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New process arrangements for upgrading of heavy oils and residua

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ABSTRACT

In this paper we report the results of integration of residue fluid catalytic cracking (RFCC) and hydrocracking (HCR) units with a hydroconverting plant (HRH) in a crude oil refinery was studied. Initially, a target refinery with available HCR and RFCC units was simulated using Hysys-refinery simulator, and then HRH unit was added to this complex. After validating the wide plant simulator using actual and design data, four integration strategies were examined to increase the yields of gasoline and diesel. These cases named Simple series, Series, Parallel and Residue upgrading were compared to the base (designed) one. The results showed that by implementing the mentioned cases, the production yields of gasoline and diesel would increase considerably. For the best case i.e., residue upgrading strategy, the yields of gasoline and diesel would increase to 6.98% and 53.96%, respectively in comparison to the base case. Moreover, with the presented integration strategies, without any changes in the operating conditions, the bottom of barrel could be minimized while fresh feed flowrates and their impurities remained constant.

KEYWORDS

Integration;
Hydroconversion;
Residue upgrading;
Hysys-refinery;
RFCC;
HCR.

INTRODUCTION

The market demand for heavy petroleum products such as heavy oil will decline while the demand for lighter products such as gasoline and diesel is expected to increase. The projections of the demand for the refined products indicate that middle distillates, i.e., diesel fuel and jet fuel, grow at the highest rate. Diesel fuel demand was projected to grow by 2 % per year worldwide[1]. In many countries the need for gasoline is a crucial subject; so, any improvement in the refinery process to increase the yield of these products is appreciable.

Hydrocracking (HCR) and residue fluid catalytic cracking (RFCC) are the major processes to produce diesel and gasoline respectively. Moreover, hydroconverting processes such as hydroconversion (HRH)[2] can be utilized to convert residue and heavy cuts to lighter products.

To study the synergy of these units, a process simulator can be applied before implementing any arrangement or integration in an industrial scale plant i.e., a commercial crude oil refinery. Hysys-refinery is a simulation tool commercialized by KBC Advanced Technologies, and AEA Technology-Hyprotech. This simulator has made significant advances in detailed representation of reactor sections. Mohaddecy and Sadighi[3] have demonstrated the ability of this software for simulating the HCR and catalytic reforming units. Lee[4] applied Hysys-refinery software to study the integration of FCC and Hydrotreating units. The research was conducted in two steps. First the simulation and calibration of these units was carried out, and then the integration was performed. The results revealed that increasing the hydrotreating severity decreased the production of SO_x and NO_x in FCC unit. Additionally, Dean et al.[5] integrated FCC and HCR units to improve the conversion of residue to more valuable products in the gasoline range. FCC unit was assumed as the upstream unit and products above the gasoline boiling range were sent to the HCR unit. HCR offtest stream was fed to FCC and the FCC cycle oil was desulfurized and cracked. The simulated integration scheme resulted in 60% reduction of hydrogen consumption. Furthermore, in this field, Tallman et al.[6] integrated FCC with thermal cracking unit to maximize the ethylene and propylene production.

In this paper, initially a target refinery with HCR and RFCC units was simulated using the HCR-sim and FCC-sim modules, available in Hysys-refinery simulator. For the sake of validation, actual and design data were obtained for HCR and RFCC units, respectively; then, the HRH plant was introduced. Finally, keeping constant the quality and flowrate of the HCR and RFCC feedstocks, all units were integrated by various strategies to increase the yields of diesel and gasoline.

PROCESS DESCRIPTION

Hydroconversion unit

The hydroconverting unit used in this research (HRH) is a liquid phase mild hydrogenation (at 60-100 atm and 400-500^{o}C) process for upgrading extra-heavy oil which alternatively could be used as feedstock for refineries[7]. The main objective of this process is the breakup of high molecular weight hydrocarbons to light and medium molecular weight products. This process is a novel method of upgrading heavy residue to lighter products in which two types of reactions, namely, cracking and mild hydrogenation occurs simultaneously. The hydrogenation and operating conditions allow higher conversion with minimized coke formation and polymerization (<0.2% wt). HRH process has high flexibility with regards to the type of feed and the amounts of sulfur and heavy metal contents in the feed. Additionally, it can eliminate all the heavy metals and almost fifty percent of sulfur components in the feed. The main products of HRH are gasoline, diesel and FCC feed stock, and the designed yields for these cuts are 20, 39.6 and 30 wt% respectively on the basis of the fresh feed.

