INTERCRITERIA AND REGRESSION ANALYSES TO DECIPHER THE MEANING OF CHARACTERISTICS OF FEEDS CONTAINING RESIDUES FOR THE PREDICTION OF CATALYTIC CRACKING PERFORMANCE

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ABSTRACT

Data for catalytic cracking of ten feeds, which contain residues were evaluated by using intercriteria and regression analyses with the aim to verify the established in a previous study relations, based on catalytic cracking of nine vacuum gas oils, and to develop new correlations to predict product selectivity. The previously developed correlation that calculates vacuum gas oil conversion from aromatic carbon and hydrogen contents was found to be the best for prediction of conversion of the feeds containing residues too. It was found that the selectivity towards production of dry gas, coke, and gasoline of both VGOs and residue containing feeds can be predicted from the same feed characteristics: aromatic carbon, hydrogen, sulphur, and polars contents, and molecular weight. However, the bottoms cracking of the VGOs needs to be modelled separately from that of the residue containing feeds.

Keywords: cracking, residue, ICrA, regression, modelling.

INTRODUCTION

Fluid catalytic cracking (FCC) is a major petroleum refining process that converts the low value heavy oil fractions to high value transportation fuels and feeds for petrochemicals [1, 2]. In addition, the FCC process has been employed as bio-fuel producer, and waste (srap tyre, plastics) processor [3, 4]. The number of FCC units around the world amounts of about 600, which are located in 59 countries, with total FCC unit capacity of around 2.27×10^6 m^3 d^{-1} [1]. The FCC unit along with the residue conversion units is considered as the refinery money makers for their capability of attaining high level of low value dark heavy oil conversion to the high value light oil products. As heavier crudes account for 70 % of the world's proven oil reserves, as well as the demand for refineries to process cheaper crudes to improve refinery profitability, the proportion of FCC feedstocks that fall within the definition of residue is increasing. [1]. Residue is often defined as the fraction of feed that boils above 524°C and it features with higher than the typical vacuum gas oi level of impurities such as sulphur, carbon residue, organic nitrogen, and metals [2]. Conventional vacuum gas oil (VGO) feeds generally have a carbon residue less than 0.5 wt.%, while for feeds containing resid, the number can be as high as 15 wt.% [2]. Typically, the content of residue fraction in the VGO amounts of between 1 and 5 wt.%, while the residue containing blends are considered those which contain more than 5 % fraction boiling above 524°C [5]. Navaro et al. reported that among more than 100 tested FCC feeds including such containing residues the conversion varies between 50 and 85 wt.% [6]. Fisher investigating nine vacuum gas oils with a very different composition, analysed by using mass spectroscopy, confirmed the findings of Navaro et al. [6] that the FCC conversion of the distinct VGO feeds fluctuated between 50 and 85 wt.% [7]. Stratiev employing the data of Fisher [7] revealed that the empirical parameters aromatic carbon and hydrogen contents calculated from the routine laboratory daily analyses performed in a refinery such as density, refractive index, and distillation

are better feed descriptors than the costly sophisticated mass spectroscopy [8]. Employing intercriteria analysis (ICrA) he proved that the empirical parameters exhibited the same positive and negative consonances as those derived from the mass spectroscopic analysis data [8]. Although VGO conversion in catalytic cracking and product selectivity were found to be well correlated with empirical parameters, the question whether the same would be true for feeds containing residues has not been answered yet. That was the reason for the author of this research to investigate the conversion and product selectivity obtained during laboratory catalytic cracking of ten feeds, some of which contained residues, in the work of Ng et al., applying ICrA and regression analysis [5]. In addition to the best of this author knowledge, no correlations have been reported in the literature yet to calculate FCC product selectivity from feed characterizing parameters. The aim of this study is to verify whether the relations observed with the VGO feeds reported by Choudhary and Meier are valid for the feeds containing residues and to develop correlations to predict product selectivity from best feedstock descriptors [9].

