

# Avoiding unplanned reactor shutdowns

In hydroprocessing operations, prevention is better than just dealing with the effects of corrosion and fouling problems

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Refineries worldwide are showing a growing interest in processing a wide range of renewable feedstocks and opportunity crudes. These can provide good commercial opportunities, but unfortunately also often feature more impurities, impurities of different, less familiar types and high total acid numbers. This in turn usually means having to deal with larger amounts of corrosion debris and other contaminants from upstream equipment and fittings.

In the chemically aggressive operating environments prevalent in refineries, older installations wear and corrode faster and more easily because they were not designed to cope with these many, newer kinds of more corrosive feedstocks. Such corrosion problems will only increase and accelerate, because it is an inescapable fact that the majority of refineries were built more than 40 years ago, and we are unlikely to see new refineries built in economies reducing their reliance on fossil fuels.

## Corrosion and fouling impact on hydroprocessing

Hydroprocessing units are critical in effective refinery operations, and such corrosion – along with other forms of contamination that affect what is going on in the reactor – is one of the major causes of unplanned shutdowns here.

Any such unscheduled stoppages usually end up costing millions of dollars, with knock-on effects and penalties that reverberate throughout the supply chain. This makes them the one thing refineries want to avoid.

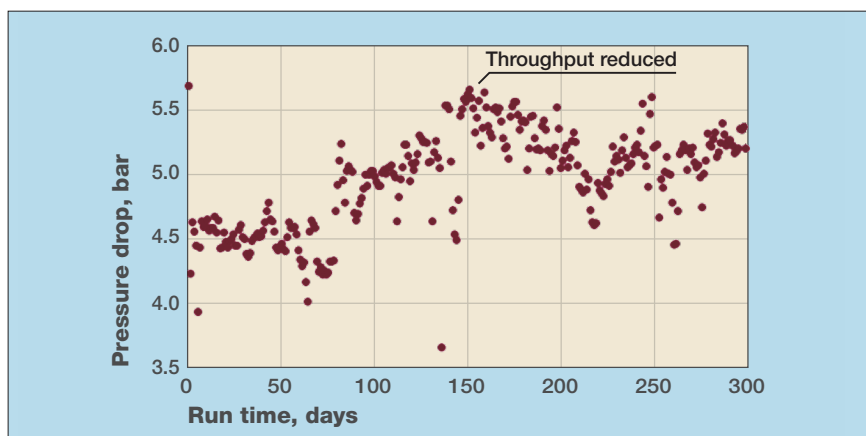


Figure 1 The refinery had to reduce throughput in order to reduce the pressure drop

## Pressure drop is disruptive and expensive

Corrosion particles and other contaminants entering the hydroprocessing reactor cause build-up of pressure drop across the hydroprocessing reactor by blocking the feedstock's passage through the catalyst bed.

Two scenarios are common, usu-

ally depending upon how the scale particles are distributed in size (see Figures 1 and 2). The first is when the many corrosion particles and contaminants lodge in the voids between the catalyst pellets and accumulate more or less homogeneously throughout the grading, and sometimes even down to the active catalyst layer. The pressure drop

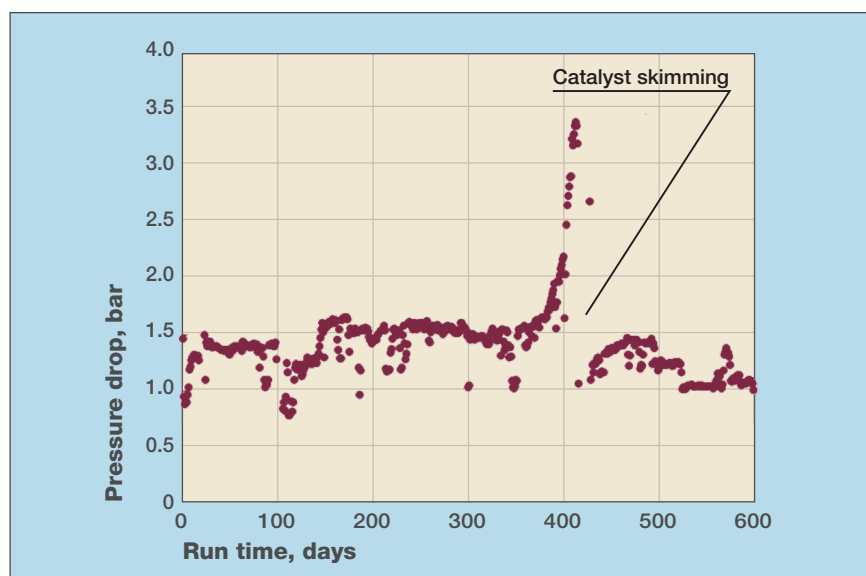


Figure 2 The refinery had to perform a catalyst skimming operation in order to complete the desired cycle

