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Industrial investigation on feasibility to raise near zero sulfur diesel production by increasing fluid catalytic cracking light cycle oil production

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ABSTRACT

Evaluation of opportunity to raise Euro V diesel production by increasing fluid catalytic cracking (FCC) light cycle oil (LCO) production was carried at the Lukoil Neftochim Bourgas, Bulgaria (LNB) refinery. The FCC LCO (IBP-360 °C) production was investigated in the FCC conversion range between 69 and 83 wt.% and LCO initial boiling point (IBP) between 177 and 210 °C. It was found that the LCO yield increased from 16.0 up to 20.7 wt.% by decreasing conversion from 83 to 69 wt.%. At constant conversion in the FCC unit of 79.7 wt.% the LCO yield increased from 17.8 to 24.8 wt.% by decreasing the IBP from 210 to 177 °C. A further 3.5 wt.% LCO yield increase and meeting the diesel flash point specification of 55 °C can be achieved by lowering the LCO IBP down to 163 °C. It was found that during hydrotreatment of a blend of the LNB middle distillates and LCO in a high pressure (70 bars) hydrotreater employing Co-Mo catalyst the maximum LCO (IBP = 210; FBP = 300 °C) content that allows meeting the EN specifications is 10 wt.%. If the LCO IBP is reduced to 177 °C then the maximum LCO content in the feed can reach 20 wt.%. The limitation of density not higher than 0.845 g/cm^3 in the hydrotreated product at 15 °C is the restriction for further increase of LCO content in hydrotreater feed. Replacing the Co-Mo catalyst by Ni-Mo and noble metal catalysts in the high pressure hydrotreater can allow more than double increase of LCO content in hydrotreater feed. Hydrogen chemical consumption in that case, however is also more than twofold.

1. Introduction

The process of dieselization has a significant impact on the refining industry by distorting the traditional demand structure for transport fuels. Diesel demand is already much larger than gasoline globally [1]. The continual growth of diesel demand, especially in Western Europe, Asia and Latin America is driven by a number of factors: the superior economy and efficiency of diesel engines; advances in combustion systems and improvements in emission devices including filters for the removal of micro-particulates and NOx reduction systems [2]. The declining gasoline demand in North America, the main outlet for Europe's excess gasoline, adds a further challenge for the European refining. Most of Europe's oil refineries are more geared towards producing gasoline as the major conversion process is FCC. In this type of refinery configuration, diesel is mainly formulated from the straight run diesel (SRD) that is obtained from the crude unit, light cycle oil (LCO) produced by the FCC plant and other streams like hydro-cracker middle distillate, visbreaker or coker gas oil [3]. For a typical FCC based refinery the LCO is the main conversion gas oil that can be upgraded and used for production of near zero sulfur diesel. Unfortunately the FCC LCO is characterized by high density, high aromatics content, and low cetane [4–23]. LCO cetane ranges from 15 to 24, compared to 40–60 for the straight run distillates produced from the same crude [16]. The aromatics content of LCO from FCC units varies between 60 and 90% and therefore besides desulfurization dearomatization is also needed to make feasible blending of this stream into refinery automotive diesel pool [9]. Refiners are faced with two challenges: on one hand how to increase FCC LCO production; and on the other hand how to upgrade the increased quantity of this high density, high aromatics material to such an extent that can allow using this stream as a component for production of automotive diesel that meets specification of the European EN 590. There are several publications dealing with increasing LCO production from the FCC unit [1,24–31]. There are also several publications dealing with hydrotreatment and hydrocracking of FCC LCO [12–23]. However little is published about investigations carried out on commercial FCC and hydroprocessing units with the aim to boost production of automotive near zero sulfur diesel. The aim of this work is to fill this gap by investigating the opportunity of increasing LCO at the commercial Lukoil Neftochim Bourgas, Bulgaria (LNB) FCC unit by varying the operation conditions and gasoline cut points and hydroprocessing the LCO in a commercial high pressure hydrotreater.

2. Materials and methods

Commercial investigations were carried out on the LNB refinery. It is a FCC based refinery. Its processing scheme is presented on Fig. 1.

