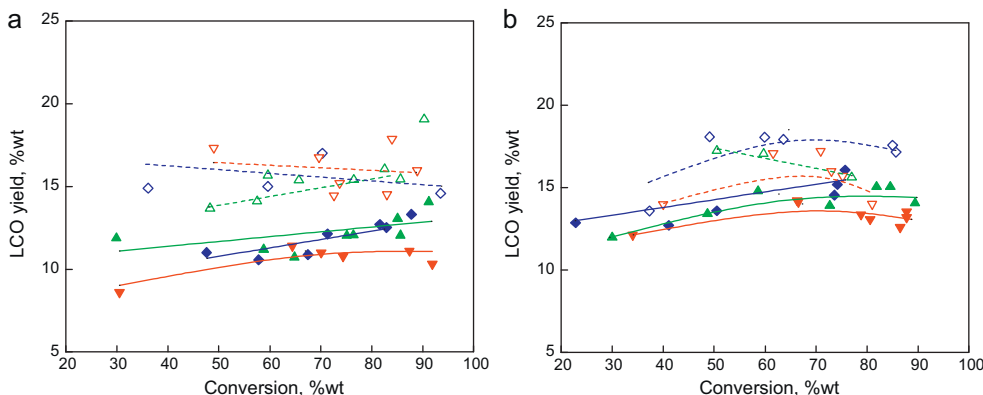


Fig. 7. LCO yield as a function of conversion. (a) E-cat M; (b) E-cat R. Symbols as Fig. 3.

### 3.2.4. LCO 216–344 °C

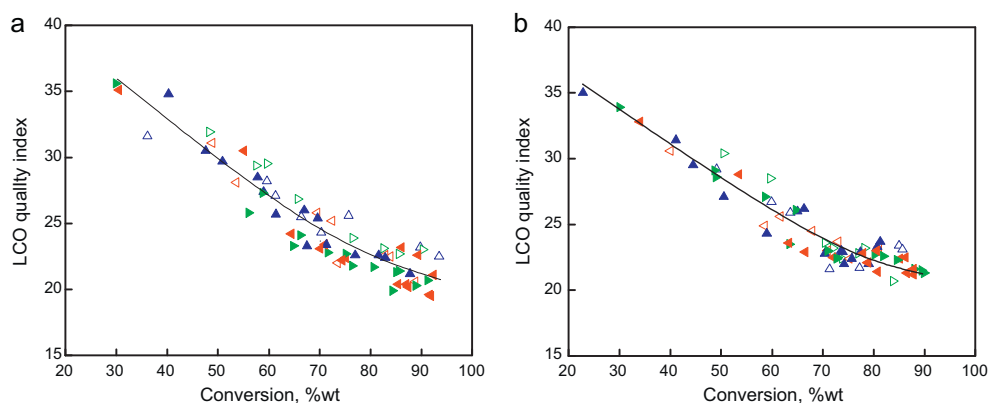
Fig. 7 shows the examples of LCO (hydrocarbons boiling between 216 and 344 °) yield curves for the 6 wt.% LDPE in VGO with the two catalysts at the three reaction temperatures, which are compared with the pure VGO feedstock. It can be seen that the yield curves increase slightly with conversion and that for given conversion, reaction temperature and catalyst, a decrease in the LCO yield is apparent when the polymer is present in the feedstock. This change in LCO is distributed among the other hydrocarbon groups.

Catalysts E-cat R yields more LCO than catalyst E-cat M in all the cases, and the differences are even larger when a plastic-VGO feedstock is used. This is characteristic of resid catalysts such as E-cat R, which are usually less active than conventional octane-barrel catalysts, such as E-cat M.

