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Hydroprocessing Units Using SynTechnology**

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Abstract

This paper focuses on the use of SynTechnology for the revamp and debottlenecking of hydroprocessing units. Revamp projects are discussed along with the opportunities for staging investment commensurate with product quality objectives. Several specific cases are presented.

Introduction

The SynAlliance, consisting of Shell Global Solutions, ABB Lummus Global, and Criterion Catalyst Company L.P., has developed various options and approaches to improving diesel quality. The technology involved is referred to as SynTechnology, consisting of various reactor system designs in conjunction with advanced high activity SynCat catalysts. By employing the right combination of catalyst(s), reactor system, and high performance reactor internals the SynAlliance has developed optimized solutions for producing improved quality diesel. Through the use of reactor system technology that can include both cocurrent and countercurrent reactors, various new unit and revamp options have been achieved.

SynTechnology and Reactor Systems Selection

SynTechnologies include SynHDS, SynShift, SynSat, and SynFlow. SynHDS technology is primarily focused on producing ultra low sulfur diesel and is capable of meeting sulfur specifications of <10 wppm. SynShift is a selective ring opening technology for processing even the most difficult-to-treat feedstocks for the purpose of density reduction, T95 reduction (shift), cetane improvement and aromatics (polynuclear or total) reduction. SynSat is specifically focused on aromatics saturation, providing added density reduction and cetane improvement. SynShift and SynSat can be combined for deep HDA and T95 reduction, along with other process objectives. SynFlow technology can be applied in conjunction with other SynTechnologies as required to achieve cold flow improvement. Table 1 provides an overview of SynTechnologies and the various processing objectives that can be faced by refiners.

Table 1

SynTechnology	SynHDS	SynShift	SynShift/SynSat
Processing Objectives			
Deep HDS	X	X	X
Density Reduction (API Gain)	Some	X	X
Cetane Increase	Some	X	X
Polynuclear Aromatic Reduction	Some	X	X
Total Aromatics Reduction	Some	Some	X
ASTM T95 Reduction (Shift)		X	X
Cold Flow Improvement	← SynFlow →		

To date, we have designed and implemented a wide number of different reactor system configurations. These have included single-stage and two-stage systems with cocurrent reactors, or integrated two-stage systems with a cocurrent first-stage reactor together with either a cocurrent or countercurrent second-stage reactor. In such integrated two-stage systems, interstage flashing/stripping has been utilized, and its use will depend on the specific processing objectives and required SynCat catalyst(s). Reactor systems have also been designed and implemented that have staged investment configurations, using a cocurrent reactor initially with the ability to modify the system at a future date to a two-stage configuration if required as a result of changing product specifications.

In order to meet new and changing hydroprocessing objectives,

particularly with regard to existing units, it is key to maximize the performance of the reactor system by optimizing the hydrogen partial pressure, and in doing so, obtain the highest hydrogen partial pressure for a given existing system's operating pressure. In this way, maximum performance can be obtained from the right catalyst(s) while minimizing investment. Particularly for revamps, reactor systems utilizing both cocurrent and countercurrent contacting of distillate with hydrogen-rich gas have been proven as an effective means to achieving an optimum hydrogen partial pressure profile throughout the reactor system.

Typical reactor configurations are depicted in Figure 1. It should be noted that the number of catalyst beds in each reactor stage can vary depending on feedstock type/quality and diesel objectives.

Figure 1

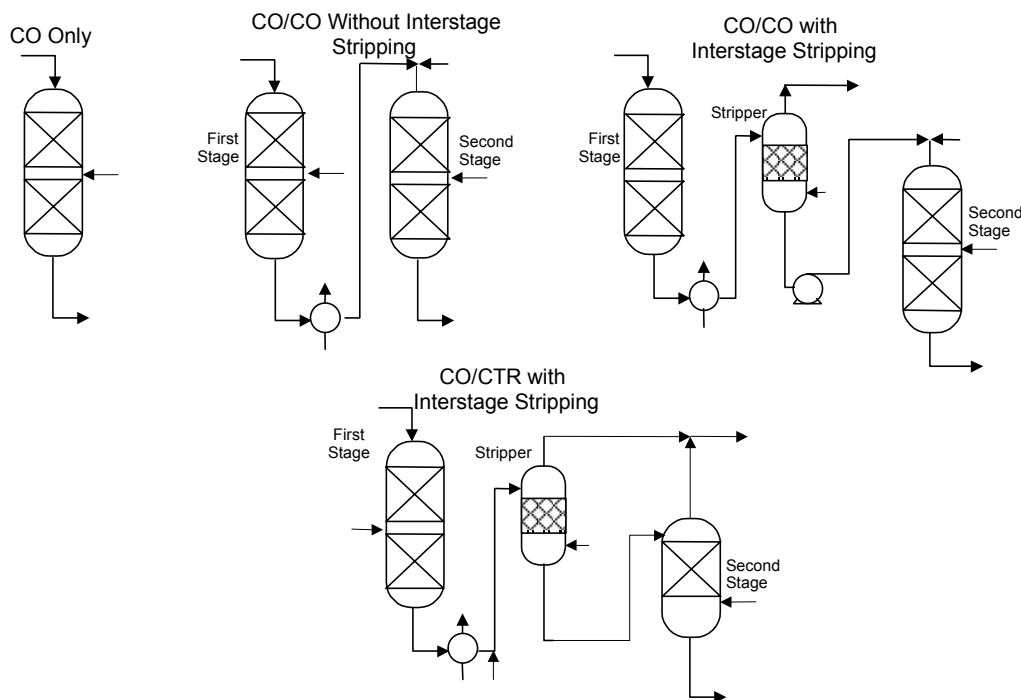


Table 2 provides a general guide to applying the right reactor system and associated SynTechnology.

