Clean diesel project

A process review, including the improvement of atmospheric and vacuum distillation columns, for the reformulation of the diesel pool

LUIGI VALAGUSSA
Koch-Glitsch Italia

The reformulation of diesel oil fuel was introduced by the European Union in 2009. The aim of the Fuel Directive is to reduce pollution from vehicle emissions. One feature of this directive, discussed in this article, is the specification that the maximum distillation final point of the diesel oil is set at 360°C for 95% of distilled volume measured according to the ASTM D86 analysis (D86T95). Additionally, the Fuel Directive requires a reduction of sulphur content to a maximum 10 ppm. Both the specifications affect refinery operations. More specifically, catalytic processes such as hydrocracking (HDC) and hydrotreating (HDT) are used to improve the diesel yield and to limit the sulphur content respectively. A more extensive analysis, which looks at the atmospheric distillation unit (CDU) and vacuum distillation unit (VDU), may improve total diesel production and minimise the impact on existing units of the refinery. This analysis has the benefit of lower capital cost for the project; furthermore, the improvements can no longer be postponed in view of the market regulation of diesel oil.

Study approach

The scope of this work was to analyse and compare different ways to achieve the required diesel distillation end point from the CDU/VDU as specified by the shorter diesel oil cut (D86T95=360°C), while minimising the impact on the HDC and HDT downstream units and optimising the total diesel production yield.

A refinery requested a licensor to conduct a feasibility study and to draw up a cost estimate for the revamp of the refinery's HDT unit to achieve the specified clean diesel oil requirements.

No consideration was given and no modification was proposed to produce in-specification, straight-run diesel from the existing CDU. Therefore, the design basis for the HDT revamp was a diesel stream with D86T95=360°C at the HDT battery limit. The HDT does not significantly change the diesel distillation endpoint. The HDT feasibility study investigated whether this diesel stream property can be achieved by mixing the present straight-run diesel from the CDU with an additional light stream to reach the maximum distillation point. The evaluation showed that if a D86T95=325°C blending stream is mixed with the present straight-run diesel stream at D86T95=382°C, the light blending should be about 1.7 times (by volume) the total atmospheric diesel produced. This solution does not look very attractive because it requires an increase in treatment capacity, which can affect the revamp of the existing HDT unit substantially and the size of a new unit as well. It also omits any consideration of the availability of a light blending stream and the total cost.

Two main points to consider from this example are:
- The clean diesel project must take the overall refinery process scheme and production capacity into account
- Alternatives are available to improve clean diesel production and to limit the impact on the new/existing equipment and facilities.

PDF courtey of PTQ. First published in PTQ Q1 2011.