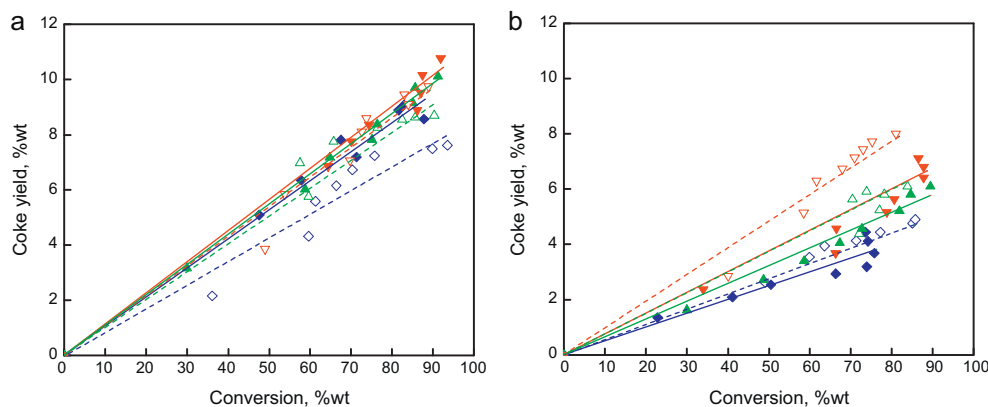
Since the CREC Riser Simulator reactor does not allow collecting samples large enough to perform the standard analysis for cetane numbers, an estimation can be performed based on the composition of the LCO cut, which in turn is very complex [59]. A linear model with contributions from pure compounds (considering that n-paraffins can be observed clearly) and groups (considering that they are mostly polyaromatic) given by the cetane numbers published in reference [60], can provide a view on LCO fuel quality [61]. The resulting LCO Quality Index (see Fig. 8) is not absolute, but allowed to distinguish clearly that the addition of plastic to the VGO does not induce significant changes in LCO quality; as expected, the lower the conversion, the larger the index.

### 3.2.5. Coke

Fig. 9 shows the coke yield curves for both the pure VGO and the 6 wt.% LDPE + VGO examples, which are linear over both catalysts. It can be seen that coke yields increase with reaction temperature.



**Fig. 8.** LCO Quality Index as a function of conversion. (a) E-cat M; (b) E-cat R.: (▲) 500 °C, (▼) 525 °C, (◄) 550 °C. Symbols: open, VGO; closed, VGO + 2 wt.% and 6 wt.% LDPE.



**Fig. 9.** Coke yield as a function of conversion. (a) E-cat M; (b) E-cat R. Symbols as Fig. 3.

Catalyst E-cat M (specifically formulated for this VGO) shows better coke selectivity when the pure VGO is processed, but the overall better coke selectivity of the resid catalyst E-cat R (designed for processing residual feedstocks) is apparent when plastic was added.

Nevertheless, the coke yields at conversions close to 70% are all lower than 7.7 wt.%, that is, not much higher than typical examples of the standard commercial operation [43,62]. It must be noticed that, even though CCR values increase with the concentration of LDPE in the mixtures with VGO, they do not impact significantly on the coke yields. Coke yield assessments in this laboratory unit are more realistic, as opposed to time-averaged operated units such as MAT fixed bed and fixed fluidized bed reactors [54,59].

In this way, the co-processing of plastic wastes would not alter significantly the coke yields and, consequently, the delicate and self-sustained heat balance in FCC. Furthermore, if needed, it should be considered that technical solutions exist to handle high coke yields such as those seen in resid FCC [63].

The analysis performed about the yields of both the main hydrocarbon groups and individual compounds, however, should be considered examples and, actually, each case in a given refinery (e.g., catalyst, standard feedstock, operative conditions, amount of plastic added) should be evaluated separately.

#### 4. Conclusions

It was shown by means of experiments in a batch, fluidized bed laboratory unit with equilibrium commercial catalysts and feedstocks, that recycling waste LDPE by co-processing it as part of

conventional feeds to the process of catalytic cracking of hydrocarbons does not interfere with the standard operation. Thus, it would not be necessary to develop new commercial technologies to process plastics in a conventional refinery, and it is possible to take advantage of a fully proven, established and cost-effective process.

The conversion of the LDPE–VGO mixtures over two different equilibrium catalysts (conventional and resid types) did not reflect differences between the two concentrations used. Conversions did not change substantially in comparison to the VGO alone, but the higher the temperature, the more perceptible an increase in conversion when plastic was present. The resid catalyst showed a better global performance.

The analysis of the product yields from those mixtures showed that the yields of dry gas and LPG increased up to 10% on the two catalysts, propylene yield being particularly favoured. The yield of gasoline also showed increases of about 12% at typical commercial process conversions, together with a slight rise of up to one RON point in all the cases, due to the relative increase in olefin concentration. On the contrary, LCO selectivity decreased about 25%, maintaining its properties as a fuel. Coke loads in the co-processing of LDPE and VGO would not represent any problem for the operation of the FCC units.

LDPE is easily converted and seems to be subjected to primary reactions of catalytic cracking which reflect in higher yields of olefins in the LPG and gasoline boiling ranges.

In order to analyze more safely the advantages and disadvantages of this recycling option in a given refinery, a comprehensive laboratory evaluation such as the one showed here should include the actual feedstock, equilibrium catalyst and process conditions in the FCC unit.

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