Table 2

Objectives					Reactor System			SynTechnologies		
Deep HDS	Deep HDA	PNA Reduction	Cetane Increase	API Gain	CO	CO/CO	CO/CTR	SynHDS	SynShift	SynShift / SynSat
X					X			X		
X			X	X	X				X	
X		X	X	X		X	Or X		X	X
X	X	X	X	X			X			X

CO - Cocurrent only

CO/CO - Cocurrent / cocurrent with or without integrated interstage stripper

CO/CTR - Cocurrent / countercurrent with integrated interstage stripping

As previously noted, cold flow properties improvement via SynFlow technology can also be achieved, if required, within each of the reactor system configurations.

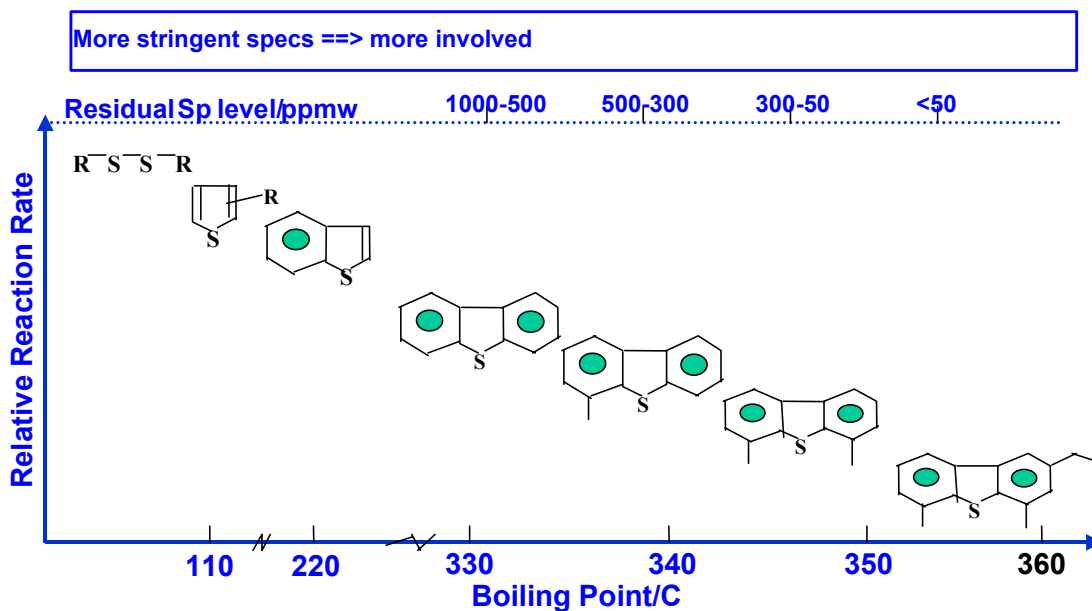
Selecting the Right Catalysts

Whether for new units or revamps, the key to an optimized yet flexible no-regret solution is to be found in selecting the right reactor configuration, operating conditions, and catalyst or catalyst combination. Various high-activity SynCat catalysts are available including CoMo, NiMo, NiW and noble metal containing. Understanding the process chemistry is important when selecting the right catalyst(s) in all hydroprocessing applications no matter what the objective, and this is no less true when considering ultra deep desulfurization of middle distillates.

For ultra deep desulfurization, we have put special emphasis on the importance of understanding the chemistry associated with deep desulfurization. The reduction of sulfur in gas oil feedstocks, especially cracked feedstocks such as coker gas oil and LCO, requires careful selection of catalysts and operating conditions specifically tailored to the chemistry of achieving ultra deep desulfurization. Investigation of the various sulfur species in gas oil feedstocks indicates that the more difficult to remove sulfur is associated with the higher boiling point material and are very refractory, being bound in aromatic compounds. This becomes an important factor when desulfurizing feeds to ≤ 50 wppm sulfur, and in particular to <10 ppm.

Figure 2 illustrates schematically that it is the dimethyl-dibenzothiophenes (DMBT's) that need to be treated in order to achieve very low residual sulfur levels. The steric hindrance of these sulfur species and the fact that they are inherently linked with aromatics compounds means that higher hydrogenation catalysts such as high activity SynCat catalysts CoMo, or stacked bed combinations of NiMo and CoMo or even NiMo alone are needed to treat these sulfur species. Selection of the right SynCat catalyst(s) depends on several factors including feedstock type, feed blend components, distillation boiling range of feedstocks, and reactor system operating pressure, which become very apparent when considering the capabilities of existing units.

Figure 2



Distillation/end point effects have been mapped and clearly demonstrate the sulfur species distribution in both feed and product. Figures 3 and 4 illustrate this by presenting feed sulfur/boiling point relationship and product analysis after hydrotreating. The results show that indeed all the residual sulfur species are in the tail, predominantly above 340°C. While this assessment was conducted for a specific gas oil feed, the effect can be seen generally on various gas oil feedstocks.