Base case

The base case arrangement takes vacuum gas oil (VGO) from vacuum distillation tower as HCR fresh feed, and combined it with recycle stream coming from the bottom of HCR fractionation tower. The RFCC feed is composed of light vacuum gas oil (LVGO), heavy vacuum slops (HVS), heavy gas oil (HGO) and treated residue (TR). The latter is the product of vacuum residue hydrotreating plant which removes sulfur and metallic impurities; thus, it makes TR a suitable feed for the RFCC unit. In particular, unlike hydrotreating, RFCC redistributes sulfur into its products. Consequently, in all integration strategies, the quality of RFCC feedstock has been kept the same as in the base case. The block diagram and flow rates of the base case are shown in Figure 1 and TABLE 1, respectively. Both units has been simulated, calibrated and validated using the actual data obtained from the target refinery[8,9].

INTEGRATION OF RFCC, HCR AND HRH UNITS

Four case studies for the integration of the RFCC, HCR and HRH units have been surveyed. The main objective of integration is to increase the yield of gasoline whilst maintaining feed specifications of the RFCC and HCR units the same as in the base case. The HRH unit, utilized for this research, is flexible towards variation of feed quality; therefore, the variation in the feed specification is deemed not important for this unit.

Simple series integration

The block diagram and feed flow rates of simple series integration strategy are shown in Figure 2 and TABLE 2, respectively. The feed and product properties for HCR were the same as in the base case. The HRH unit takes the HCR offtest stream and the RFCC's clarified slurry oil (CSO) as feed. The RFCC recieves the LVGO, HVS, TR and HGO as feedstock.

Series integration

The block diagram, feed and product flow rates of series integration strategy are shown in Figure 3 and

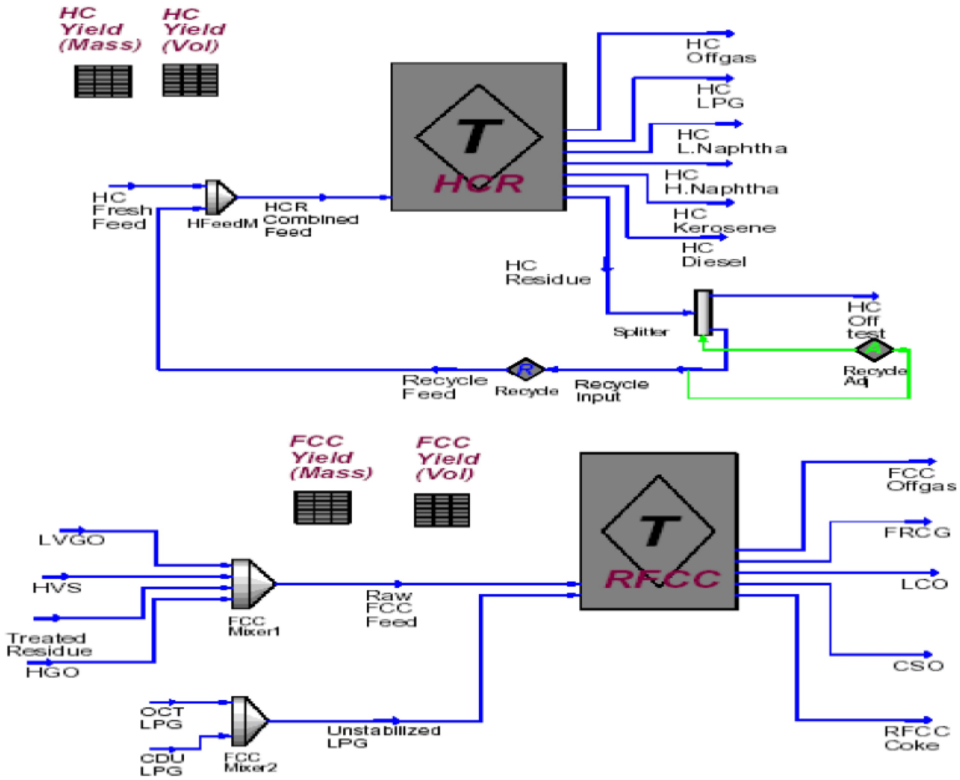

Figure 1 : Arrangement of units and streams in the base case

TABLE 3, respectively. The feed and product properties for HCR were the same as the base case. The HRH unit takes some TR as well as the CSO, and the RFCC unit takes the HCR offtest. The advantage of this strategy over the simple series is the direct feeding of residue into the HRH unit. In cases of deep catalyst deactivation or complete shutdown occurring in the residue treatment unit, the flow of untreated residue can be redirected to the HRH unit. So, this unit is capable of removing heavy sulfur and metallic compounds.