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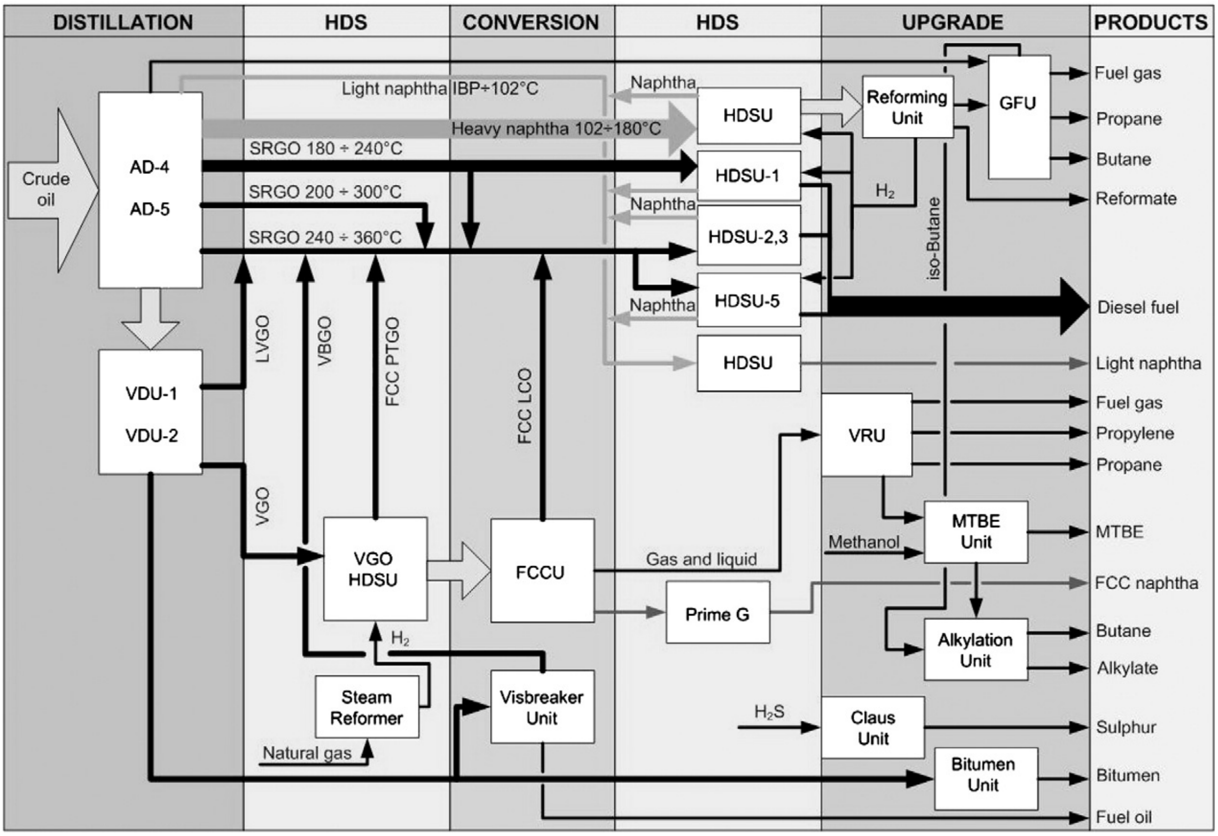

Fig. 1. Crude processing diagram of the Lukoil Neftochim Bourgas, Bulgaria refinery.

The typical LNB refinery feed is Ural crude (Russian Export Blend) and the properties of this crude oil are given in [32]. Experiments on the feasibility to increase LCO production were performed at the LNB FCC unit. More details about the LNB FCC unit are presented in [33]. Operating conditions at which the LNB FCC unit was studied are summarized in Table 1. Properties of FCC feed (hydrotreated vacuum gas oil from Ural crude oil) are given in [33]. Properties of equilibrium FCC catalyst employed in the study are given in Table 2.

Physical and chemical properties of middle distillates used as feed for the LNB hydrotreating units are given in Table 3. The operating conditions of the high pressure LNB hydrotreater HDS-5 under study are summarized in Table 4. Simplified diagram of the HDS-5 unit is presented on Fig. 2.

Table 1
Operating conditions in the LNB FCC unit under study.

Operating conditions	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Capacity, t/h	174	140	176	206	182	184
Residence time[a], s	3.3	3.8	3.1	2.5	2.7	2.4
Reactor temperature, °C	497	503	526	522	521	534
Combined feed temperature, °C	324	329	334	344	332	336
Regenerator dense bed temperature, °C	666	657	663	648	648	657
Regenerator dilute phase temperature, °C	688	680	690	665	664	669
Air, kNm^3/h	70.0	68.0	66.0	104.0	97.3	101.8
Combined feed ratio	1.00	1.00	1.00	1.06	1.06	1.02
Catalyst-to-oil ratio, wt./wt.	4.75	5.41	6.56	7.59	8.53	8.35
Delta coke[b], wt.%	0.63	0.62	0.49	0.50	0.49	0.49
Coke yield, wt.% [b]	2.99	3.32	3.22	3.58	3.9	4.03
Conversion (TBP = 215°C)	69.0	73.0	75.0	76.0	79.7	82.8

[a] The residence time was estimated based on the procedure described in ref. [37].
[b] Estimated from the FCC unit heat balance.

Density of the investigated middle distillates was measured in accordance with ASTM D-4052. Distillation characteristics of the middle distillates were measured in accordance with ASTM D-86. Cetane index of middle distillates was calculated based on data of density and distillation characteristics according to ASTM D-4737. Chemical hydrogen consumption in the process of hydrotreatment of middle distillates was estimated based on the correlation of Stratiev and Tzingov [34,35]. The FCC gasoline olefin content was measured in accordance with ASTM D1319 (FIA) method. The mono-, di- and tri aromatics in diesel were determined in accordance with ASTM D 6591.

3. Results and discussion

3.1. FCC Unit operating conditions impact on LCO yield and quality

Influence of operating conditions on yield distribution in the LNB FCC unit as can be seen from Table 1 was studied by varying riser outlet

Table 2
Physical and chemical properties of the commercial equilibrium FCC catalyst under study.

Chemical composition	
Al_2O_3,%	41.4
Na_2O,%	0.14
RE_2O_3,%	1.58
Fe, %	0.56
V, ppm	208
Ni, ppm	35
Physical properties	
Average particle size, μm	76
Apparent bulk density, g/ml	0.92
Surface area, g/m^2	141
Matrix surface area, g/m^2	49
Unit cell size, 10^{-9} m	2.427
MAT conversion,%	73