EXPERIMENTAL

The ten feeds investigated in the work of Ng et al. were characterized by mass spectrometry, by routine laboratory analyses such as density at 15°C, refractive index, sulphur, nitrogen, aromatic carbon, and hydrogen contents, and SAP analysis (saturates, aromatics, polars) [5]. As no data was reported for $T_{50\%}$, and for molecular weight of the studied ten FCC feeds the Conoco Philips correlation (COP) was used to estimate $T_{50\%}$ (Eq. (1)) [9].

$$T_{50\%}(^{\circ}C) = \frac{\left(\frac{292.1 \times SG - 212.2 - C_A}{0.043} - 32\right)}{1.8} \quad (1)$$

where, SG = specific gravity at 15.6°C; C_A = aromatic carbon content, wt.%; $T_{50\%}$ = boiling point of 50 % of FCC feed, °C.

The molecular weight of the ten feeds was calculated by the correlation of Goosens (Eq. (2)) [10].

$$MW = \frac{0.010770 \times T_{50\%}^{\left[1.52869+0.06486\times ln\left(\frac{T_{50\%}}{1078-T_{50\%}}\right)\right]}}{d} \quad (2)$$

where MW = molecular weight of FCC feed, g mol^{-1}; d = density of FCC feed at 20°C, g cm^{-3}

Employing the data of $T_{50\%}$ estimated by Eq. (1) one can figure out the K_W-characterizing factor by applying Eq. (3).

$$K_W = \frac{\sqrt[3]{1.8 \times \left({T_{50\%}}^{C} + 273.15\right)}}{SG} \quad (3)$$

The characterization data of the ten gas oils studied by mass spectrometry, SAP analysis and empirical methods, together with experimental FCC data taken from the work of Ng et al., are presented in Table 1 [5]. Intercriteria analysis (ICrA) was availed to evaluate the relationship between FCC conversion and product selectivity at constant catalyst-to-oil ratio and feedstock properties for the 10 heavy oils containing residues studied [11, 12]. Atanassov et al. explained in their research the foundation of the theory and application of ICrA [13]. Two intuitionistic fuzzy functions: μ and υ are computed in the ICrA method which determine the extent of the relationship between studied variables. Positive consonance is defined for the domain μ = 0.75 - 1.00 and υ = 0 - 0.25, whereas negative consonance is assigned for the values in the interval μ = 0.75 - 1.00 and υ = 0 - 0.25. All other values for μ and υ are classified as dissonance. A strong consonance is considered at values of μ = 0.95 - 1.00, υ = 0.00 - 0.05 (positive), μ = 0.00 - 0.05, υ = 0.95 - 1.00 (negative), while a weak consonance is deemed at μ = 0.75 - 0.85, υ = 0.15 - 0.25 (positive), μ = 0.15 - 0.25, υ = 0.75 - 0.85 (negative). Two software packages for ICrA were established and freely available as open source and detailed in [14 - 17].

The ICrA assessment is performed on normalized values of the studied variables, and the normalization is carried out using Eq. (4).

$$X_{new} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (4)$$

The procedure of cracking tests and the physical and chemical properties of the ten investigated FCC feeds are given in the research of Ng et al. [5]. The FCC conversion is calculated as the sum of the yields of products light cycle oil and heavy cycle oil are detracted from the sum of the yields of all products divided by the sum of the yields of all products and multiplied by 100. The bottoms cracking is calculated using Eq. (5).