Parallel integration

The block flow diagram and feed flow rates of parallel integration strategy are shown in Figure 4 and TABLE 4, respectively. The HCR unit takes some LVGO as feed, and the RFCC takes some HCR offtest stream instead.

TABLE 1 : Feed flowrates in base case

HCR Feed Flowrate		
Fresh Feed Rate	BPD	24090
HCR Recycle	BPD	13150
RFCC Feed Flowrate		
LVGO	BPD	10430
HVS	BPD	9568
Treated Residue	BPD	60860
HGO	BPD	5344

TABLE 2 : Feed flowrates of HRH and RFCC in simple series strategy

HRH Feed Flowrate		
HCR offtest	BPD	674.3
CSO	BPD	8951
RFCC Feed Flowrate		
LVGO	BPD	5344
HVS	BPD	10430
Treated Residue	BPD	60860
HGO	BPD	9568

TABLE 3 : Feed flowrates of HRH and RFCC in series strategy

RFCC Feed Flowrate		
LVGO	BPD	10430
HVS	BPD	9568
TR	BPD	60100
HGO	BPD	5344
HCR offtest	BPD	758.7
HRH Feed Flowrate		
TR	BPD	754.3
CSO	BPD	8927

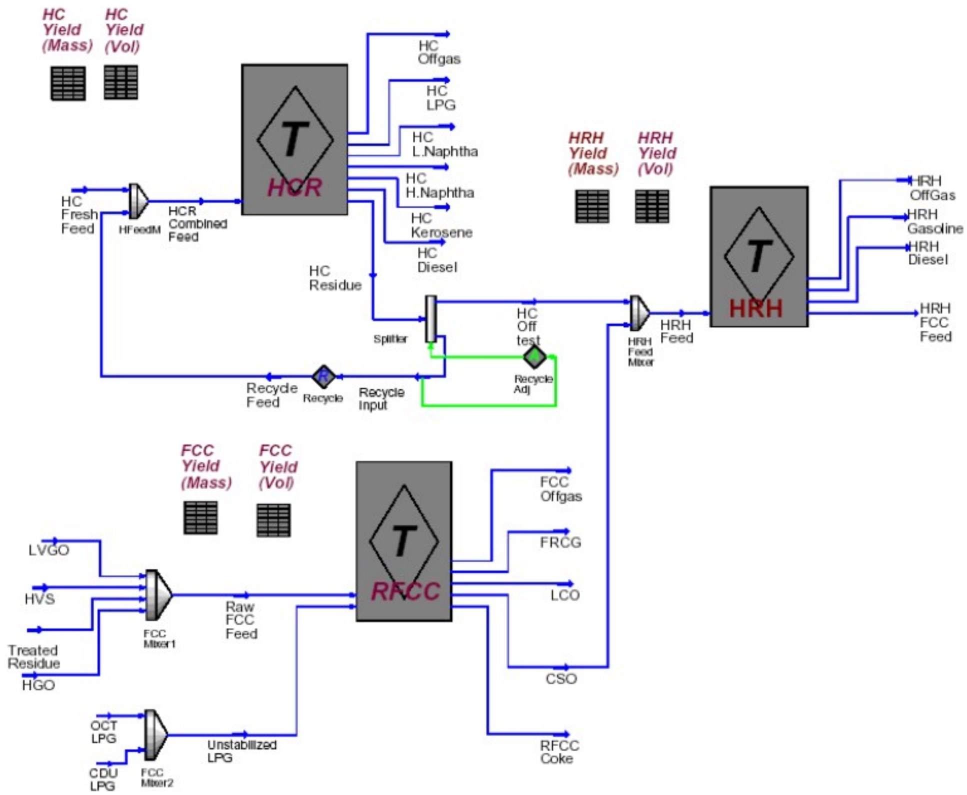

Figure 2 : Arrangement of units and streams in the simple series strateg

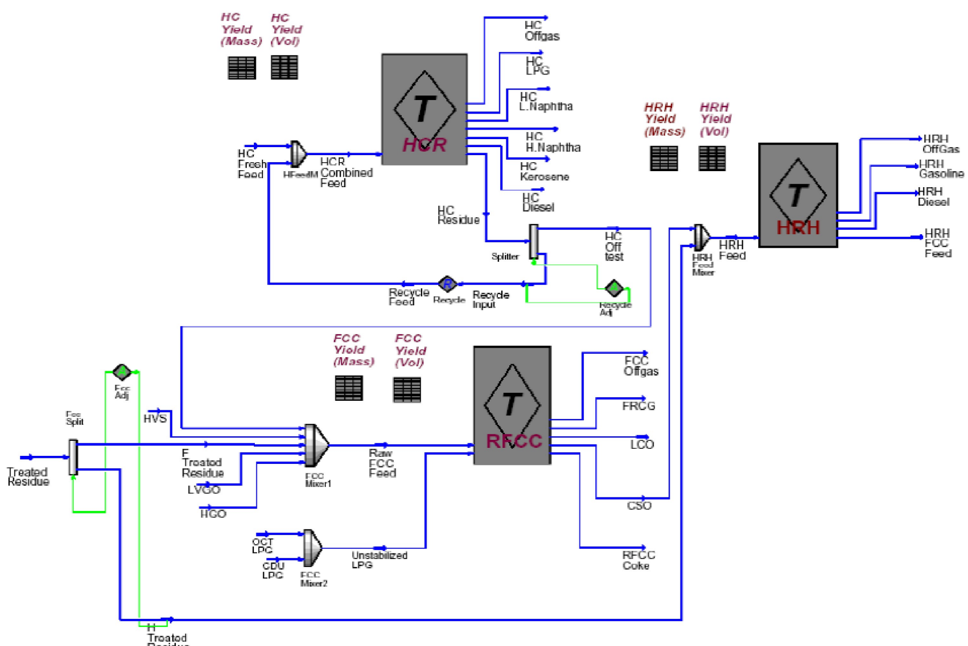

Figure 3 : Arrangement of units and streams in the series strategy

Residue upgrading integration

The block flow diagram and feed flow rates of residue upgrading strategy are shown in Figure 5 and TABLE 5, respectively. The feed for HCR were the same as the parallel case.

RESULTS AND DISCUSSION

The HRH unit yields valuable lighter products with lower sulfur and metallic impurities. It has been demonstrated that optimum integration of HRH with HCR and