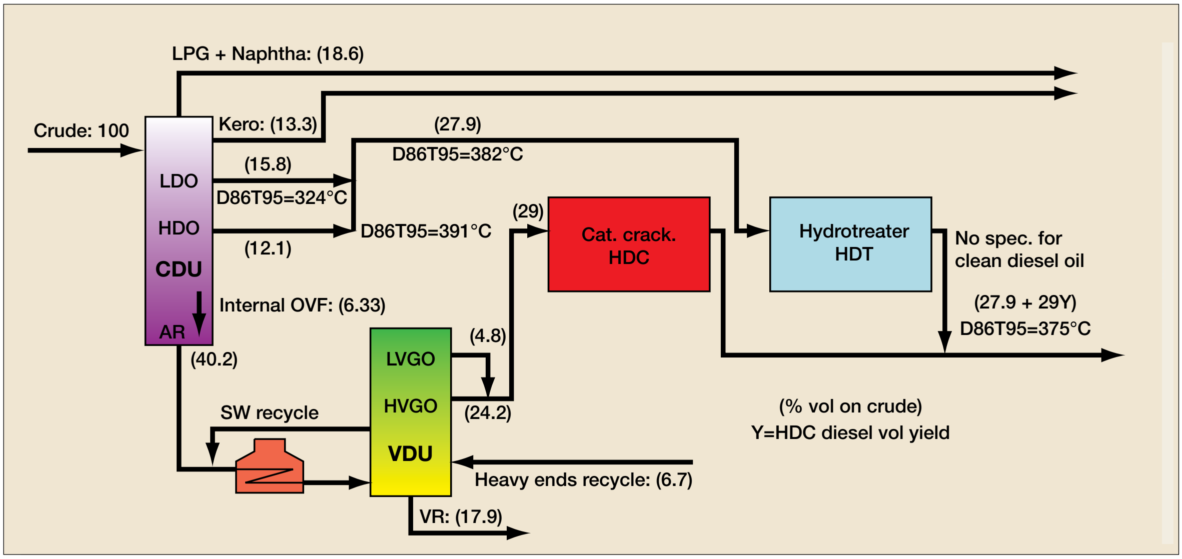

Figure 1 Present scheme

Present scheme

The main features of the existing refinery (see Figure 1) are listed below. The refinery is presently producing non-clean diesel oil:

- The crude oil-handling capacity is 125 000 b/d. To increase the handling capacity, the atmospheric column was revamped some years ago by Koch-Glitsch with Superfrac trays and Flexipac HC structured packing; it thus contains the most advanced column internals technology
- Light diesel oil (LDO) and heavy diesel oil (HDO) are produced in the atmospheric column. These streams are mixed together and fed to the HDT unit. The analysis of this straight-run diesel oil is D86T95=382°C, and this does not change significantly after HDT treatment. The present HDT unit is not able to reduce the sulphur content to the required level for clean diesel oil
- The atmospheric residue (AR) is fed to the vacuum column, which is equipped with three beds of grid packing (old style). One bed at the top of the column for top pumparound service produces a light vacuum gas oil (LVGO), a second bed at the middle of the column for mid pumparound service produces a heavy vacuum gas oil (HVGO), and a third bed at the bottom of the column is a wash bed. The two gas oils are mixed together and fed to the HDC unit
- The diesel stream from the HDC unit is mixed with the HDT straight-run diesel and a final diesel stream with D86T95=375°C (value from refinery), which is above the distillation endpoint requirement for clean diesel oil, is produced.

The refinery has to consider two main modifications in order to comply with the clean diesel specification: first, the revamp of the HDT unit (to reduce sulphur content), which will be approached and solved by a catalyst licensor; and, second, the distillation point specification of the diesel stream.

Alternative scheme to produce clean diesel oil

The first step was to evaluate whether the CDU and VDU columns can reach the target through enhanced performance. It is clear from Figure 1 that the deep cut of HDO greatly affects the diesel quality. In addition, no sensible benefit is achieved by modifying the internals of the existing atmospheric column to produce in-specification, straight-run diesel oil and by minimising the loss of HDO yield. The main reasons are:

- There is a low margin for improving the HDO final distillation points because the present column internals are already designed according to the most advanced and efficient technology
- Any attempt to maximise the straight-run diesel oil, includingdifferent splitting of LDO/HDO, affects existing equipment and operations (for

instance, pumparound and heat recovery). The total diesel oil yield must be reduced and the heavy ends that are not recoverable into the HDO stream must be left in the atmospheric residue fed to the vacuum column. An increase in atmospheric residue could affect the existing vacuum heater performance, which is already limiting the present operations.

On the other hand, a total revamp of the vacuum column internals (from the old grid packing to new structured packing beds) can produce the LVGO stream in specification for clean diesel oil and therefore be suitable for blending with the atmospheric straight-run diesel oil. This avoids additional processing of this stream through HDC. The vacuum column revamp calls for four new structured packing beds, instead of the three existing beds, with the additional bed located below the top pumparound bed for fractionation service. This is necessary to produce the in-specification LVGO product.

Currently, this arrangement is one of our recommended options, because there is extensive experience that it provides a stream suitable for a diesel oil pool without further processing. In our study, we determined that the recoverable LVGO with the revamped vacuum column is about 2 vol% on a crude feed basis.

On the basis of the above considerations, an alternative scheme, the HDO splitting and vacuum revamp scheme (HDO splitting scheme), to produce clean diesel oil without reducing the HDO yield, can be utilised (see Figure 2):

- The HDO from the atmospheric column is split into a stream that can be mixed with the LDO stream and then with the LVGO stream produced by the vacuum column in a ratio suitable to obtain D86T95=360°C in the resulting stream (LDO + HDO partially + LVGO). This stream can be sent to HDT for the final treatment
- As discussed already, the vacuum column is revamped from the existing three beds to four beds. The produced LVGO is suitable for the diesel oil pool, and the HVGO is sent to the HDC together with the excess HDO stream. Even if the vacuum column revamp reduces the total vacuum gas oil (VGO) to HDC, the total feed to HDC must account for the extra feed coming from the HDO stream not conveyed to HDT.

