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Revamping Fluid Catalytic Cracking Unit, and Optimizing Catalyst to Process Heavier Feeds

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Abstract: H-Oil gas oils have a higher density and higher nitrogen content, and consequently much lower reactivity than straight-run vacuum gas oils during fluid catalytic cracking (FCC). The conversion of H-Oil gas oils observed in a laboratory catalytic cracking unit at constant operating conditions showed a 20 wt.% lower conversion rate than straight-run hydrotreated vacuum gas oil. Thus, a revamp of commercial FCC units, and the selection of a higher activity catalyst with lower coke selectivity is needed to provide the stable trouble-free operation of the unit. The performed revamp of the commercial FCC unit allowed a stable operation at a higher throughput. It also allowed an increased riser outlet temperature from 532 to 550 °C; increased maximum allowable regenerator temperature from 705 to 730 °C; decreased afterburning from 12 to 6 °C; decreased NOx emissions in the flue gas from 250 to 160 mg/Nm^3; improved catalyst regeneration; decreased catalyst losses to 0.0142 kg/t feed; and improved catalyst circulation at a higher throughput. It was confirmed in the commercial FCC unit that the H-Oil light vacuum gas oil is the least reactive H-Oil gas oil during catalytic cracking.

Keywords: fluid catalytic cracking; VGO; H-Oil VGO; revamp; catalyst activity; coke selectivity

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1. Introduction

Over the years, fluid catalytic cracking has been extensively used and investigated as the main producer of high octane gasoline [1], middle distillate [2–6], ethylene and propylene [7–11], and bio-fuel [12–16], and as a waste (scrap tire, plastics) processor [17–19]. Its flexibility in the processing of feeds with a different quality has allowed the high penetration of FCC technology into petroleum refining. Worldwide, more than 350 FCC units, out of 650 refineries, are operated in petrochemical complexes, converting vacuum gas oil (VGO) and high-boiling residues into lighter fuel products and chemical feedstocks [20]. Now, when mankind has started to replace internal combustion engines with electromobiles and a drop in passenger vehicle production using petrol-based fuel has already been registered [21], the place and meaning of FCC technology as an automotive fuel maker is going to change to it being a chemical producer [22,23]. The most prevalent are the recent studies devoted to the role of FCC as an ethylene and propylene producer [7–11], and bio-fuel producer [11–16]. In the next two decades, oil demand for petrochemicals is expected to increase by ca. 4 Mb/d per year, reaching 34% of the total oil market in 2040, in contrast to the current 15% rate [22]. In this respect, FCC technological solutions directed to process whole crude oils have been explored [23,24]. However, the general trend in the extraction of petroleum has been towards heavy and low-quality oil [25,26]. Thus, a combination of FCC and vacuum residue upgrading units seems to best utilize the potential hidden behind the refining of heavy petroleum. The vacuum gas oil generated in the vacuum residue upgrading units can be processed in the FCC unit. Unfortunately, the secondary VGOs coming from cokers or vacuum residue hydrocrackers are characterized by a higher

amount of refractory poly-nuclear aromatics and nitrogen compounds [20,27–29], which leads to a substantial decrease in the FCC unit conversion. The content of basic nitrogen compounds has an influence on hydrocarbon cracking during the secondary vacuum gas oil (coker and H-Oil VGO) FCC reaction [30,31]. Furthermore, the compositional and structural identification of basic extracts by positive-ion electrospray Fourier-transform ion cyclotron resonance mass spectrometry (FT-ICR MS) shows that basic nitrogen compounds in the secondary vacuum gas oils include N, N2, NO, N2O1, and NS class species [30]. The N1 class species centered at 9 < DBE < 13 with a carbon number ranging from 20 to 24 is the most abundant, and it is a key for coker and H-Oil VGO retarding performance. The effect of the structure and composition of basic nitrogen compounds was found to be much more obvious than that of content, and it was stronger with the increase in their rings plus double-bond equivalence [30]. The secondary vacuum gas oil, nitrogen, determines the ratio between available metal and acid sites of the hydrocracking catalyst. The aromatics generate coke precursors on the available acid sites. Both factors play a coupled role that promotes coke deposition on the catalyst surface, which leads to an increase in the deactivation rate [32]. Thus, both the higher polynuclear aromatic content, and the higher nitrogen content of the coker and H-Oil vacuum gas oils, make them undesirable components of the feed for vacuum gas oil hydrocracking. That is the reason why their processing seems most suitable in fluid catalytic cracking because it is less vulnerable to the higher content of nitrogen and aromatics than fixed-bed vacuum gas oil hydrocracking.

It is a challenge to find the optimum catalyst and operating conditions to maximize conversion during the processing of secondary VGOs [28,33,34]. Another issue when processing secondary vacuum gas oils is the higher coke load of the commercial FCC unit regenerator, which requires more air that can impair cyclone efficiency, and results in higher catalyst losses and poor unit performance [35]. The poor cyclone performance was found to affect catalyst aging that resulted in a lower inventory catalyst activity [35]. All of this was experienced in the LUKOIL Neftohim Burgas FCC unit since it has started processing heavier, more refractory H-Oil vacuum gas oils [36]. That was the reason to revamp the LNB FCCU with the aim of reducing catalyst losses, improving catalyst retention in the reactor–regenerator vessels, increasing catalyst activity, and enhancing conversion by operating at a higher severity during the processing of blends of straight-run and H-Oil vacuum gas oils.