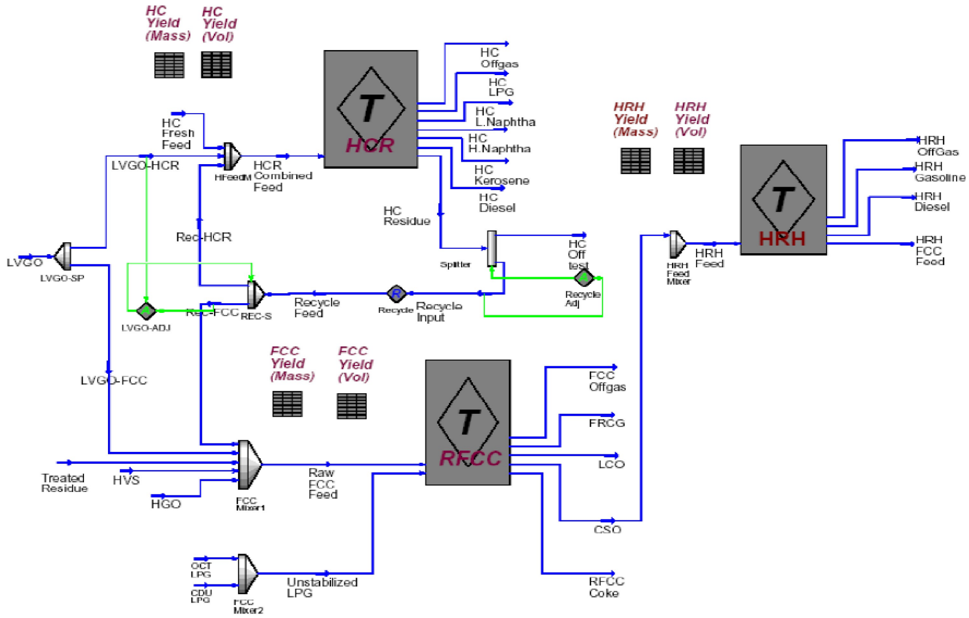

Figure 4 : Arrangement of units and streams in the parallel strategy

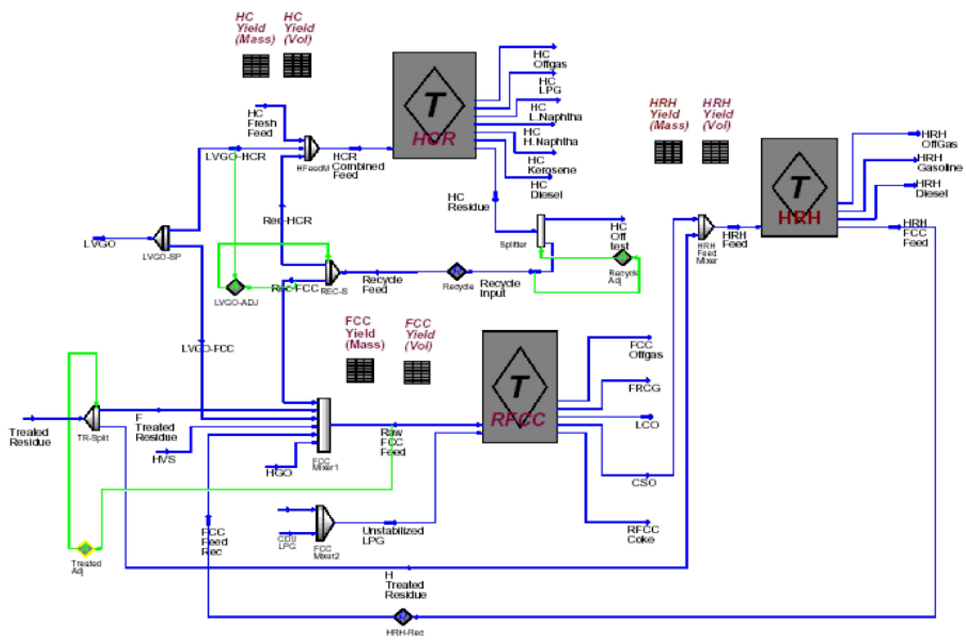

Figure 5 : Arrangement of units and streams in the residue upgrading strategy

RFCC units can lead to the production of the highest amount of gasoline and diesel. Four integration schemes consisting of Series, Simple series, Parallel and Residue upgrading strategies were studied using the Hysys-refinery simulator. Figures 6 and 7 show the percentage increase of gasoline and diesel yields with respect to the base case for the presented integration strategies. The gasoline production yield reported in Figure 6 is the sum of light and heavy naphtha from the HCR, full ranged cracked gasoline (FRCG) from RFCC unit and gasoline from HRH; the diesel yield is the sum of HCR and HRH diesel streams. It can be seen that the Residue upgrading strategy produces the highest amount of gasoline and diesel in comparison to the base case. In this strategy, all of the HRH-RFCC feed is sent to the RFCC and also all of the CSO and the HCR offtest are fed to the HRH. Consequently, in this scheme all the residue streams are effectively utilized. Due to the operating conditions prevalent in the HRH, this unit is geared. Therefore, after comparing the presented scenarios, we can conclude that implementing of HRH unit in the target oil refinery can lead the complex to higher

TABLE 4 : Feed flowrates of HCR, RFCC and HRH in parallel strategy

HCR Feed Flowrate		
HCR Recycle	BPD	11530
LVGO	BPD	1690
RFCC Feed Flowrate		
LVGO	BPD	8741
HVS	BPD	9568
TR	BPD	60860
HGO	BPD	5344
HCR Offtest	BPD	1688
HRH Feed Flowrate		
TR	BPD	0
CSO	BPD	9021

diesel production.

TABLE 5 : Feed flowrates of RFCC and HRH in residue upgrading strategy

RFCC Feed Flowrate		
LVGO	BPD	8741
HRH FCC Feed	BPD	4660
HVS	BPD	9568
TR	BPD	56170
HGO	BPD	5344
HCR Offtest	BPD	1688
HRH Feed Flowrate		
TR	BPD	4686
CSO	BPD	8983