Table 1. Characterization data for ten FCC feeds containing different residue amounts studied by mass spectrometry, SAP analysis and empirical methods, together with experimental FCC data, taken from the work of Ng et al. [5].

feed name/feed characteristics	HCB	HT-VIR	RZ	HT-LCF	HT-C	HT-DA	VIR	LCF	DA-LCF	DA-BIT
Density at 15°C, g cm^{-3}	0.8643	0.9252	0.8988	0.9284	0.9511	0.9430	0.9712	0.9562	0.9642	0.9776
Molecular weight, g mol^{-1}	394	467	377	427	465	506	603	378	453	708
Kw-characterizing factor	12.6	12.1	12.1	11.9	11.8	12.0	11.9	11.5	11.6	12.0
Hydrogen content, wt.%	13.7	12.3	12.8	12.1	11.5	11.8	11.1	11.2	11.2	11.1
Total Nitrogen Content, wppm	0.0	460.0	800.0	1090.0	2150.0	2450.0	1930.0	3370.0	4020.0	3050.0
Sulphur, wt. %	0.001	0.098	0.917	0.088	0.429	0.704	3.250	1.350	1.520	3.540
Aromatic Carbon Content, %	4.4	17.6	14.6	20.2	24.7	20.9	25.4	30.1	28.8	24.4
Refractive Index at 20°C	1.4747	1.5130	1.4967	1.5153	1.5323	1.5269	1.5397	1.5324	1.5370	1.5393
Saturates, wt.%	90.1	46.8	61.0	45.7	34.4	35.4	28.7	35.5	29.1	23.0
Aromatics, wt.%	9.3	52.3	36.1	52.3	61.8	57.5	65.6	58.4	59.1	61.8
di-, wt.%	1.2	10.5	7.7	11.9	13.6	12.7	14.4	13.6	13.1	14.0
tri-, wt.%	0.3	3.9	3.7	4.9	6.3	5.4	7.2	7.3	6.0	5.7
tetra- and greater,	0.5	4.0	3.4	3.7	6.1	5.1	8.0	8.4	6.6	6.3
Aromatic Sulfur, wt.%	0.3	2.8	3.7	2.6	4.2	3.4	10.7	6.8	5.4	9.1
Polar Compounds, wt.%	0.7	0.9	2.9	2.0	3.8	7.1	5.7	6.1	11.8	15.2
Gasoline Precursors, wt.%	97.0	75.9	77.6	73.3	63.9	64.9	51.2	56.1	55.4	47.7
LCO precursors, wt.%	1.5	12.3	10.1	13.5	15.8	14.9	21.7	17.9	16.6	20.5
Maximal conversion, wt.%	85.0	75.0	77.9	68.3	65.4	70.0	64.2	58.7	64.5	66.0
Dry Gas Selectivity, %	1.51	2.01	2.51	1.91	2.42	3.55	4.51	3.13	3.43	6.28
LPG Selectivity, %	21.67	16.27	19.24	15.17	13.18	14.88	13.63	12.83	12.3	15.17
Gasoline Selectivity, %	62.64	52.99	51.55	49.00	42.34	44.52	39.39	35.86	30.04	36.68
Bottoms cracking	7.89	17.04	13.90	17.87	19.91	16.84	21.83	22.29	19.18	17.73
Coke Selectivity, %	3.0	5.2	5.4	6.3	9.0	12.8	10.1	11.7	17.5	19.7
Δ Coke	0.39	0.73	0.75	0.84	1.20	1.89	1.35	1.43	2.50	2.50
Conversion at CTO of 6 wt./wt.	86.0	72.5	73.5	66.4	60.5	70.0	60.0	52.5	61.0	67.0

$$\frac{Yield\ of\ fr.215-343°C}{(Yield\ of\ fr.215-343°C+yield\ of\ fr.>343°C}\times 100 \quad (5)$$

The sum of contents of saturates and monocyclic aromatics is coined gasoline precursors. The sum of contents of diaromatics + two-ring aromatic sulfur + 1/2 × three-ring aromatic sulfur are classified as light cycle oil (LCO) precursors. This research applies the methodology detailed in [8].

RESULTS AND DISCUSSION

Data from the ICrA evaluation of the characteristics of the ten feedstocks containing residues (Table 1 in this work) and the nine vacuum gas oils (Table 1, [8]) and the FCC conversion at maximum gasoline yield (maximum conversion, [8]) and the FCC conversion at the same catalyst-to-oil ratio (CTO), which is an indicator of the feedstock reactivity (Tables 2 and 3), show that the aromatic carbon (CA) content has the strongest consonance (μ = 0.04; ν = 0.96). In this study, like the previous one, the feed characteristics aromatic carbon, and hydrogen contents confirmed to be the best descriptors which enable to predict the conversion at maximum gasoline yield employing Eq. (6) [8].