The aim of this article is to discuss how the revamped LNB FCCU improved its performance during the processing of H-Oil gas oils of different quality.

2. Materials and Methods

The properties of the vacuum gas oil feedstock streams (straight-run hydrotreated VGO; H-Oil heavy atmospheric gas oil (HAGO); H-Oil light VGO (LVGO); and H-Oil heavy VGO (HVGO)) feeding the LNB FCCU under study are summarized in Table 1.

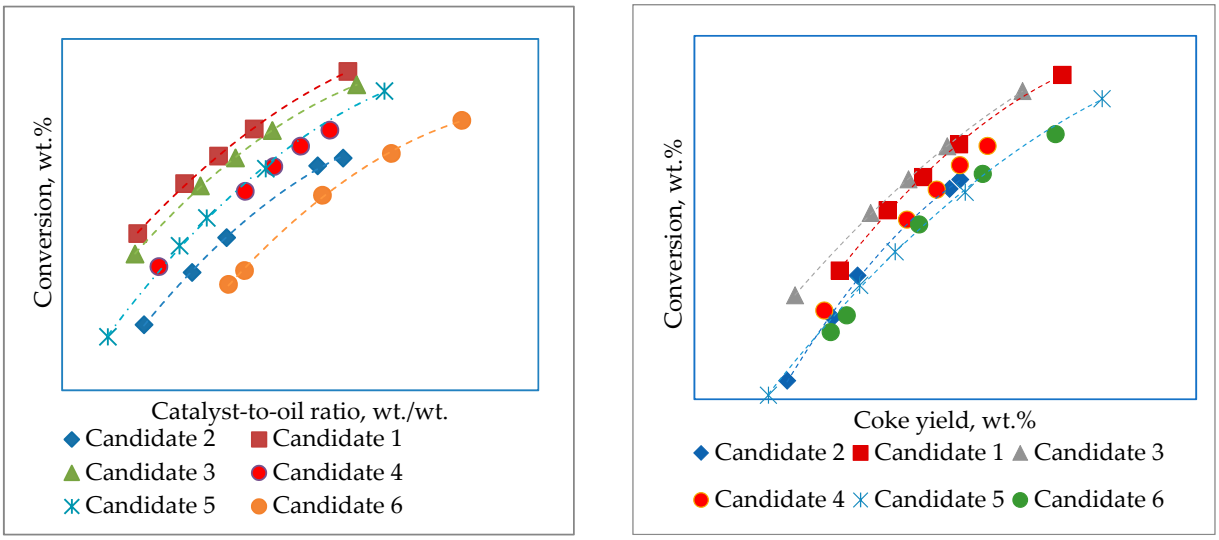
Table 1. Properties of the FCC feed streams studied in this work.

FCC Feed Properties	Methods	SRHTVGO	H-Oil HVGO	H-Oil LVGO	H-Oil HAGO
Density at 15 °C, g/cm^3	ASTM D 4052	0.9014	0.9784	0.9639	0.9393
Sulphur, wt.%	ASTM D 4294	0.1763	0.67	0.48	0.37
Nitrogen, wt.%	ASTM D 5762	0.08	0.25	0.32	0.21
Basic nitrogen, mg/kg	UOP269	393	819	1070	686
Conradson carbon, wt.%	ASTM D 189	0.24	2.67	0.34	0.15
Refractive Index, 60 °C	ASTM D 1747	1.499	1.551	1.540	1.521
C_Aromatics, wt.%	ASTM D3238	24.4	41.3	43.6	38.7
C_Paraffins, wt.%	ASTM D3238	60.1	48.6	47.6	50.7
C_Naphthenes, wt.%	ASTM D3238	15.5	10.1	8.9	10.7
Molecular Weight, g/mol	VPO	396	416	323	296

Table 1. *Cont.*

FCC Feed Properties	Methods	SRHTVGO	H-Oil HVGO	H-Oil LVGO	H-Oil HAGO
Sim. Dist., °C	ASTM D 2887-extended				
IBP		287	213	254	234
5% wt.		353	395	316	300
10% wt.		371	416	336	322
50%wt.		444	484	403	373
90% wt.		529	541	479	433
95% wt.		556	556	503	455
FBP			595	555	517
Kw-factor		12.10	11.61	11.48	11.53

Before the revamp, six catalyst candidates were tested in a laboratory FCC unit with the aim of selecting the most active, and least coke-selective catalyst. Figure 1 presents the results of the catalyst tests concerning activity (catalyst-to-oil ratio versus conversion, Figure 1a) and coke selectivity (coke yield versus conversion, Figure 1b).



(**a**) (**b**)

Figure 1. Laboratory tests with six catalyst candidates to select the most active (**a**) and coke selective (**b**) catalyst to employ in the revamped FCC unit.

The properties of the catalyst employed at the LNB FCCU before and after the revamp (catalyst G), and that of the selected, most active and coke-selective catalyst, designated as catalyst H, to employ in the LNB FCCU after the revamp are presented in Table 2.

Table 2. Properties of the FCC catalyst employed in the commercial LNB FCC unit during this study.