Figure 3

FEED SULPHUR DISTRIBUTION BY BOILING POINT

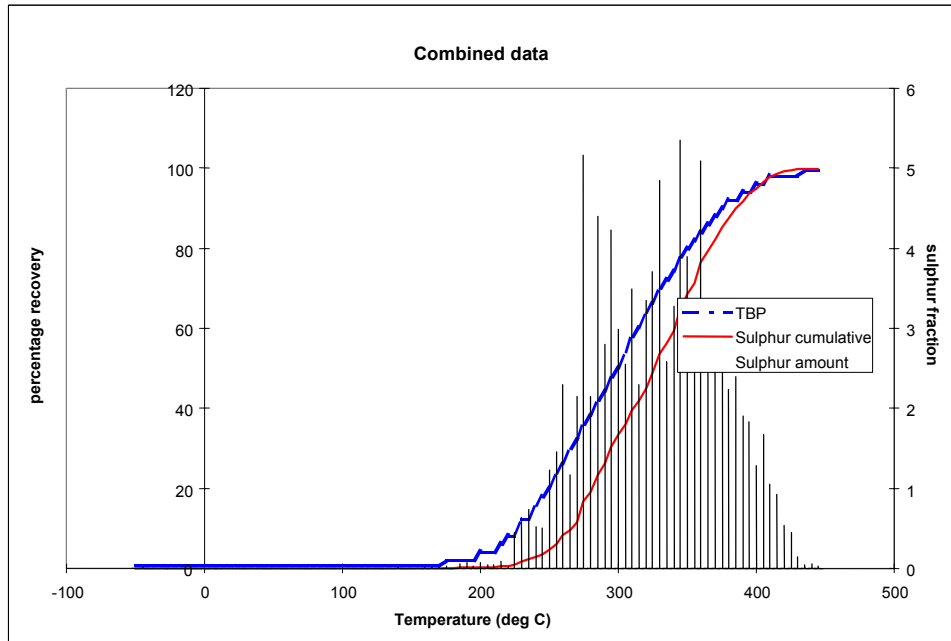
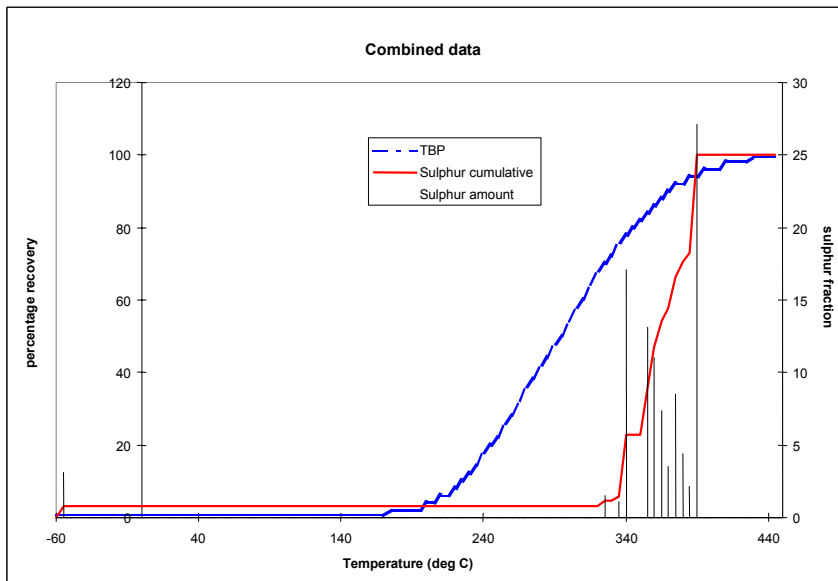


Figure 4

ULTRA-LOW SULPHUR PRODUCT DISTRIBUTION BY BOILING POINT



As noted, the removal of DMBT's can involve some degree of aromatics saturation and therefore the usual "rules" of polynuclear aromatics (PNA) saturation apply. At somewhat higher pressure, the degree of PNA saturation is improved thus aiding deep desulfurization. At lower space velocity the degree of PNA saturation is also improved. Aromatics saturation equilibrium is influenced by temperature, and as such increased temperature up to the aromatics equilibrium point, which is pressure dependent, will improve PNA saturation and deep desulfurization, while operating at temperatures higher than this equilibrium will reduce PNA saturation and make it more difficult to remove the DMBT's.

These factors need to be taken into consideration, which reemphasizes the importance of understanding the systems chemistry in order to select the optimum combination of catalyst and operating conditions for a specific feed and product low sulfur objective. Only in this way can the impact of changing diesel specifications on a unit's revamp be minimized. By example, when revamping from 50 wppm to 10 wppm sulfur diesel, chemical hydrogen consumption will increase as a result of the commensurate increased HDA. This will likely require somewhat higher treat gas rate, and naphtha (C₅-180°C) produced will also increase, thus potentially requiring some added naphtha handling capability in the diesel product stripper tower and vacuum dryer. All must be taken into account in order to properly design the revamp.

Revamp Opportunities

Depending on an existing unit's operating pressure, catalyst volume, and available make-up hydrogen and recycle gas capabilities, the number and type of revamp options will vary and be highly dependent on the revamps objectives concerning not only diesel quality, but also unit capacity. Having exhausted catalyst-replacement-only options, which in themselves can achieve performance enhancement, although sometimes at the expense of somewhat reduced catalyst cycle length, refiners are faced with the prospect of hydrotreater unit revamps to meet certain diesel product specifications.

One particular revamp opportunity includes the use of advance reactor internals:

- Maximizing utilization of existing reactor volume by implementation of advanced gas/liquid distribution internals and/or high efficiency quench internals in combination with optimized catalyst bed grading.

In this regard, the use of Shell's advanced design High Dispersion (HD) liquid and gas distribution tray creates highly uniform liquid distribution, which is of particular importance in view of meeting more stringent product specifications. In HD-nozzles the gas flow momentum is used

to disperse the liquid into a mist-flow of small droplets. Contrary to standard (conventional) distributions, the HD-nozzle enables efficient use of the first meters of catalyst without losing activity to the need to distributive top of bed. Significant reduction in the required WABT at constant hydroprocessing severity have been observed after installation of such trays in existing hydroprocessing units (up to 5°C), which is equivalent to a significant increase in run-length. Due to the pressure drop over the tray, the sensitivity of the liquid distribution to tilt is minimal.