Comparing the HDO splitting scheme to the present scheme, it can be seen that the total feed to HDT decreases from 27.9 vol% based on crude to 20.7 vol%; however, the HDC feed increases from 29 vol% based on crude to 36.1 vol%, resulting in a capacity increase of 24.5% for HDC. The increased HDC capacity requires a deeper investigation

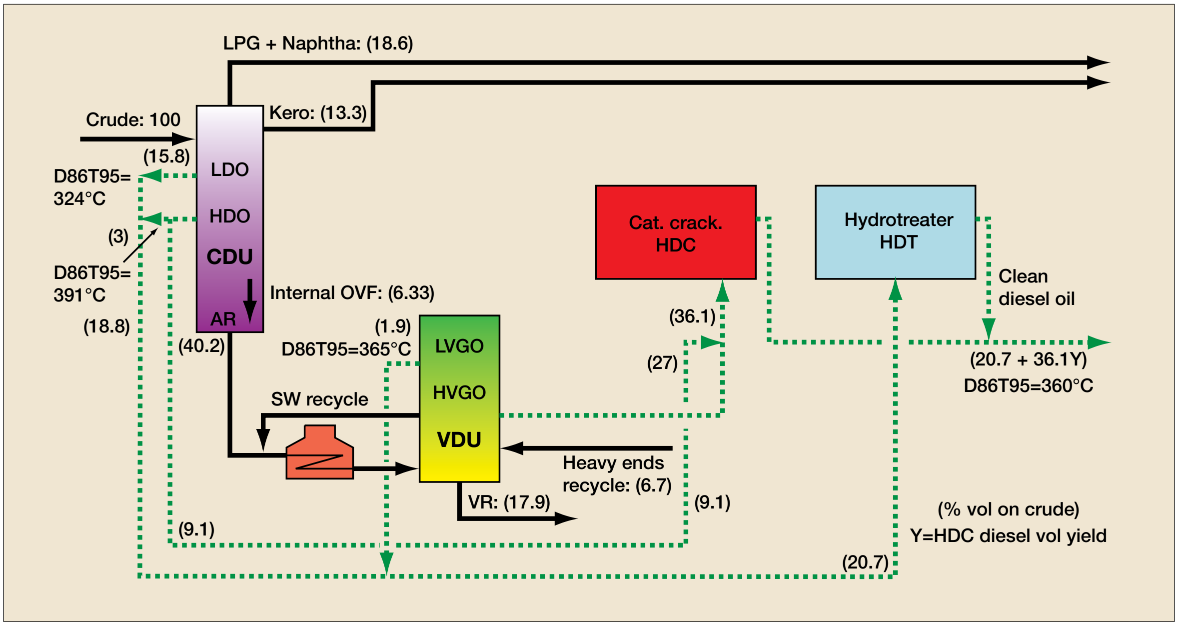

Figure 2 HDO splitting and vacuum revamp

into the suitability of running the existing unit under the new conditions, and the expected conclusion is that the HDC unit itself has to be revamped. Additionally, we have to note that diesel production from HDC depends on the conversion yield, and this may result in a decrease in overall diesel production.

New scheme for maximising clean diesel oil

The main feature of the new scheme proposal involves the atmospheric over-flash (OVF). As Figure 3 shows, this stream is drawn off from the atmospheric column, bypasses the vacuum heater and is fed to the VDU above the wash section. In this case, the vacuum column is also revamped with four beds.

The benefit of the new scheme can be quantified by comparing the values reported in Figure 1 (present scheme), Figure 2 (HDO splitting and vacuum revamp scheme) and Figure 3 (new scheme). The benefits are:

- The new scheme gives better overall clean diesel oil recovery compared to the HDO splitting solution
- In the new scheme, the feed to HDC decreases by approximately 14.7% compared to the HDO splitting scheme and therefore the required treatment capacity of HDC results in an approximate increase of only 6.2% in comparison to the present arrangement. We can expect no, or only minor, modifications to the existing HDC unit
- In the new scheme, the feed to HDT increases approximately 27% compared to the HDO splitting scheme; however, it is less than the present capacity and it is actually about 5.7% less than the capacity of the present scheme. The existing HDT could need some modifications due to the ultra-low sulphur level required by the clean fuel regulation. On the contrary, the decreased feed rate can provide additional benefit by allowing improved performances with the same arrangement or with minor modifications compared with the HDO splitting scheme
- The new scheme saves on vacuum heater duty demand, which generally is a bottleneck in revamping projects.