The Period of Using the Catalyst at the LNB FCCU	2021–August 2022 (before and after the Revamp)	After August 2022 (after the Revamp)
	Catalyst G	Catalyst H
	Fresh catalyst properties	
Total surface area, m^2/g	298	288
Na_2O, %	0.30	0.29
RE_2O_3, %	2.8	3.2
Al_2O_3, %	42.0	42.0
APS, μ	86	76
ABD, g/cm^3	0.72	0.72
Microactivity, %	81	83

Table 2. *Cont.*

The Period of Using the Catalyst at the LNB FCCU	2021–August 2022 (before and after the Revamp)	After August 2022 (after the Revamp)
	Equilibrium catalyst properties	
Total surface area, m^2/g	152	150
Na_2O, %	0.21	0.19
RE_2O_3, %	2.60	3.06
Al_2O_3, %	45.4	44.8
APS, μm	91	91
ABD, g/cm^3	0.88	0.85
Unit cell size, Å	24.31	24.32
Microactivity, %	73.4	74.5
Coke factor	0.84	0.76
Ni, ppm	120	103
V, ppm	342	265

The conversion was estimated as 100-LCO-HCO-Slurry, wt.%

Where, LCO = light cycle oil yield, wt.%; HCO = heavy cycle oil yield, wt.%; and Slurry = slurry oil yield, wt.%. The main technical and technological problems in the LNB FCCU before the revamp were:

- High catalyst losses;
- Increased APS of equilibrium catalyst (from 90 to 108 μm). Reduction in the content of the catalyst working fraction (20–80 μm decreasing from 39 to 19%) in the catalyst composition [36];
- High temperatures in the regenerator [34];
- Shortage of regeneration air;
- Unsatisfactory condition of reactor and regenerator lining of internals;
- Exhausted service life of internal devices.
- Loss of conversion;
- Low yields of target products (gasoline, BBF, PPF, LCO);
- High olefin content in FCC gasoline;
- Increased catalyst Δ coke;
- Low catalyst circulation;
- Unstable Δp of regenerated and spent catalyst valves at high throughput.

To limit the negative effects of a degraded feedstock quality, the FCCU operated at a load of 240 t/h (design capacity, 250 t/h) [34].

In late 2021, a revamp of the FCCU was carried out, the main objectives of which were:

- Adaptation of the FCCU to the processing of heavier vacuum gas oils from H-Oil;
- Increasing the mechanical reliability of the equipment by replacing the internal devices in the reactor and regenerator, which were significantly depreciated with expired service life.
- Reducing catalyst losses from the reactor and regenerator cyclone systems. Improvement in the environmental situation.

In our earlier research [37], a process diagram of the whole LNB FCCU is presented. During the revamp, only the FCC reactor–regenerator section was modified. The modifications of the reactor–regenerator section made during the revamp are presented in Figure 2.