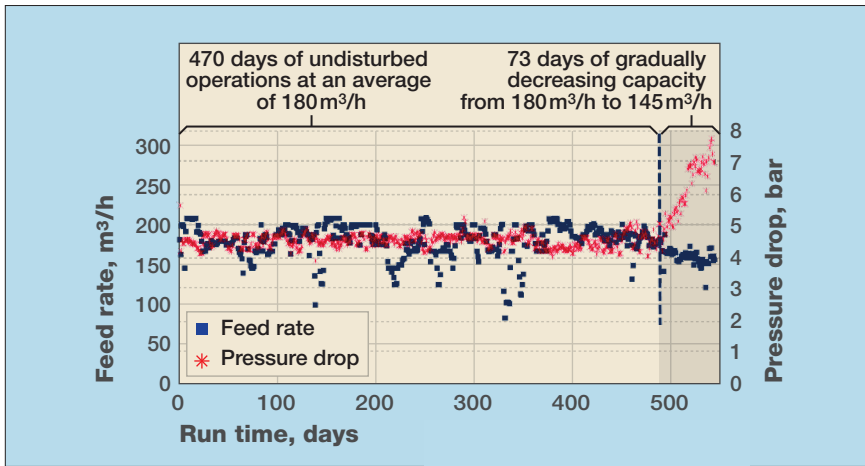


Figure 3 Reduced capacity for 73 days cost this refinery €2.3 million

build-up across the hydroprocessing reactor is then fairly continuous and relatively steady.

The second is when the contaminants get trapped in a relatively narrow layer between the different grading layers. In such cases, the pressure drop builds up exponentially and is very unpredictable. In these cases, the hydraulic or mechanical limitation of the reactor is often reached rapidly and it is therefore necessary to deal with it urgently.

Catalyst bed plugging is directly related to the total bed void available for contaminant deposition. As the available catalyst bed void is reduced over time, pressure drop develops across the reactor. The details are different for each catalyst type and shape as well as specific loading, but the overall pressure drop pattern is similar for all of them. The critical point is reached when the bed void volume is reduced to 20-25% of the original void available. From this point on, the pressure drop development curve is exponential. This is the point of no return as far as reactor shutdown is concerned.

### Two realistic solutions

Once pressure drop has started escalating, the refinery is normally left with only two realistic solutions.

If the planned turnaround is fairly imminent and the refinery wants to keep the plant running until then, it is possible to reduce throughput and the recycle gas rate until the unit can be shut down for catalyst replacement, and accept the loss of revenue this would involve (see **Case 1**).

On the other hand, if it would cost less to take the unit out of operation completely for around 15 days, it is possible to 'take the top off the contaminant load' by skimming the catalyst bed.

Managing and coping with pressure drop build-up and its many effects are multi-faceted endeavours for any refinery. The aim is to ensure the maximum productive on-stream duration at the design throughput of the specific unit with the specific catalyst loading and grading configuration, up to the pressure drop limitation.

### Case 1: Cost of operating at reduced capacity

A 27 000 b/d hydrotreating unit operated for 470 days undisturbed. After 470 days, the reactor started experiencing pressure drop build-up and, consequently, the refinery chose to start reducing the feed rate in order to delay the shut-down. The unit was able to run for another 73 days.

In those 73 days, the loss of production was 61 300 m<sup>3</sup>, corresponding to 386 000 bbl. At a €6/bbl diesel spread, this corresponds to a total cost of €2.3 million for the reduced production (see **Figure 3**).

### Reducing risk and uncertainty

Unscheduled interruption of refinery operations involves uncertainty and risk – which are always bad for business.

Different kinds of temporary solutions and traditional preventive measures enable refineries to reduce risk and uncertainty, and improve

processing efficiency by ensuring better control of what is happening in the reactor at any given time.

### Partial solutions are common

There are several traditional ways to try to prevent and deal with difficulties with pressure drop build-up across hydroprocessing reactors.

### Feed filters

Topsoe recommends always having effective feed filter systems installed upstream of the reactor pump, in order to prevent the influx of carry-over contaminants from transport and/or upstream processing.

Effective filtration requires a filter medium specifically configured to allow the right amounts of liquid to pass through, while holding back solid particles exactly as required. An effective, well-functioning feed filter normally removes impurities with particle sizes down to 25 microns.