Flexibility of feed rate of these trays is high: typically +50%/-50% for the liquid as well as the gas, while the pressure drop over the HD trays is low, typically 10-20 mbar at full throughput. Operation under a 100% gas feed is possible as well. In addition, for each tray the panel geometry is optimized for fast entrance (e.g. no use of bolts, optimized panel choice in which only two panels need to be removed to create a man-way), easy cleaning, and optimal catalyst loading. Their design is simple, robust against handling during multiple shutdowns, while having the necessary corrosion resistance. In addition, they feature a re-usable sealing construction.

For reactors requiring the use of multiple catalyst beds and appropriate quenching to optimize WABT and control SOR to EOR temperature profiles, the use of Shell's latest ultra flat quench (UFQ) interbed internals achieve better thermal uniformity at the interbed mixing zones. UFQ performance is quench load independent and requires minimum reactor volume due to its unique design.

Use of such advanced internals reduces the reactor space required thus allowing for more catalyst to be placed in a given reactor volume. This is a major benefit for both new and revamped reactors.

Other revamp opportunities include various reactor system modifications:

- Install additional catalyst volume (see Figure 5) by adding a new reactor either in parallel or in series with the existing reactor. The choice of which approach is best will depend on several factors, including existing high pressure loop hydraulics (available pressure drop), upstream feed heater design/tube layout, feed preheat exchanger train configuration, unit layout and equipment location/placement and piping issues.
- Install additional catalyst volume by converting the existing reactor system to an integrated cocurrent/cocurrent two stage reactor system with interstage stripper (see

Figure 6).

- Install additional catalyst volume by converting the existing reactor system to an integrated cocurrent / countercurrent reactor system with interstage stripper (see Figure 7).
- Leave the existing reactor system largely unmodified and add a new integrated cocurrent / countercurrent reactor system with interstage stripper and dedicated new treat-gas system (see Figure 8). In this case, since the new reactor system is an add-on, the installation of the two reactor stages could be phased, installing only the cocurrent reactor initially to meet the necessary objectives, and installing the stripper and countercurrent reactor at a later date if/when diesel product specifications change thus requiring additional hydroprocessing. By tying into the existing unit's reactor effluent system, the existing reactor section and new add-on reactor system can both utilize the existing low pressure product recovery section.