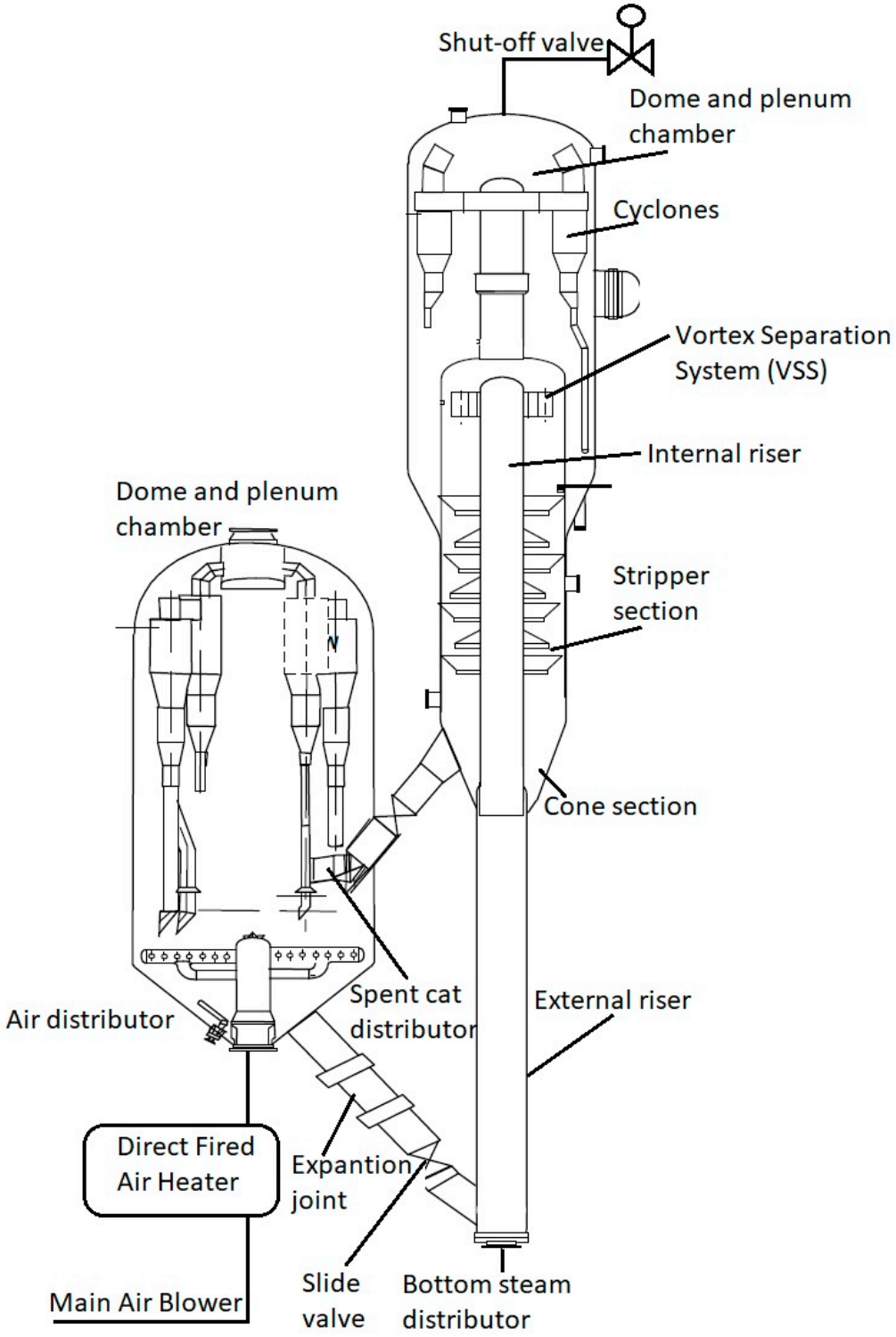


Figure 2. A diagram of reactor–regenerator section of the FCC unit, whose parts shown with inscriptions were revamped.

3. Results

3.1. Modifications of the FCC Reactor–Regenerator Section Performed during the Revamp

During the revamp carried out in late 2021, the following scope of modifications was implemented:

For the FCC rector P-201 (Figure 2):

- Replacement of the separator at the end of the riser (VSS = vortex separation system);

- Replacement of riser and reactor inner and outer liner, U-shaped section, and reactor plenum;
- Replacement of feed nozzles;
- Replacement of the cyclone system in the reactor including the upper plenum and the VSS chamber;
- Replacement of the internal components and devices of the reactor stripping section (AF Packing™ was used to fill the reactor section);
- Replacement of the steam distributors which were adapted to the internal devices of the stripper section in the reactor;
- Installation of an isolation gate on the transfer line between the reactor and the main fractionation column in the plant and a new reactor vent valve;
- Replacement of spent and regenerated catalyst transfer lines and installation of new valves to regulate catalyst flow rates between the reactor and regenerator;
- Installation of new instrumentation and adaptation of existing instrumentation.

For regenerator P-202 (Figure 2):

- Replacement of the air distributor;
- Replacement of the regenerator bottom cone;
- Replacement of the cyclone system in the regenerator and installation of a new upper bottom and a new collection chamber;
- Installation of a new distributor for the spent catalyst flowing from the reactor (P-201) into the regenerator (P-202);
- New extraction system for the regenerated catalyst;
- Replacement of liquid fuel injectors (LFI);
- Installation of new instrumentation and adaptation of existing instrumentation.
- Supply and installation of a new air compressor:
- Installation of a new air compressor, CC-202, and connection of the latter to the technological scheme of the installation.
- Construction of a new air line to the spent catalyst distributor in the regenerator.
- Installation of control system for the direct fired air heater (DFAH)-P-201:
- Replacement of the main and pilot burners of the DFAH;
- Installation of new instrumentation and construction of an automatic control system for the combustion process.

3.2. Performance of the FCC Unit before and after the Revamp

The H-Oil gas oils are heavier, with higher aromatic and nitrogen contents, which makes them more difficult to crack, and produce more coke during fluid catalytic cracking than the straight-run hydrotreated vacuum gas oils [38,39]. Table 3 exemplifies the difference in the reactivities of the straight-run VGO and the H-Oil gas oils: HAGO, LVGO, and HVGO obtained on the base of laboratory ACE (advanced cracking equipment) unit operating at 527 °C, with 30 s time on stream, and a catalyst-to-oil ratio = 7.5 wt.

Table 3. Conversion of SRHTVGO, H-Oil HAGO, LVGO, and HVGO obtained in a laboratory ACE unit during the use of catalyst G. The quality of the cracked gas oils was identical to that shown in Table 1.

Gas Oils	Conversion, wt.%	Coke Yield, wt.%
SRHTVGO	77.8	3.7
H-Oil HAGO	58.7	5.0
H-Oil LVGO	53.4	5.8
H-Oil HVGO	58.5	8.6

Their quality is a function of the H-Oil reaction temperature, H-Oil throughput, the content of FCC slurry oil (SLO) in the H-Oil feed, and the content of the recycling in the H-Oil feed [40]. The H-Oil LVGO is the most difficult to crack, probably because it has