Selection of the most appropriate filter type depends on feed type and quality, temperature and fouling level. The actual location of the feed filter also plays an important role in maximising filtration effectiveness, because the viscosity of the feed has to be low enough to ensure smooth filtration of impurities and to extend the filtration cycle.

### Grading solutions

Conventional grading solutions are effective and satisfactory in many reactor operations. However, as soon as a refinery has fouling problems due to the incoming corrosion products and other particles (such as coke fines, salts or silicon), special care should be given to the design of the grading layer to ensure cost-effective operation.

The principle behind pressure drop build-up prevention is to use grading materials of differing sizes, shapes and specifications on top of the bulk catalyst in order to create a filtering effect that traps the largest inorganic feedstock contaminants in the upper layers and the smaller particles in the lower layers.

In order to prevent undesired products (such as polymers or crusts) forming inside the reactor, the grading catalytic activity must

be incremented from the inert topping to the bulk catalyst to control the level of these reactions.

### Skimming

When the previous two solutions are not enough to avoid pressure drop build-up, probably the most common 'fix' for staving off the effects of fouling problems is catalyst bed skimming.

This process usually involves a reactor cooling period extending over several days, blinding off all the pipes and connections, opening the reactor, vacuuming the affected catalyst, reloading fresh catalyst and then restarting the whole unit. These time-consuming and costly measures (see **Case 2**) are normally sufficient to remove the most obvious plugs, encrustations and agglomerated catalyst particles.

However, an unknown quantity of contaminants will still remain in the reactor, which means that the pressure drop limit will still be reached more quickly than with a completely fresh catalyst load, and there will still be a considerable element of unpredictability.

This means skimming does not solve the problem – it only buys time before the next reactor shut-down. And the additional cycle time gained becomes progressively shorter after each skim.

Conventional uses of feed filters, relatively standard catalyst grading and occasional skimming operations if/when needed are really only delaying the inevitable. If they are not configured to deal with the specific corrosion and fouling problems in the refinery's operations, then repeated, revenue-denting skimming operations become unavoidable, and they will take place unpredictably. Which is always bad for business.

This approach does not bring reactor pressure drop into the realms of the controlled and predictable, where it can be planned for and scheduled.

### Case 2: Time is money

The reactor downtime required to carry out a single skimming operation can easily exceed seven days.

In a naphtha reactor designed for

Mounting cost of a single skimming operation		
<b>Activity</b>	<b>Duration in hours</b>	
Reactor cooling	96	
Pipe blinding	12	
Inertization	3	
Removal of inlet diffuser	3	
Unloading of affected catalyst	12	
Reloading of fresh catalyst	12	
Unit integration	4	
Activation	36	
Production	Time "zero"	
Total hours	178	
	<b>Cost (EUR/day)</b>	<b>Total cost (EUR)</b>
Contractor costs (equipment+ manpower)	~25 000	~175 000
Loss of production (15 000 bpd + 6 EUR/bbl refining margin)	~105 000	~735 000
Total cost of skimming	–	910 000

**Table 1**

a cycle length of 5–10 years, skimming operations may have to be carried out as many as five times. In such cases, up to 35 production days can easily be lost to skimming over the five-year period.

Topsoe documentation shows that a single seven-day skimming operation in a 15 000 b/d naphtha hydrotreating unit costs approximately €910000 in terms of direct costs and loss of production – and that is a conservative estimate.

**Table 1** shows how this all quickly adds up.

### Knowing what to do – and what is best

For any reactor affected by pressure drop build-up issues, there are three basic likely causes:

- Corrosion products from upstream storage and refinery equipment – or elsewhere in the supply or processing chain
- Solids, debris and other contaminants present in the feedstock
- Deposits in the catalyst bed resulting from reaction products

In order to know how best to tackle the problem(s) involved, it is crucial to identify:

- The exact problem(s)
- The exact cause of these operating glitches and problem(s)
- The specifications and condition of the feedstock being processed
- The type, size and distribution of the contaminant materials
- The operating profile of the specific hydroprocessing reactor.

### Nothing beats analysis and experience

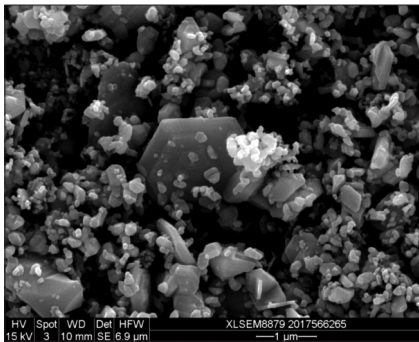
Forty years of Topsoe experience with these refinery processes makes it crystal clear that there are no cookie-cutter answers in reactor chemistry and managing the build-up of pressure drop across hydroprocessing reactors. Nothing beats analysis, experience and expertise when tackling complicated reactor operating challenges.