The new scheme is unusual in existing plants where the atmospheric over-flash is typically combined with the atmospheric residue. Recent atmospheric column revamps have mostly been carried out to increase not only capacity but also the distillates yield (including diesel oil yields), therefore reducing gas oil losses in the atmospheric residue. This approach was acceptable because a longer diesel oil cut was allowed, enabling the atmospheric residue to dry up. Practically all of the straight-run diesel product was recovered in the atmospheric column, and the vacuum column was arranged to produce a long gas oil cut from the mixing of LVGO and HVGO (see Figure 1) containing heavy ends to be converted into lighter products in HDC.

The new scheme (see Figure 3) shows how a review of conditions in the CDU and VDU allows for major benefits with minor impact.

CDU operations

In Figure 3, it can be seen that the HDO yield from the CDU has been reduced to produce a HDO stream that can be mixed with LDO (same yield as the present scheme and the HDO splitting scheme) and with LVGO from the VDU to produce a straight-run, in-specification diesel oil (D86T95=360°C) that is fed to HDT. This stream results in 26.3 vol% based on crude, which is lower than the not-in-specification present feed, but definitely higher than the feed computed for the HDO splitting scheme. The crude heater duty is the same for all the schemes and, because of the reduced yield of HDO in the new scheme, the extra distillate is recovered in the over-flash stream, which increases to 10.3 vol% based on crude, compared with 6.33 vol% in the earlier schemes. Different rates for the over-flash stream or splitting thereof (partially drawn off and partially conveyed into atmospheric residue) can be investigated more deeply according to needs and constraints, while taking the recoverable yield of HDO and the impact on crude and vacuum heater duties into account.

In the new scheme, we used all of the crude heater duty available from the present scheme. Since the over-flash stream is totally conveyed to the vacuum column rather than being sent to atmospheric residue as in the other schemes, the resulting atmospheric residue product decreases to 34.7 vol% based on crude, compared with 40.2 vol% in the earlier schemes. In this specific case, a few mechanical modifications to the existing unit are needed