the highest nitrogen content, aromatic carbon content, and lowest Kw-characterization factor (see Table 1) [28,33,41]. The H-Oil HVGO is the most coke-producing gas oil, probably because it contains the highest level of heavy higher-molecular-weight poly-nuclear aromatic hydrocarbons [28,33,41]. The average content of HAGO, LVGO, and HVGO in H-Oil VGO for the 178 studied cases was 19%, 27%, and 54%, respectively, with a variation in HAGO between 5 and 33%; LVGO between 15 and 43%; and HVGO between 36 and 74%. The content of H-Oil VGO in the FCC feed varied between 17 and 37% [39]. As a result of processing, the higher coke made the H-Oil VGO catalyst losses vary between 2.4 and 8.1 t/d before the revamp in 2021, as shown in Figure 3. After the revamp, they fell to 0.9 t/d (Figure 3). The average particle size (APS) of the equilibrium catalyst (E-Cat) increased from 90 to 114 µm from the maintenance turnaround in 2018 until the next turnaround in 2021, which coincided with the FCCU revamp (Figure 4). After the revamp, the APS of E-Cat decreased to the normal level of 90 µm (Figure 4). Having in mind that the catalyst losses affect the content of the working fraction of the catalyst (0–80 µm) and, hence, the catalyst age distribution and activity [35], we decided to compare the LNB FCCU performance at normal catalyst losses before and after the revamp. In this way, the effect of modifications made in the reactor and regenerator section on the FCC unit performance could be evaluated. Table 4 presents data of the operation of the LNB FCCU before and after the revamp.

Table 4. LNB FCCU performance before and after the revamp.

Date	10 September–11 September 2018 before Revamp	11 September–13 September 2022 after Revamp	2 October–3 October 2022 after Revamp
FCC Operating conditions			
Straight-run VGO flow rate, t/h	205	222	225
FCCPT trough-put, t/h	225	200	230
H-Oil VGO in FCCPT feed, wt %	20	0	5
FCCPT Feed density at 15 °C, g/cm^3	0.915	0.9227	0.9198
5%, °C	344	354	350
10%, °C	367	373	369
50%, °C	442	445	444
90%, °C	518	522	520
95%, °C	532	539	537
Kw	**11.89**	**11.81**	**11.84**
Sulphur, %	1.98	N.D.	N.D.
Concarbon, % m/m	0.48	0.26	0.18
HTVGO flow rate, t/h	203	172	203
HTVGO density at 15 °C, g/cm^3	0.906	0.903	0.896
Δ Density, kg/m^3	**9**	**21**	**23.8**
Kw	**12.05**	**12.06**	**12.15**
Sulphur, %	0.192	0.102	0.14
H-Oil VGO flow rate, t/h	52	78	47
H-Oil VGO in the blend HTVGO-H-Oil VGO, wt %	27.5	31.2	18.8
H-Oil VGO density at 15 °C, g/cm^3	0.9273	0.9526	0.9403
5%, °C	330	300	296
10%, °C	353	324	322
50%, °C	422	397	395
90%, °C	494	497	474
95%, °C	517	523	504
Kw	**11.62**	**11.17**	**11.31**
Sulphur, %	0.624	0.622	0.366
Concarbon, % m/m	0.15	0.21	0.11
FCC feed flow rate, t/h	255	250	250
FCC slurry in FCC feed, %	0	0	0

Table 4. *Cont.*

Date	10 September–11 September 2018 before Revamp	11 September–13 September 2022 after Revamp	2 October–3 October 2022 after Revamp
H-Oil VGO in FCC feed (coming from FCCPT and directly in FCCU), %	27.5	31.2	18.8
FCC feed density at 15 °C, g/cm^3	0.9105	0.9157	0.9119
5%, °C	368	337	348
10%, °C	388	359	368
50%, °C	442	434	442
90%, °C	501	514	519
95%, °C	519	533	537
Kw	**11.95**	**11.84**	**11.93**
Sulphur, %	0.254	0.281	0.19
Concarbon, % m/m	0.14	0.14	0.26
Reactor temperature, °C	**535**	**550**	**543**
Combined feed temperature, °C	308	307	323
Regenerator dense bed temperature, °C	694	704	710
Regenerator dilute phase temperature, °C	708	710	718
Air, kNm^3/h	124,480	136,745	138,034
CTO wt/wt,	6.60	8.5	7.3
Heat of reaction kJ/kg feed	309	412.2	470
Hydrogen in coke, %	8.5	6.3	7.2
Δ Coke, %	**0.63**	**0.59**	**0.65**
TOS, s	2.2	2.1	2.1
Yields on fresh feed basis, wt%			
C2	3.62	6.4	5.42
C3	6.61	6.39	7.1
C4	10.8	10.89	11.85
C5+ Gasoline (corrected to $T_{90\%}$ = 170 °C)	47.2	45.1	47.1
LCO	10.13	7.6	8.54
HCO	10.4	9.0	8.92
Slurry	6.34	8.13	6.85
Coke	4.18	4.96	4.72
Conversion	73.2	73.1	75.7
C3 = in PPF, vol, %	81.1	81.9	81.5
iC4 in BBF, vol, %	31.5	30.0	31.9
iC4 = in BBF, vol, %	16.2	17.1	15.6
C4 = in BBF, vol, %	59.4	61.8	59.1
FCC gasoline properties			
Density at 15 °C, kg/m^3	739.5	738.4	738.1
IBP, °C	36	34.3	34.9
10%, °C	52	50	51.8
50%, °C	92	86.9	88.9
90%, °C	167	163.5	167.1
FBP, °C	199	200.3	204.2
RON	93.6	94.4	94.2
RVP, kPa		58.9	54.9
Sulphur content, ppm	144	134	94
MON	81.8	82.5	82.6
LCO Properties			
Density at 15 °C, kg/m^3	928.4	934.1	926.9
IBP, °C	209	186	183
10%, °C	213	204	204
50%, °C	237	241	239
90%, °C	272	273	267
FBP, °C	304	299	306
Kw	10.56	10.57	10.57