FCC conv.(wt.%) = -0.36441×C_A + 6.6859 × H
R = 0.977, st. error = 2.29 % (6)

The standard error for the nineteen feeds (nine from the previous research [8] and ten from the current study) was 2.29 %.

The gasoline precursor correlation (Eq. (19)) from previous our work demonstrated less accuracy with a standard error of 4.3 % (R = 0.912) for the nineteen FCC feeds mentioned above [8]. It deserves mentioning here that even the FCC characteristic refractive index at 20°C (RI) predicts the maximal FCC conversion with a higher accuracy (Eq. (7)) than the mass spectrometric determination of the sum of saturates plus mono-nuclear aromatics, the so-called gasoline precursors.

FCC conv.(wt.%) = 711.98 - 423.232 × RI
R = 0.964, st. error = 2.8 % (7)

The dry gas selectivity of the 19 FCC feeds (ten feeds, whose data are summarized in Table 1, and nine feeds whose data are presented in Table 1 in our previous work was found to be capable of predicting by the regression Eq. (8) [8].

FCC Dry gas selectivity (%) = -3.1574 + 0.07171×C_A + + 0.70784 × Sulphur + 0.01066 × MW
R = 0.954, st. error = 0.67 % (8)

The gasoline selectivity of the 19 FCC feeds was established to depend on FCC feed hydrogen and polars contents as shown in the regression Eq. (9).

FCC gasoline selectivity(%) = 51.959 - 1.5031 × Polars + + 1.67094 × H
R = 0.935, st. error = 2.8 %. (9)

The Δ Coke like the FCC gasoline selectivity was also ascertained to depend on FCC feed hydrogen and polars contents as shown in the regression Eq. (10).

FCCΔCoke = 3.454 - 0.2211 × H + 0.11235 × Polars
R = 0.955, st. error = 0.2 % (10)

The bottoms cracking for the nine FCC vacuum gas oil feeds, discussed in the previous study, was determined to depend on the contents of aromatic carbon and hydrogen as summarized in Eq. (11) [8]:

FCC bottoms cracking (%) = 73.0856 - 0.57856 × C_A + + 0.98631 × H
R = 0.943, st. error = 3.3 % (11)

The bottoms cracking for the ten FCC feeds, discussed in this research (Table 1), was established to depend on the content of hydrogen and the molecular weight as displayed in Eq. (12).

FCC bottoms cracking (%) = 80.4167 + 9.5174 × H + + 0.0571 × MW
R = 0.90, st. error = 3.8 % (12)

Although the nine VGO feeds investigated in our previous work, and the feeds, containing residues explored in this research (Table 1) demonstrated that their conversions obey the same correlations (Eq. (5)

Table 2. μ- values from ICrA evaluation of the FCC feed characterization data and conversion and product selectivity at maximum gasoline yield and the same catalyst-to-oil ratio of 6 wt./wt.