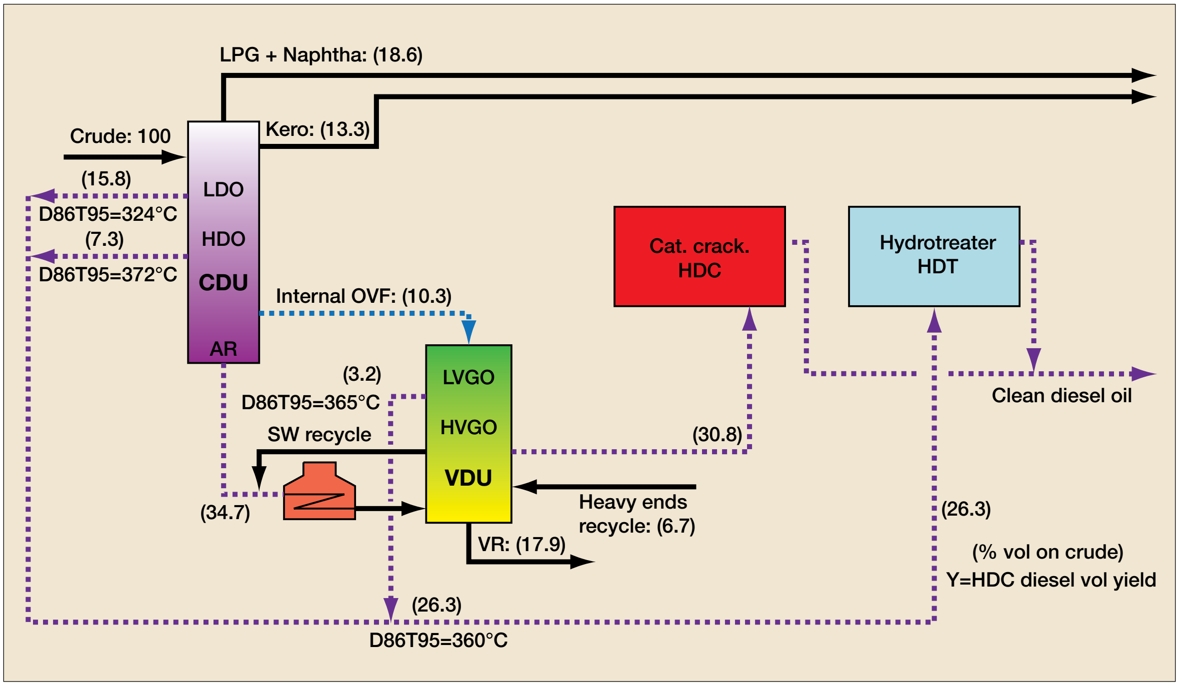

Figure 3 New scheme

to be able to apply the new processing scheme:

- A new draw-off nozzle is installed in the atmospheric column vessel for over-flash service
- A new circuit complete with pumps, piping, control and instrumentation is installed to feed the over-flash product to the vacuum column.

VDU operations

The existing vacuum column is still arranged with an old-style design consisting of three beds with low-efficiency grid packing. We propose a total revamp of the column internals, providing four beds equipped with new structured packing from Koch-Glitsch.

The additional bed is located between the HVGO and LVGO pumparound beds, providing a fractionation section for the LVGO product. In this way, the LVGO product, drawn off below the LVGO pumparound bed, is made available in specification for mixing with the atmospheric diesel oil and avoiding further processing in HDC, as in the present scheme. The arrangement shown is not necessarily required to realise the clean diesel project, but it has been applied in many projects (practically since the introduction of structured packing in the market) to improve the performance of vacuum columns worldwide with significant results. It is clear that the clean diesel regulation pushes heavily towards any investment that can improve the recovery of diesel oil while limiting the penalty of paying for the production of the required shorter cut.

Figure 3 shows that the recovery of in-specification LVGO is 3.2 vol% based on crude, compared with 1.9 vol% according to the HDO splitting scheme. Furthermore, the recovery of HVGO (with a slightly higher endpoint compared with the previous cases) is 30.8 vol% based on crude, compared with 24.2 vol% according to the present scheme and 27 vol% according to the HDO splitting scheme.

The new scheme (with the atmospheric over-flash fed to the vacuum column) enables better recovery of in-specification LVGO and also increases the HVGO yield, resulting in a maximisation of the total distillates yield (LVGO + HVGO) compared with the other schemes. In conclusion, this looks to be the most efficient way to improve gas oil recovery.

In the reported comparisons, the slop wax (SW) recycle to the vacuum heater, the external feed (heavy ends recycle) and the yield of vacuum residue (VR) product have been set at the same values for all of the schemes.

Since the over-flash is drawn off totally from the atmospheric column, rather than being conveyed into the atmospheric residue according to the new scheme, the atmospheric residue feed decreases to 34.7 vol% based on crude, compared with 40.2 vol% for the other schemes; as a result, the vacuum heater will be affected.

For the same vacuum residue, the vapourisation rate to the furnace according to the new scheme is thus less than that required for the other schemes, both as quantity of vapour flow and as percentage of total feed to the heater. As a result, the heater duty demand in the new scheme is 12.7 MMKcal/h with a vapourisation of 22 wt% of total feed, compared with 14.8 MMKcal/h and a vapourisation of 24.8 wt% in the other schemes. These figures are very attractive when evaluating the performance of an existing furnace at the new conditions, even with the increased temperature at the heater outlet. In fact, this temperature increases in the new scheme by approximately 6°C compared with the previous schemes because a heavier cut of atmospheric residue is fed to the heater. This point should be evaluated more deeply during the engineering phase, as well as the fact that the lower vapour rate will cause a reduction in the pressure drop along the transfer line, which results in a lower heater outlet temperature.

Some final consideration must be given to the conditions and location of the over-flash stream entering the vacuum column. In the new scheme, the atmospheric over-flash is fed above the wash bed of the vacuum column at the draw-off conditions from the atmospheric column. This means that this stream is fed at about 363°C, a very high temperature, into a column under vacuum. This will cause high flashing rates at the inlet of the vacuum column or, more specifically, downstream of the valve controlling the over-flash flow rate. This condition requires a relatively large nozzle. In the case of a revamp, the necessary room has to be evaluated carefully to provide sufficient room for the nozzle, the disengagement space above the wash bed and a feed inlet device.