Table 4. *Cont.*

Date	10.9–11 September 2018 Before Revamp	11.9–13 September 2022 After Revamp	2.10–3.10.2022 After Revamp
HCO Properties			
Density at 15 °C, kg/m^3	1021.1	1045	
IBP, °C		288	
10%, °C		320	
50%, °C		350	
90%, °C		387	
FBP, °C		409	
Kw		9.94	
Sulphur, wt,%	0.815	0.946	

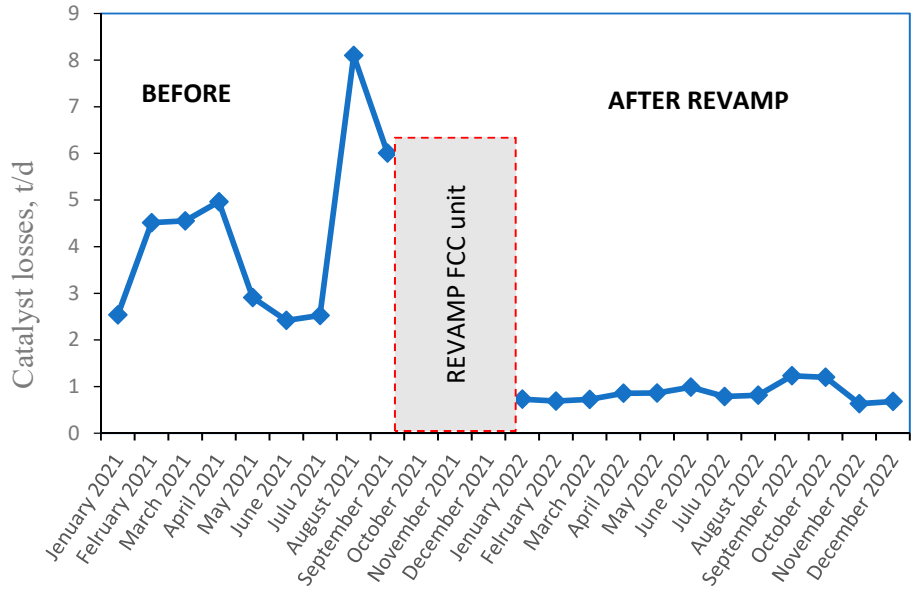


Figure 3. Variation in catalyst losses before and after the revamp of the LNB FCCU.

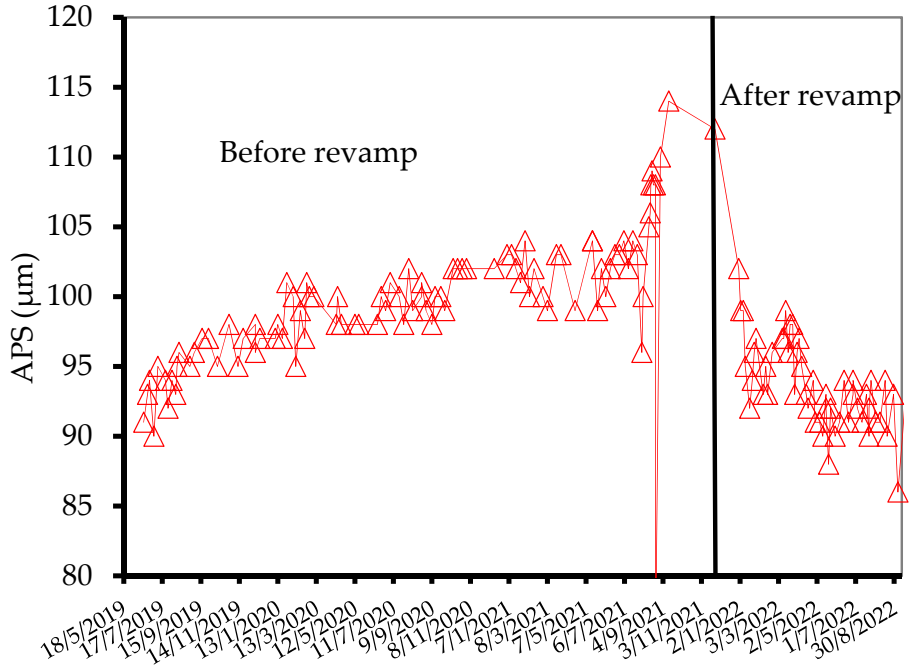


Figure 4. Variation in average particle size (APS) of E-Cat before and after the revamp.