Figure 5
Cocurrent Reactor System

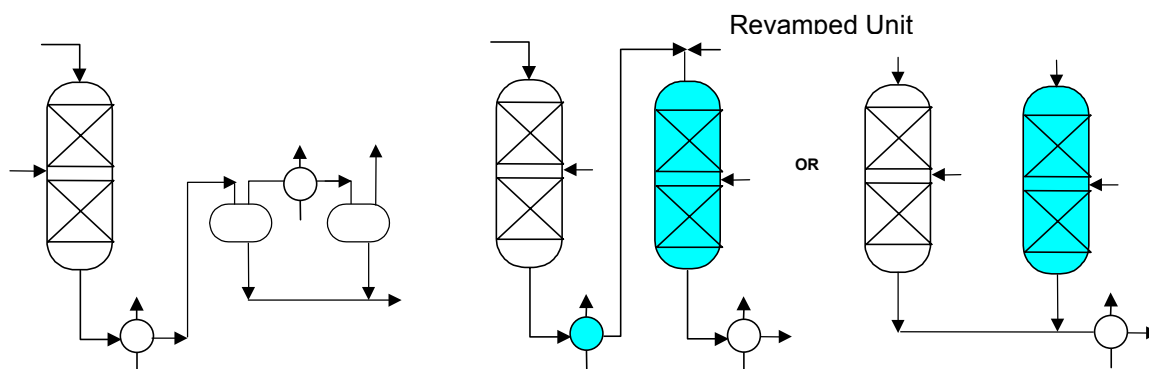


Figure 6
Cocurrent / Cocurrent Reactor System

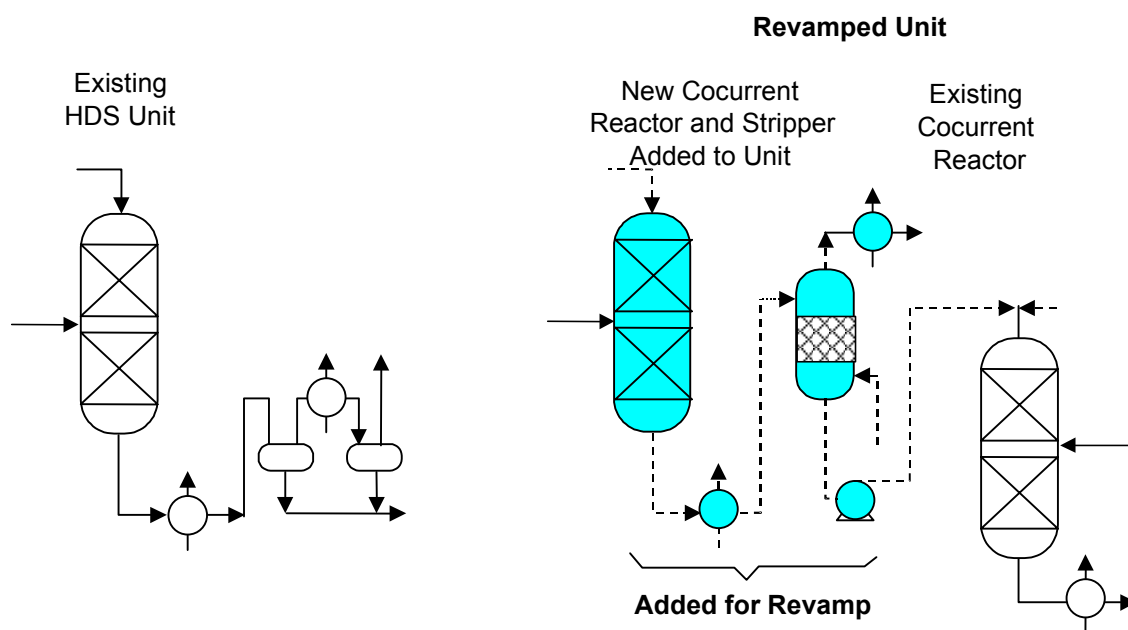


Figure 7
Cocurrent / Countercurrent Reactor System

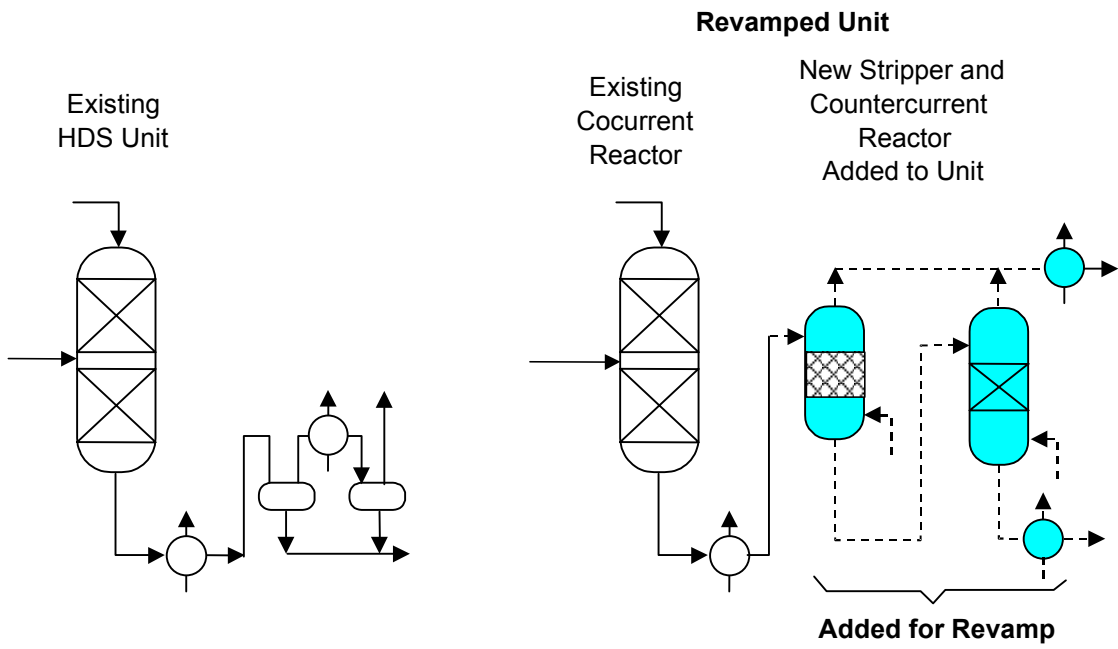
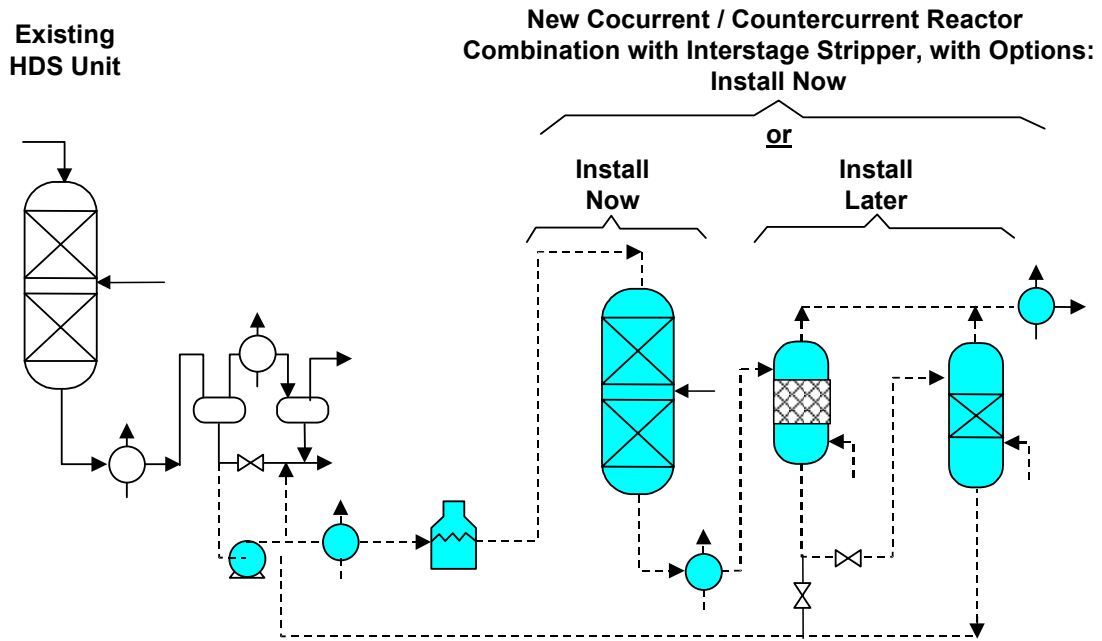


Figure 8

"Add-On" Cocurrent / Countercurrent Reactor System



The decision as to which revamp approach to take can only be decided after a careful evaluation of many issues including revamp complexity, constructability/down time, total installed cost of revamp, catalyst cost, operating cost and operating ease. The need to meet changing specifications and the time frame between diesel specification changes must also be considered. In addition to specification changes, the need for capacity increase, either now or in the future, and/or different feedstocks from that which is currently processed must be factored into the decision.