The diesel oil pool is now subject to more stringent specifications according to the EU's Fuel Directive

Cooling of the over-flash stream, before feeding it to the wash section of the vacuum column, reduces the flashing rate but increases the heater duty demand. In this case, a critical piece of equipment, such as the vacuum heater, can cause a bottleneck because of the increase in the vapourisation rate and the heater outlet temperature.

An alternative was evaluated; namely, cooling down the over-flash stream to the temperature of the bottom pumparound (150°C) and moving the feed location to above the bottom pumparound bed. The results are in line with the new scheme in terms of recovery, product characteristics and heater duty, but the bottom pumparound duty decreases substantially (approximately half that of the new scheme). However, flashing of the over-flash stream is practically nil, and this solves the space problems described earlier.

On the other side, feeding the over-flash between the bottom pumparound bed and the LVGO fractionation bed increases the risk of contamination with unwanted material that can be entrained into the distillates products. The risk is higher than in the case where the over-flash is fed above the wash bed. This matter should be evaluated in more detail, while taking the quality and characteristics of the over-flash stream into account.

The simplified process flow diagram shown in Figure 4 indicates the new over-flash circuit and the new beds of the vacuum column.

Summary and conclusion

The diesel oil pool is now subject to more stringent specifications according to the EU's Fuel Directive for the utilisation of clean diesel oil. The reformulation of the diesel oil pool can be achieved by a review of operations and improvement of the performances of the atmospheric and vacuum distillation columns.

A new processing scheme, applied to an existing refinery, has been presented and the attainable benefits have been discussed. These benefits