4. Discussion

4.1. Effects of Performed Revamp on the Operation of the FCC Unit

As a result of the performed revamp of the reactor–regeneration section, the following effects were observed:

- Increasing riser outlet temperature from 540 to 550 °C;
- Increasing maximum allowable regenerator temperature from 705 to 730 °C;
- Decreasing afterburning (ΔT between TRG_{dilute}–TRG_{dense}) from 12 to 6 °C;
- Reduction in NOx emissions in the flue gas from 250 to 160 mg/Nm^3;
- Improvement in catalyst regeneration (coke on the regenerated catalyst before revamp = 0.18 wt.%; after revamp = 0.12 wt.%);
- Reduction in catalyst losses from average losses of 4.28 t/d (0.89 kg/t feed) in 2021 before the revamp to 0.85 t/d (0.0142 kg/t feed) in 2022 after the revamp
- Improved catalyst circulation at higher throughput (lower fluctuations in ΔP of regenerated and spent catalyst valves);

Before the revamp in 2021, the LNB FCCU was not in position to run at a capacity higher than 200 t/h because the catalyst losses were increasing linearly with throughput magnification [35], while after the revamp, it ran smoothly and was trouble-free at a capacity of 250 t/h.

4.2. Performance of the FCC Unit before and after the Revamp

By processing the data from the commercial LNB FCCU after the revamp, the variation in the content of H-Oil HAGO, LVGO, and HVGO in the H-Oil VGO blend was as follows:

17.8 wt.% ≤ HAGO ≤ 33.2 wt.%; 19.7 wt.% ≤ LVGO ≤ 37.5 wt.%; 36.1 wt.% ≤ LVGO ≤ 57.2 wt.%; and the H-Oil VGO blend content in the FCC feed varied between 15.7 wt.% and 34.5 wt.%. The following multiple regression was developed:

$$\begin{gathered}\text{LNB FCCU conversion} = 8.8 + 0.1212 \times \text{Riser Temperature} \\ +0.5873 \times \text{Catalyst to oil ratio}\left(\frac{\text{kg}}{\text{kg}}\right) - 0.0756 \times \text{Content of HAGO in FCC feed, \%} \\ -0.2215 \times \text{Content of LVGO in FCC feed, \%} \\ -0.1093 \times \text{Content of HVGO in FCC feed, \%} \quad R = 0.875, \text{ abs. rel. error} = 0.8\%\end{gathered} \tag{1}$$

Figure 5 shows the parity graph of the estimated versus observed conversion. This data shows a very good agreement between observed conversion and that predicted by Equation (1), keeping in mind that this is commercial data, where the noise of the data is relatively high. Equation (1) indicates that the commercial FCCU data confirms the H-Oil gas oil reactivity data (see the data in Table 3) obtained in the laboratory ACE unit, showing that the least reactive H-Oil gas oil is LVGO. The data in Table 3, and that shown in Figure 1, suggest that the most appropriate catalyst to process the heavier gas oils from H-Oil is that possessing both the highest activity and the lowest coke selectivity.

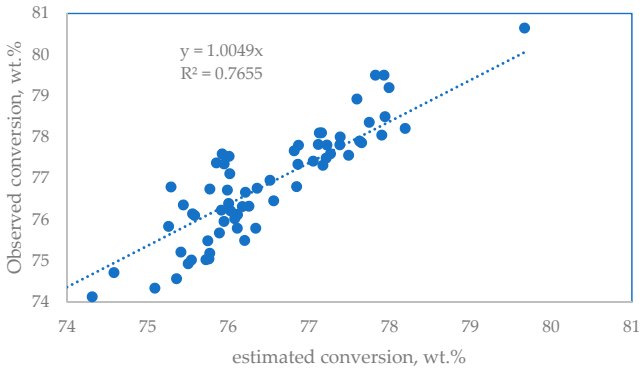


Figure 5. Parity graph of conversion estimated by Equation (1) versus observed conversion at the LNB FCCU.

The data in Table 4 shows that the H-Oil VGO suppresses hydrogenation in the FCC feed hydrotreater (pretreater = FCCPT). This is evident from the lower density reduction in the hydrotreated VGO (9 kg/m^3 at 8.9% H-Oil VGO content in the FCCPT feed) than that during processing only straight-run VGO (21 kg/m^3 at zero content of H-Oil VGO in the FCCPT feed). The data in Table 4 also indicate that the quality and quantity of the H-Oil VGO in the FCC feed for the three studied cases are different. The highest share in the FCC feed and the lowest Kw-characterization factor of the H-Oil VGO was observed for Case: 11–13 September 2022 (after FCC revamp). The FCC feed for this case was also characterized by the lowest Kw-characterization factor. This means that the feed for this case is the most refractory among the studied three cases. Considering the relation of FCC feed containing H-Oil VGO established in our earlier research [28] and shown in Equation (2):

$$Conversion = 0.1787 \times e^{0.5013Kw} \quad R = 0.99, \text{ av. error} = 1.7\% \tag{2}$$

The estimated conversions which reflect FCC feed reactivity are as follows:

- Case: 10 September –11 September 2018 (before revamp) = 71.2 wt.% estimated conversion;
- Case: 11 September –13 September 2022 (after revamp) = 67.3 wt.% estimated conversion;
- Case 2.10–3.10.2022 (after revamp) = 70.4 wt.% estimated conversion.

These data suggest that Case: 11 September –13 September 2022 (after revamp) has the lowest reactivity feed, while the other two cases have the same reactivity feeds (the difference between estimated conversions is 1.1%, which is lower than the error of prediction of Equation (2)). Despite the poor quality of the feed for the Case: 11 September –13 September 2022 (after the revamp), it demonstrated the same conversion level as that observed in Case: 10 September –11 September 2018 (before revamp). Comparing the cases which have the same quality of FCC feed, Case: 10 September –11 September 2018 (before the revamp) and Case 2.10–3.10.2022 (after the revamp), one can see that the case after the revamp registered a 2.5 wt.% higher conversion. Another big advantage of the revamp is the higher octane number of the gasoline (+0.8 points for both RON and MON).