In evaluating the revamp approach for any unit, the current "as installed" reactor system limitations and constraints must be taken into account. These include:

- Available catalyst volume
- Number of catalyst beds and interbed quench
- Maximum safe operating pressure
- Maximum available make-up hydrogen
- Maximum available circulated treat gas
- Available reactor system pressure drop
- System- or equipment-specific bottlenecks or other hydraulic constraints.

Consideration is also given to any need to operate the unit in a blocked operating mode for the purpose of processing various feeds to make different product grades.

Add-On versus Pull-Apart Revamp Options

Recent revamp studies and designs have given rise to consideration of what might be best referred to as the "add-on" revamp approach as described above and illustrated in Figure 8. This particular approach can facilitate a unit revamp, especially if the existing unit's reactor system has specific constraints and/or is limited by its available maximum operating pressure. In such cases, the add-on system is designed for a somewhat higher operating pressure consistent with optimizing the catalysts to the product goals.

The more typical "pull-apart" revamp approaches, as illustrated in Figures 5, 6 and 7, can be and have been designed and implemented but must logically fit within all necessary considerations. An overview of "pull-apart" versus "add-on" revamp approaches, their issues and considerations is illustrated in Table 3.

Table 3

	<u>Revamp Type</u>	
	<u>Pull-Apart</u>	<u>Add-On</u>
• Existing reactor system capability		
- Pressure insufficient		X
- Pressure sufficient	X	
- Existing reactor limiting		X
- Existing reactor not limiting	X	
- Other capacity/hydraulic constraints limitations		X
• Constructability		
- Available plot space within unit	X	
- Available plot space adjacent to existing unit (within reasonable distance)		X
- Existing unit equipment/piping accessible for revamping	X	
- Existing unit equipment/piping has limited accessibility		X

With the "add-on" revamp approach, the kinetics of the entire unit can be optimized so as to maximize the performance of the existing reactor within its given constraints, then setting the kinetic requirements of the new add-on systems reactor(s) to meet the overall diesel product quality objectives. At this point, selection of the right catalysts and combination of catalysts is key to optimizing the revamp by carefully tailoring the performance of each reactor. Furthermore, should the revamp require an increase in capacity in addition to the need to produce better quality diesel, the feed to the unit can be split so that the amount which can be handled by the existing reactor goes to the existing reactor system, while the remaining feed is combined with the effluent (treated material) from the existing reactor system and fed to the new, appropriately sized, add-on reactor system. The ability to split the feed in this manner also provides the opportunity with feed blends, consisting of straight run and cracked feedstocks, to be selective about which feedstock or blend is sent to the existing reactor system and which is processed in the add-on reactor system.

Revamp and Debottlenecking Examples

The following describes revamp cases using SynTechnology; one an add-on revamp and the others pull apart. All of the revamps included stepwise (phased) investment to meet the challenge of changing diesel specifications.

Example 1

In this first example, the refiner required a revamp of their existing HDS unit in order to process a blend of various straight run feeds and cracked feedstocks, while producing better quality diesel product. The unit had been revamped previously by the refiner to include a dewaxing step. Their objectives and needs were to minimize changes to the existing unit, construct the revamp while the existing unit operates, minimize down time for tie-ins and design a revamp that could be implemented either in steps (phases) or all at once, depending on diesel product specification needs.

In this case, an "add-on" approach was selected, somewhat analogous to that which is illustrated by Figure 8. The revamp would consist of the following elements which can be accomplished in a logical phased approach:

Phase I

- Change the existing reactor catalyst to a more active SynCat catalyst, resulting in additional hydrogenation of the feed blend within the constraints of the existing reactor system; and
- Add-on of a second cocurrent reactor complementing the existing reactor to provide the necessary performance required for either an intermediate quality product or to provide suitable treated feed quality to the countercurrent reactor for additional hydrogenation;

Phase II

- Add-on of an interstage stripper and a second stage countercurrent reactor for deep hydrogenation.

Table 4 summarizes the feed blend to the existing reactor system and the diesel quality to be produced by the revamped unit for each of the phases/operating cases.

Table 4

	Feed Blend⁽¹⁾	Feed Blend⁽²⁾	Phase I Operation A Diesel Product	Phase II Operation B Diesel Product	Phase II Operation C Diesel Product
API Gravity	31.9	30.3	36.4	38.6	41.1
Sp. Gr. @ 15.6°C	0.8631	0.8746	0.843	0.832	0.820
Sulfur, wt% (wppm)	0.964	1.01	(<30)	(<20)	(<10)
Nitrogen, wppm	422	442	<10	<10	<5
Bromine no. gr/100gr	9.4	8.3			
Cetane index	39.5	47	55.5	57	59
Aromatics, wt%					
Monos	24.3	24.9			
Polys	15.0	16.7	11	6	1
Total	39.3	41.6			
Distillation D86 T95, °C		370	352	347	340

(1) Feed blend includes approximately 10 wt% cracked naphtha material.

(2) Feed blend properties without cracked naphtha material.

Since the unit revamp was designed for phased implementation, the add-on new cocurrent reactor could be installed first (Phase I - Operation A) and the new countercurrent reactor installed later (Phase II - Operation C), as required. Alternatively, the refiner could install the entire revamp add-on now and provide maximum upgrading of the feed blend, or a tailored upgrading of the feed blend depending on hydrogen availability. The add-on cocurrent / countercurrent reactor configuration allows for the partial or total bypassing of the countercurrent reactor (Phase II - Operation B).