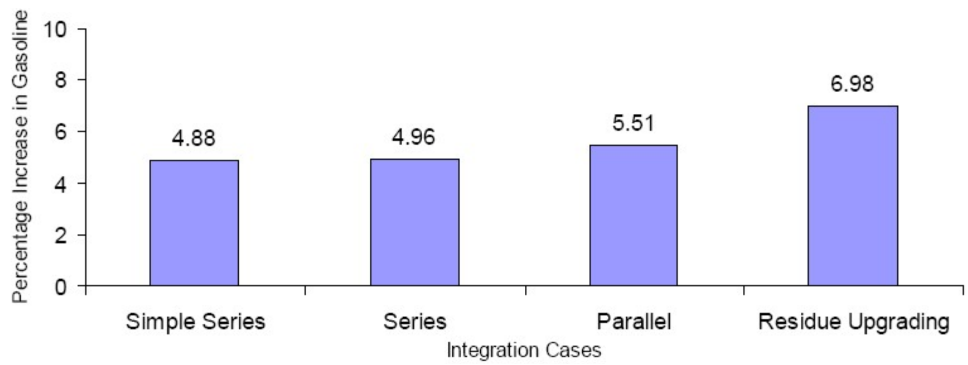

Figure 6 : The comparison of growth in gasoline production to base case

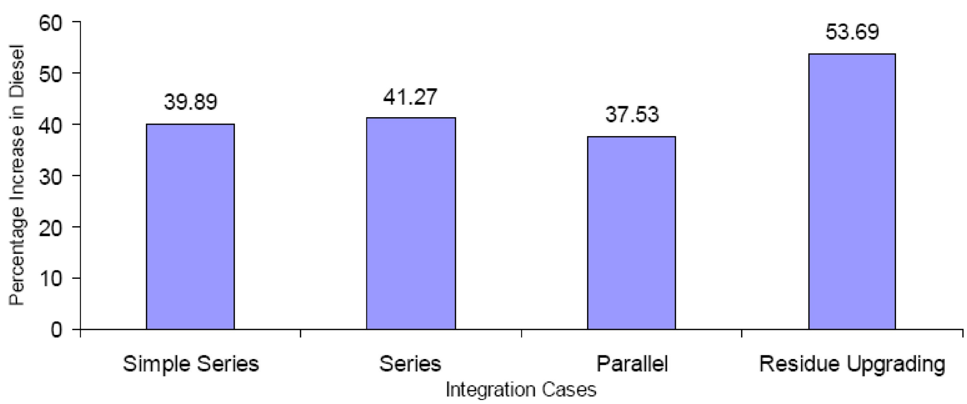

Figure 7 : The comparison of growth in diesel production to base case

TABLE 6 : Feed quality of HCR unit in base case and integration strategies

HCR Feed	Ni+ (ppmwt)	Sulfur (wt%)	IBP (^{0}C)	FBP (^{0}C)
Base	2.98	1.222	309	516.4
Simple Series	2.98	1.222	309	516.4
Series	2.98	1.222	309	516.4
Parallel	3.18	1.323	285.5	516.3
Residue Upgrading	3.18	1.323	285.5	516.3

TABLE 7 : Feed qualitiy of RFCC unit in base case and integration strategies

RFCC Feed	Ni+V (ppmwt)	Sulfur (wt%)	IBP (^{0}C)	FBP (^{0}C)
Base	14.723	1	264.6	592.6
Simple Series	14.723	1	264.6	592.6
Series	14.615	1.006	264.6	599.5
Parallel	14.874	0.9667	267.3	592.6
Residue Upgrading	13.734	1.088	267.3	592.1

Comparing Series, Simple series and Parallel strategies reveals that Parallel strategy produces the highest amount of gasoline and the least amount of diesel. Because the HCR unit is fed the lighter LVGO stream in the Parallel strategy, it can effectively act as a gasoline booster in this scheme. From data in TABLES 6 and 7, it can be seen that the sulfur and metallic contents of HCR and RFCC feedstock do not considerably vary in different integration strategies. As mentioned before, the product quality of RFCC unit is closely tied with its feed quality; therefore, the product quality of the RFCC is guaranteed under different integration strategies. Moreover, the impurities in HRH products are negligible, and therefore they can be directly added to the gasoline and diesel pools with no further treatment.

CONCLUSIONS

The market demand for heavy petroleum products such as heavy oil declines while the demand for valuable products such as gasoline and diesel is expected to increase rapidly. The increasing demand for the refined products indicates that middle distillates, i.e., diesel fuel and gasoline, grow at the highest rate. In this work, a target refinery with available HCR and RFCC units was simulated and calibrated using Hysys-Refinery simulator, and a heavy oil hydroconverting plant (HRH) was implemented to this refinery for maximizing the overall yield of the plant. Four integration strategies, i.e., Simple series, Series, Parallel and Residue upgrading scenarios were studied to enhance the yields of gasoline and diesel. The results showed that by applying those cases, the yield of diesel increased to 39.89%, 41.27%, 37.53%, and 53.63%, respectively. Additionally, the yield of gasoline increased to 4.89%, 4.96%, 5.31%, and 6.98%, respectively. It was also confirmed that sulfur and metallic contents of HCR and RFCC feedstock were not considerably affected, assured the quality of products, and durability of the catalyst.

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