Concerning the olefinicity of the PPF and BBF, the revamp does not affect it, showing the same propylene content in the PPF, and the same content of C4 olefins in the BBF.

The quality of the E-Cat after the revamp in terms of micro-activity shows stabilization with a slight tendency to increase from 73.4 to 74.5% with the replacement of the lower-activity catalyst G with the higher-activity catalyst H (Figure 6). Before the revamp the micro-activity of E-Cat varied across a very wide range (between 61 and 76%), which was caused by the higher catalyst losses, and the resulting higher catalyst addition rate, and the retention in the inventory of the more aged catalyst with a lower content of the working fraction 0–80 µm.

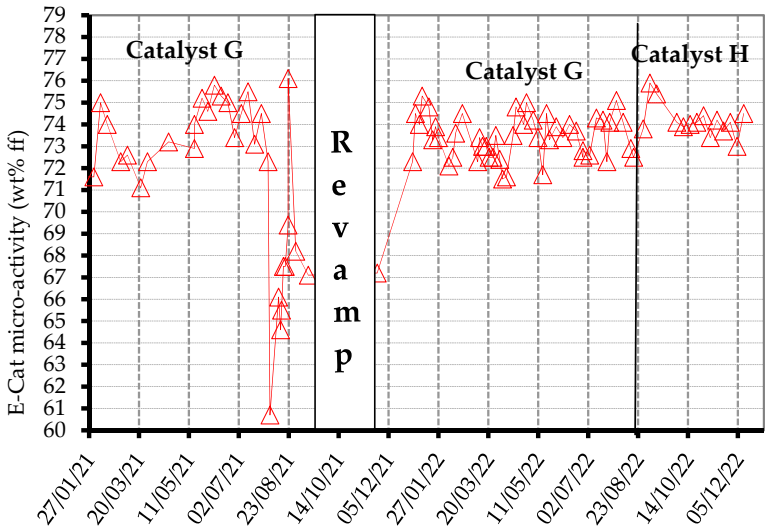


Figure 6. Micro-activity of E-Cat variation in time before and after the revamp.

5. Conclusions

The processing of heavier H-Oil gas oils in FCC is associated with conversion reduction and coke-made augmentation. Thus, a higher activity catalyst with lower coke selectivity can deliver a higher conversion of feeds containing H-Oil gas oils. The finding that H-Oil LVGO is the least reactive H-Oil gas oil observed in a laboratory FCC ACE unit was confirmed during processing of the H-Oil VGO blend consisting of HAGO, LVGO, and HVGO in the commercial FCCU.

The revamp of the LNB FCCU performed in late 2021 allowed an increase in riser outlet temperature from 532 to 550 °C; an increase in maximum allowable regenerator temperature from 705 to 730 °C; a decrease in afterburning from 12 to 6 °C; a decrease in NOx emissions in the flue gas from 250 to 160 mg/Nm^3; an improvement in catalyst regeneration; a decrease in catalyst losses to 0.0142 kg/t of feed; and improved catalyst circulation at a higher throughput.

The experience gained during the processing of H-Oil gas oils in both laboratory and commercial FCC units has shown that a commercial FCC unit which is intended to process H-Oil vacuum gas oils with different quantity and quality badly needs a revamp. The revamp should consist of modifications of internal parts in both the reactor and regenerator to guarantee good catalyst regeneration, retention in the inventory, and higher catalyst circulation, to provide a higher vacuum gas oil conversion. A future investigation in this area is directed to increasing the propylene yield by selecting a proper catalyst and additives, and the modification of the main fractionator and vapor recovery unit while processing feeds containing H-Oil gas oils.

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Nomenclature

ACE	Advanced cracking evaluation
APS	Average particle size of FCC catalyst
BBF	Butane-butylene fraction
C2-	Yield of dry gas, wt.%
C3	Yield of propane-propylene fraction, wt.%
C3=	Propylene
C4=	Butylenes
C4	Yield of butane-butylene fraction, wt.%
CTO	Catalyst-to-oil ratio, *wt./wt.*
DHAH	Direct heating air heater
E-Cat	Equilibrium catalyst
FBP	Final boiling point
FCC	Fluid catalytic cracking
FCCPT	Fluid catalytic cracking pretreater (feed hydrotreater)
FCCU	Fluid catalytic cracking unit
HAGO	Heavy atmospheric gas oil
HCO	Heavy cycle oil
HTVGO	Hydrotreated vacuum gas oil
HVGO	Heavy vacuum gas oil

IBP	Initial boiling point
iC4=	Iso-butylene
iC4	Iso-butane
Kw	Characterization Watson factor
LCO	Light cycle oil
LFI	Liquid fuel injector
LNB	LUKOIL Neftohim Burgas
LVGO	Light vacuum gas oil
MON	Motor octane number
PPF	Propane-propylene fraction
RON	Research octane number
RVP	Reid vapour pressure
SRHTVGO	Straight-run hydrotreated vacuum gas oil
TOS	Time on stream
VGO	Vacuum gas oil

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