Table 5 shows the relative operating pressures levels and type of catalysts applied for the revamp. The specific combination of non-noble metal SynCat catalysts utilized in the existing and new cocurrent reactors constitutes what we refer to as SynShift, which provides selective ring opening to facilitate deep heteroatom (S,N) reduction, some aromatics saturation, density reduction, and distillation shift (i.e., T95 reduction). The noble metal containing SynCat catalyst used in the new SynSat countercurrent reactor provides aromatics saturation and additional density reduction. The application of the noble metal containing catalyst is optimized relative to the product objectives and the non noble metal SynCat catalysts in the cocurrent reactors. In this way, the revamp investment, including overall cost of catalyst, can be minimized.

Table 5

	Phase I	Phase II	
		Add-On Reactor System	
	<i>Existing Cocurrent Reactor</i>	<i>New Cocurrent Reactor</i>	<i>New Countercurrent Reactor</i>
Pressure	Base	Base x 1.4	Base x 1.3
Catalyst	Non-noble base metal	Non-noble base metal	noble Metal Containing
Technology	SynShift		SynSat
Primary Goal	<ul style="list-style-type: none"> • Selective Ring Opening • Deep HDS/HDN • Some HDA • Density Reduction • Distillation Shift (T95 Reduction) 		<ul style="list-style-type: none"> • Deep HDA • Density Reduction

Example 2

In this second example, the refiner required a revamp of their existing HDS unit in order to process a blend of straight run and cracked feeds to provide better quality diesel product while debottlenecking the existing unit to increase capacity by twenty percent. The unit had been previously debottlenecked and was hydraulically constrained in addition to not having enough available reactor volume to achieve the product quality goals. Like many other refiners, the existing unit was already being pushed kinetically via new catalyst and operations at higher temperature, resulting in shortening cycle length.

In this case, a pull apart approach was proposed somewhat analogous to that which is illustrated by Figure 7 except that due to the severe hydraulic and kinetic constraints, the existing reactor, being too small, would be utilized as a new hot separator, with new reactors being added (stepwise/staged) for both the cocurrent first stage and countercurrent second stage.

The revamp would consist of the following phases.

Phase I

- Replace the existing small reactor with a new cocurrent reactor suitably sized for the required hydroprocessing objectives;
- Utilize the existing reactor as a hot separator (the existing unit only had a cold separator) in order to flash the reactor effluent thereby providing additional heat recovery opportunities for feed oil and recycle gas preheating;

Phase II

- Add an interstage stripper and a second stage countercurrent reactor for deep hydrogenation, if/when required as a future revamp step.

By revamping the unit as noted above, the following objectives could be achieved:

- Feed/effluent preheat and fired heater were hydraulically debottlenecked to accommodate the higher capacity;
- Fired heater duty was reduced at current capacity and maintained within the as installed heaters' capabilities at revamp conditions;
- Required pressure drop throughout the reactor system loop was maintained within the capabilities of existing compressors and feed pumps;
- Revamp design allowed for the stepwise (staged) installation of the new reactors and associated modifications.

Table 6 summarizes the feed blend to the unit and the diesel quality to be produced by the revamped unit for each phase of the revamp.

Table 6

	Feed Blend	Phase I HDS Revamp	Phase II HDS/HDA Revamp
API Gravity	34.0	36.9	41.4
Sp. Gr. @15.6°C	0.8550	0.8401	0.8184
Sulfur, wt% (wppm)	0.9	(<50)	(<10)
Nitrogen, wppm	200	<10	<5
Bromine No. gr/100 gr	3.2		
Cetane Number	50.5	53.7	57.6
Aromatics, wt%			
Monos	17.8		
Polys	14.2	11	1
Total	32.0		10
Distillation D86 T95, °C	354	352	<345

Table 7 shows how the specific non-noble metal SynCat catalysts, utilized in this case, would be changed from Phase I to Phase II revamps. The SynCat catalyst used for Phase I is specifically tailored for ultra deep HDS via SynHDS, while for Phase II the non-noble metal SynCats used in the cocurrent first stage constitutes SynShift while a noble metal containing SynCat catalyst is used in the SynSat countercurrent reactor.

Table 7

	Phase I HDS Revamp	Phase II HDS/HDA Revamp	
	New Cocurrent Reactor	Cocurrent Reactor	New Countercurrent Reactor
Pressure	Base *	Base *	Base *
Catalyst	Non-Noble Base Metal	Non-Noble Base Metal	Noble Metal containing
Technology	SynHDS	SynShift	SynSat
Primary Goal	<ul style="list-style-type: none"> • Deep HDS • Some Density Reduction • Some Cetane Increase 	<ul style="list-style-type: none"> • Selective Ring Opening • Deep HDS/HDN • Some HDA • Density Reduction • T95 Shift • Cetane Increase 	<ul style="list-style-type: none"> • Deep HDA • Density Reduction

* Revamp achievable within the existing units pressure limitation.