m	D15	Kw	H	Total N	Sul	CA	RI	Sat	Aromatics	Aromatic Sul	Polars	Gasoline Prec	LCO prec	Conv. at CTO of 6	C2 sel	LPG sel	CN sel	Bottoms cracking	Coke Sel	Maximal conversion	Δ Coke
D15	1.00	0.22	0.00	0.82	0.87	0.84	0.96	0.04	0.89	0.87	0.84	0.00	0.96	0.18	0.89	0.27	0.13	0.31	0.87	0.16	0.84
Kw	0.22	1.00	0.78	0.18	0.36	0.07	0.20	0.73	0.22	0.27	0.29	0.78	0.18	0.91	0.27	0.69	0.76	0.84	0.27	0.93	0.24
H	0.00	0.78	1.00	0.18	0.13	0.11	0.00	0.91	0.04	0.09	0.16	0.96	0.00	0.82	0.09	0.69	0.80	0.67	0.13	0.84	0.13
Total N	0.82	0.18	0.18	1.00	0.78	0.84	0.78	0.22	0.71	0.73	0.89	0.18	0.78	0.22	0.80	0.27	0.09	0.22	0.91	0.20	0.91
Sul	0.87	0.36	0.13	0.78	1.00	0.71	0.82	0.18	0.78	0.91	0.84	0.13	0.82	0.31	0.91	0.40	0.13	0.33	0.82	0.29	0.80
CA	0.84	0.07	0.11	0.84	0.71	1.00	0.84	0.20	0.80	0.80	0.78	0.16	0.89	0.07	0.76	0.29	0.16	0.16	0.80	0.04	0.80
RI	0.96	0.20	0.00	0.78	0.82	0.84	1.00	0.04	0.91	0.87	0.80	0.02	0.96	0.16	0.84	0.27	0.16	0.29	0.82	0.13	0.80
Sat	0.04	0.73	0.91	0.22	0.18	0.20	0.04	1.00	0.07	0.18	0.16	0.96	0.09	0.78	0.11	0.78	0.80	0.62	0.13	0.80	0.13
Aromatics	0.89	0.22	0.04	0.71	0.78	0.80	0.91	0.07	1.00	0.82	0.73	0.07	0.89	0.18	0.82	0.27	0.20	0.27	0.76	0.16	0.73
Aromatic Sul	0.87	0.27	0.09	0.73	0.91	0.80	0.87	0.18	0.82	1.00	0.80	0.13	0.91	0.22	0.89	0.40	0.18	0.24	0.78	0.20	0.76
Polars	0.84	0.29	0.16	0.89	0.84	0.78	0.80	0.16	0.73	0.80	1.00	0.16	0.80	0.29	0.87	0.29	0.07	0.29	0.98	0.27	0.96
Gasoline Prec	0.00	0.78	0.96	0.18	0.13	0.16	0.02	0.96	0.07	0.13	0.16	1.00	0.04	0.82	0.07	0.73	0.84	0.67	0.13	0.84	0.13
LCO prec	0.96	0.18	0.00	0.78	0.82	0.89	0.96	0.09	0.89	0.91	0.80	0.04	1.00	0.13	0.87	0.31	0.18	0.27	0.82	0.11	0.80
Conv. at CTO of 6	0.18	0.91	0.82	0.22	0.31	0.07	0.16	0.78	0.18	0.22	0.29	0.82	0.13	1.00	0.22	0.69	0.76	0.84	0.27	0.93	0.24
C2 sel	0.89	0.27	0.09	0.80	0.91	0.76	0.84	0.11	0.82	0.89	0.87	0.07	0.87	0.22	1.00	0.33	0.07	0.27	0.84	0.20	0.82
LPG sel	0.27	0.69	0.69	0.27	0.40	0.29	0.27	0.78	0.27	0.40	0.29	0.73	0.31	0.69	0.33	1.00	0.67	0.62	0.27	0.67	0.24
CN sel	0.13	0.76	0.80	0.09	0.13	0.16	0.16	0.80	0.20	0.18	0.07	0.84	0.18	0.76	0.07	0.67	1.00	0.73	0.09	0.78	0.07
Bottoms cracking	0.31	0.84	0.67	0.22	0.33	0.16	0.29	0.62	0.27	0.24	0.29	0.67	0.27	0.84	0.27	0.62	0.73	1.00	0.31	0.78	0.29
Coke Sel	0.87	0.27	0.13	0.91	0.82	0.80	0.82	0.13	0.76	0.78	0.98	0.13	0.82	0.27	0.84	0.27	0.09	0.31	1.00	0.24	0.98
Maximal conversion	0.16	0.93	0.84	0.20	0.29	0.04	0.13	0.80	0.16	0.20	0.27	0.84	0.11	0.93	0.20	0.67	0.78	0.78	0.24	1.00	0.22
Δ Coke	0.84	0.24	0.13	0.91	0.80	0.80	0.80	0.13	0.73	0.76	0.96	0.13	0.80	0.24	0.82	0.24	0.07	0.29	0.98	0.22	1.00