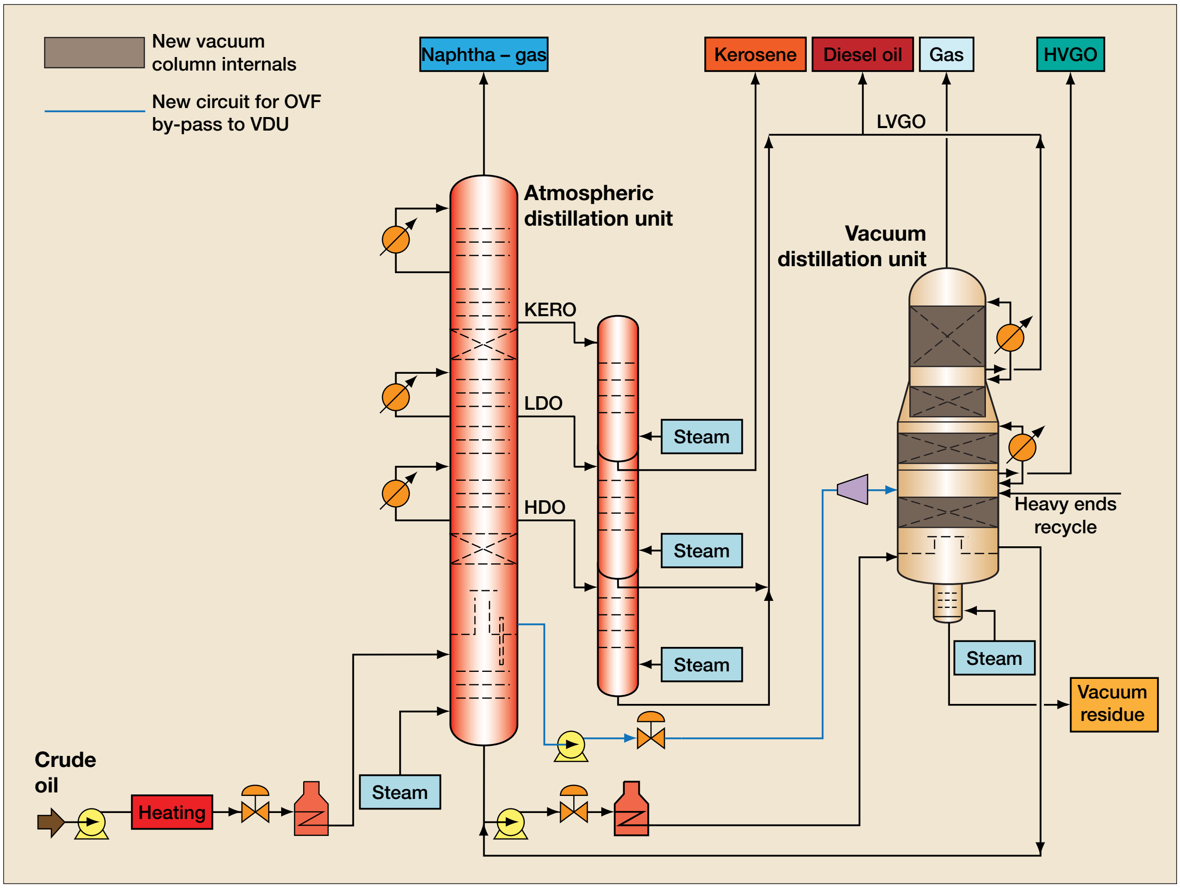

Figure 4 New process flow diagram

include increased overall clean diesel recovery with minor impact on the existing downstream HDC and HDT units. The new scheme is compared with the present scheme (reproducing the actual operations/ arrangement) and with the HDO splitting scheme. The new scheme, representing an alternative for clean diesel production based on a traditional route, is shown and discussed.

A new process route where the atmospheric over-flash is fed to the vacuum column bypassing the vacuum heater has been suggested. With this scheme, the recovery of gas oil in the vacuum column can be enhanced, partially as in-specification LVGO for the diesel pool (3.2 vol% based on crude) and partially as HVGO feedstock to HDC, resulting in an increase in total gas oil recovery (LVGO + HVGO) of about 17 vol% in comparison to the present operations. Under the stated conditions, the vacuum heater duty demand decreases by approximately 14% in comparison to the present operations. This adds a solid benefit because the vacuum heater, a critical item, is often a bottleneck in revamp projects. The vacuum column internals play an especially important role in improving products separation and gas oil recovery. Two main modifications to the vacuum column are proposed: first, the installation of the latest generation of structured packing; and second, the introduction of a new LVGO fractionation bed below the top pumparound (not shown in the present arrangement). These modifications will improve the product quality and yields as described.

Important issues to resolve while developing a revamp project according to the new scheme are the increased temperature at the vacuum heater outlet and the feed location of the atmospheric over-flash stream to the vacuum column. In the reported new scheme, the over-flash has been fed hot above the wash section, but an

Total clean diesel production summary

Case	Present scheme	HDO splitting scheme	New scheme
	vol% on crude (% difference vs present)		
LDO to HDT (hydrotreating)	15.80	15.80	15.80
HDO to HDT	12.10	3.00	7.30
LVGO to HDT	0.00	1.90	3.20
Total to HDT	27.90	20.70	26.30
LVGO to HDC (hydrocracking)	4.80	0.00	0.00
HVGO to HDC	24.20	27.00	30.80
HDO to HDC	0.00	9.10	0.00
Total to HDC	29.00	36.10	30.80
Total diesel D86 95%v, °C	375	360	360
HDC diesel conversion yield %v 30	36.60	31.53 (-5.07)	35.54 (-1.06)
50	42.40	38.75 (-3.65)	41.70 (-0.70)
70	48.20	45.97 (-2.23)	47.86 (-0.34)
90	54.00	53.19 (-0.81)	54.02 (0.00)

Table 1

alternative with a cold feed above the bottom pumparound bed could be considered.

In Table 1, the production rates referred to are reported in terms of vol% based on crude feed. Total diesel production depends on the conversion yield of the HDC unit; therefore, we reported several cases at various values of conversion yield. The new scheme, in comparison with the alternative HDO splitting scheme, enables better splitting of the treatment capacity between HDT and HDC, which is closer to the existing capacities. Total clean diesel production is better in the new scheme, in comparison with the HDO splitting scheme, for all the assumed conversion yields in HDC. We conclude that the new scheme can achieve the recovery of clean diesel while minimising the penalty in clean diesel production, which is an expected result of the stricter specification for market diesel oil.

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Luigi Valagussa is Refining Process Manager with Koch-Glitsch in Italy. He has more than 30 years' experience in oil refining and process design, and graduated in chemical engineering from Politecnico of Milan, Italy.
Email: luigi.valagussa@kochglitsch.com