For revamp Examples 1 and 2, there were specific advantages for the use of a countercurrent reactor in revamping the existing HDS units particularly in view of the 10 wt.% total aromatics specification for Phase II. The advantages included the following:

- Use of the cocurrent / countercurrent reactor system in conjunction with the right SynCat catalyst combination provides improved hydrogenation performance at the available pressures and temperatures through the increased hydrogen partial pressure afforded by the countercurrent reactor.
- Unlike cocurrent only reactor systems which rely on hydrogen-rich treat gas to the reactor inlet and interbed quench (where required) to achieve and maintain the desired minimum hydrogen partial pressure, the countercurrent reactor provides the opportunity to introduce hydrogen-rich gas directly into the reactor in such a way so as to maximize the benefit from its higher H₂ purity/content. Hydrogen-rich gas is added countercurrent to the downflowing liquid, thereby further enhancing the increase in H₂ partial pressure achieved in the countercurrent catalyst bed. The hydrogen-rich gas can be circulated treat gas, make-up hydrogen or a mixture of both, depending on the hydroprocessing needs and optimum hydrogen utilization within the unit.
- For such revamps in particular, where existing treat gas

compression was limited, the use of hydrogen-rich make-up gas in the countercurrent reactor instead of additional circulated treat and quench gas (such as would be required with a cocurrent reactor) provided debottlenecking and better hydrogen utilization opportunities and lower revamp investment.

- The upflowing hydrogen and light ends generated by the reactions taking place continuously assist in the strip-out of H₂S and NH₃ from the downflowing reactant liquid in the countercurrent reactor. Even through a packed stripping section (or separate stripper) is utilized specifically for this purpose as part of the reactor system, the fact that the upflow of gas through the countercurrent catalyst bed assists with this strip-out is of importance from the standpoint of obtaining maximum catalyst activity and life.

The above noted advantages contributed to reducing the amount of catalyst required for a specific objective, and are applicable to pull-apart and add-on revamps, as well as new units.

Example 3

For the third example, the refiner required a staged revamp of their existing unit in order to produce diesel meeting changing specifications, in conjunction with a unit debottlenecking. In this case, the refiner's objectives called for <10 wppm sulfur as a first revamp phase, followed by <10 wppm sulfur and 1 wt.% polynuclear aromatics as a second revamp phase. For the second revamp phase, there were also ASTM T95 and density reduction requirements and cetane improvement. Table 8 summarizes the feed blend to the unit and the diesel quality produced by the revamped unit for each phase of the revamp.

Table 8

	Feed Blend	Phase I HDS Revamp	Phase II HDS/HDA Revamp
API Gravity	33.4	36.0	38.0
Sp. Gr. @ 15.6°C	0.8580	0.845	<0.835
Sulfur, Wt.% (wppm)	1.04	<10	<10
Nitrogen	207	<10	<5
Bromine No. gr/100 gr	3.7		
Cetane Number (Index)	49.2	52	(56.5)
Aromatics, Wt.%			
Monos	18.6		
Polys	14.1		
Total	32.7	11	1
Distillation D86 T95°C	376		345

In this revamp, a pull-apart approach was designed somewhat analogous to that which is illustrated by Figure 5, whereby a second cocurrent reactor was added in series for Phase II. Table 9 illustrates how the specific non-noble metal SynCat catalysts, utilized in this case, would be changed from Phase I to Phase II revamps. Like Example 2, the SynCat catalyst used for Phase I is specifically tailored for ultra deep HDS via SynHDS. However, for Phase II the non-noble metal SynCat catalysts utilized in the cocurrent first stage reactor constitutes SynShift. In this case for Phase II, non-noble metal SynCat catalyst is used in the cocurrent second stage reactor. The basic difference between revamp Examples 2 and 3 is in the difference in Phase II revamp diesel specifications, with Example 2 requiring deep HDA to achieve 10 wt.% total aromatics, while Example 3 requires 1 wt.% polynuclear aromatics specification, thereby requiring less overall HDA then in Example 2. Both revamp examples utilize SynShift in the first stage reactor to achieve the desired cetane improvement, and T95 reduction. However, in this Example 3, the required level of HDA can be economically achieved without the use of a countercurrent reactor and interstage stripper.

Table 9

	Phase I HDS Revamp	Phase II HDS/HDA Revamp	
	Cocurrent Reactor	Cocurrent Reactor	New Cocurrent Reactor
Pressure	Base *	Base *	Base *
Catalyst	Non-Noble Base Metal	Non-Noble Base Metal	Non-Noble Base Metal
Technology	SynHDS	SynShift	SynSat
Primary Goal	<ul style="list-style-type: none"> • Deep HDS • Some Density Reduction • Some Cetane Increase 	<ul style="list-style-type: none"> • Selective Ring Opening • Deep HDS/HDN • Some HDA • Density Reduction • T95 Shift • Cetane Increase 	<ul style="list-style-type: none"> • Polynuclear Aromatics Reduction • Some Additional HDA • Density Reduction

*Revamp achievable within the existing units pressure limitation.

Conclusion

Through the application of the right combination of high activity SynCat catalysts, reactor system arrangement and advanced reactor internals, various revamp options are available to refiners from the SynAlliance. Advantages include:

- Advance reactor internals can provide improved catalyst utilization, extend cycle length, and increase SOR/EOR operating temperature window, while requiring less reactor volume.
- Hydrogenation efficiency can be improved at a given operating pressure;
- Lower pressure hydrotreater can achieve more severe hydroprocessing goals;
- Improved hydrogen utilization within the unit maximizes H₂ partial pressure;
- Opportunities exist for revamping lower pressure hydrotreaters to process poorer quality feedstocks, improve diesel quality, and increase capacity, if required;
- Flexible reactor system configuration is able to produce

different diesel product qualities;

- Various pull-apart and add-on revamp options are possible;
- Add-on revamp provides a logical approach to revamping bottlenecked hydrotreaters that have physical layout and/or constructability constraints;
- Possibility to incorporate a "no regret" future revamp strategy to achieve other hydroprocessing goals via a logical cost-effective revamp should it become necessary due to diesel specification changes;
- Opportunities exist for minimizing revamp investment;
- Revamps can be logically implemented in stages, thereby phasing the investment.

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