Table 3. ν- values from ICrA evaluation of the FCC feed characterization data and conversion and product selectivity at maximum gasoline yield and the same catalyst-to-oil ratio of 6 wt./wt

n	D15	Kw	H	Total N	Sul	CA	RI	Sat	Aromatics	Aromatic Sul	Polars	Gasoline Prec	LCO prec	Conv. at CTO of 6	C2 sel	LPG sel	CN sel	Bottoms cracking	Coke Sel	Maximal conversion	Δ Coke
D15	0.00	0.78	0.96	0.18	0.13	0.16	0.02	0.96	0.07	0.13	0.16	1.00	0.04	0.82	0.07	0.73	0.84	0.67	0.13	0.84	0.13
Kw	0.78	0.00	0.18	0.82	0.64	0.93	0.78	0.27	0.73	0.73	0.71	0.22	0.82	0.09	0.69	0.31	0.22	0.13	0.73	0.07	0.73
H	0.96	0.18	0.00	0.78	0.82	0.84	0.93	0.04	0.87	0.87	0.80	0.00	0.96	0.13	0.87	0.27	0.13	0.27	0.82	0.11	0.80
Total N	0.18	0.82	0.78	0.00	0.22	0.16	0.20	0.78	0.24	0.27	0.11	0.82	0.22	0.78	0.16	0.73	0.89	0.76	0.09	0.80	0.07
Sul	0.13	0.64	0.82	0.22	0.00	0.29	0.16	0.82	0.18	0.09	0.16	0.87	0.18	0.69	0.04	0.60	0.84	0.64	0.18	0.71	0.18
CA	0.16	0.93	0.84	0.16	0.29	0.00	0.13	0.80	0.16	0.20	0.22	0.84	0.11	0.93	0.20	0.71	0.82	0.82	0.20	0.96	0.18
RI	0.02	0.78	0.93	0.20	0.16	0.13	0.00	0.93	0.02	0.11	0.18	0.96	0.02	0.82	0.09	0.71	0.80	0.67	0.16	0.84	0.16
Sat	0.96	0.27	0.04	0.78	0.82	0.80	0.93	0.00	0.89	0.82	0.84	0.04	0.91	0.22	0.84	0.22	0.18	0.36	0.87	0.20	0.84
Aromatics	0.07	0.73	0.87	0.24	0.18	0.16	0.02	0.89	0.00	0.13	0.22	0.89	0.07	0.78	0.13	0.69	0.73	0.67	0.20	0.80	0.20
di-	0.07	0.78	0.91	0.24	0.20	0.13	0.04	0.89	0.02	0.11	0.22	0.91	0.02	0.82	0.11	0.67	0.76	0.71	0.20	0.84	0.20
tri-	0.16	0.89	0.84	0.20	0.29	0.04	0.13	0.80	0.11	0.20	0.27	0.84	0.11	0.93	0.20	0.67	0.78	0.82	0.24	0.96	0.22
tetra+	0.13	0.87	0.87	0.18	0.22	0.07	0.11	0.82	0.13	0.13	0.24	0.87	0.09	0.91	0.16	0.64	0.80	0.76	0.22	0.93	0.20
Aromatic Sul	0.13	0.73	0.87	0.27	0.09	0.20	0.11	0.82	0.13	0.00	0.20	0.87	0.09	0.78	0.07	0.60	0.80	0.73	0.22	0.80	0.22
Polars	0.16	0.71	0.80	0.11	0.16	0.22	0.18	0.84	0.22	0.20	0.00	0.84	0.20	0.71	0.09	0.71	0.91	0.69	0.02	0.73	0.02
Gasoline Prec	1.00	0.22	0.00	0.82	0.87	0.84	0.96	0.04	0.89	0.87	0.84	0.00	0.96	0.18	0.89	0.27	0.13	0.31	0.87	0.16	0.84
LCO prec	0.04	0.82	0.96	0.22	0.18	0.11	0.02	0.91	0.07	0.09	0.20	0.96	0.00	0.87	0.09	0.69	0.80	0.71	0.18	0.89	0.18
Conv. at CTO of 6	0.82	0.09	0.13	0.78	0.69	0.93	0.82	0.22	0.78	0.78	0.71	0.18	0.87	0.00	0.73	0.31	0.22	0.13	0.73	0.07	0.73
C2 sel	0.07	0.69	0.87	0.16	0.04	0.20	0.09	0.84	0.13	0.07	0.09	0.89	0.09	0.73	0.00	0.62	0.87	0.67	0.11	0.76	0.11
LPG sel	0.73	0.31	0.27	0.73	0.60	0.71	0.71	0.22	0.69	0.60	0.71	0.27	0.69	0.31	0.62	0.00	0.31	0.36	0.73	0.33	0.73
CN sel	0.84	0.22	0.13	0.89	0.84	0.82	0.80	0.18	0.73	0.80	0.91	0.13	0.80	0.22	0.87	0.31	0.00	0.22	0.89	0.20	0.89
Bottoms cracking	0.67	0.13	0.27	0.76	0.64	0.82	0.67	0.36	0.67	0.73	0.69	0.31	0.71	0.13	0.67	0.36	0.22	0.00	0.67	0.20	0.67
Coke Sel	0.13	0.73	0.82	0.09	0.18	0.20	0.16	0.87	0.20	0.22	0.02	0.87	0.18	0.73	0.11	0.73	0.89	0.67	0.00	0.76	0.00
Maximal conversion	0.84	0.07	0.11	0.80	0.71	0.96	0.84	0.20	0.80	0.80	0.73	0.16	0.89	0.07	0.76	0.33	0.20	0.20	0.76	0.00	0.76
Δ Coke	0.13	0.73	0.80	0.07	0.18	0.18	0.16	0.84	0.20	0.22	0.02	0.84	0.18	0.73	0.11	0.73	0.89	0.67	0.00	0.76	0.00

and (6)) and that their selectivity are controlled by the same feed characteristics (Eq. (7), (8) and (9)) their bottoms cracking was not possible to be described by a single equation [8]. The reason for this observation may lie in the different behaviour of the high boiling residual components in the feeds from Table 1, or from the different bottoms cracking characteristics of the catalysts used to crack them [18].

The ICrA evaluation of the data in Table 1 (Tables 2 and 3) with respect to the μ and ν values of the different feed characteristics shows similar relationships with product conversion and selectivity when comparing the catalytic cracking of vacuum gas oil discussed in [8] with the catalytic cracking of oils containing residues reported in the present study. This was confirmed by the same regression Eq. (6) to (10) developed for the 19 feeds (ten feeds containing residual oils, presented in Table 1 and nine vacuum gas oils whose data was reported in [8]) showing that the same feed characteristics control the selectivity in the catalytic cracking of vacuum gas oils and oils containing residues. However, it was found that bottoms cracking of vacuum gas oils and those containing residual oils cannot be described with the same characteristics of the FCC feed.

CONCLUSIONS

This study confirms again that the joint use of intercriteria and regression analysis allows to determine the feedstock characteristics that govern the level of conversion and product selectivity in the FCC process during the cracking of vacuum gas oils and oils containing residues. The feed characteristics, which were found to control conversion, product selectivity, and the bottoms cracking are aromatic carbon, hydrogen, polars, sulphur contents, and molecular weight. The FCC feeds containing residue were established to control their bottoms cracking by the feed parameters hydrogen content and molecular weight while the vacuum gas oil feeds were observed to control their bottoms cracking by their aromatic carbon, and hydrogen contents.

Authors' contributions

All contributions are the author's own.

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