The company therefore insists on examining every operating context and reactor configuration individually, on a case-by-case basis, aiming to identify the exact nature and scope of the problem in order to tailor a suitable solution to each refinery's specific operating circumstances.

### Long-term comparative data

Relevant and representative spent catalyst samples are crucial to any detailed understanding of contamination type, degree and profile. As one of the world's largest catalyst providers, and the first company to pioneer the concept of catalyst grading by size, void and activity, starting with the introduction of Raschig rings 40 years ago, Topsoe has unparalleled access to long-term data and practical experience about the reactor chemistry and practical details about fouling problems.

One way to do this is to sample the catalyst and corrosion materials while the reactor is being unloaded, to secure valuable information



**Figure 4** Micrometre-sized scales generated from nucleation and growth of iron sulphide crystals



**Figure 5** Millimetre-sized debris from steel degradation due to corrosion and/or erosion particles downstream of the feed filter

about the contamination profile and how certain contaminants migrate through the different catalyst layers. The company also conducts comprehensive analysis of spent catalysts.

### Sampling provides accuracy and insights

The company's specialists use advanced analysis tools to identify the exact nature of the often intensely complex chemical processes involving feedstocks that contain a highly diverse range of contaminants and corrosion products. Unfortunately, it is difficult to realistically simulate the whole processing cycle in fixed-bed reactor contamination processes in lab-scale set-ups or in pilot units. This is why a lot of development work on new, improved catalysts and other products capable of trapping corrosion particles and dealing with crust formation problems relies on retrieving and analysing spent materials from real-world refinery operations.

This is usually done by installing test baskets or canisters in a particular location within a specific hydroprocessing reactor. Such canisters hold multiple catalysts in different compartments, to measure and test how each reacts to a known set of contaminants in the course of the entire cycle. The canister is removed once the cycle is complete.

In collaboration with refiners all over the world, Topsoe is able to install more than 100 such test canisters in different hydroprocessing set-ups every year, in order to sample and analyse the contents – including the material trapped in the voids between the particles – and exactly what has happened to them.

One of the methods the company's labs use to analyse the contaminants entering the reactor is scanning electron microscopy (SEM, see **Figures 4 and 5**).

### Spectrum of solutions

'One size fits all' or 'best guess' approaches simply cannot provide the refiner with a catalyst loading and/or filtering hardware to ensure effective protection of the active main bed catalyst. This impacts cycle length.

In order to have access to the flexibility and know-how necessary to deal with this large range of potential corrosion and fouling problems, refineries need to be able to draw on suppliers that can provide a substantial range of products, technologies and solutions suitable for the purpose – in many different combinations, tailored to individual operational requirements.

Topsoe provides a spectrum of solutions as well as technology-agnostic, R&D-backed advice about how best to deal with corrosion and contaminants in refinery feedstocks, and to prevent the resulting fall-off in unit performance and the reactor pressure drop build-up that ends up in unscheduled plant shutdowns.

### Conventional solutions sometimes are not enough

Feedstocks that contain corrosion scales, rust, fines, inorganic matter, and so on can cause excessive, uncontrolled pressure drop build-up in hydroprocessing reactors. This prevents these units from delivering maximum value, because operators are forced to undertake premature shutdowns in order to carry out

costly catalyst skimming operations, with big impacts on revenue.

A well-configured catalyst load can provide cycle lengths of four to five years or more, but such performance is often unobtainable in practice. This is because malfunctions and inefficiencies in feed filters and other up-stream equipment often result in corrosion debris and fouling agents contaminating any reactor feedstock.

Problems caused by these contaminants make it important to use a wide range of specialist graded bed catalysts to handle contaminants and foulants, each of which functions with its own chemistry. It can also be beneficial to combine these with the latest specialist grading technology and scale catcher configurations, in order to avoid skimming, prolong cycle length and ensure maximum efficiency for the main catalyst load.

In all cases, prevention is better than cure because there are such large amounts of revenue at stake.

Topsoe provides multiple proprietary hardware and catalytic technologies for installation inside hydroprocessing reactors.

Two of the main types of solution to help refineries deal with reactor contaminants associated with corrosion are dedicated grading and scale catchers.

### Dedicated grading

Topsoe provides a range of specialist grading products configured to help refineries deal with reactor fouling problems caused by solid contaminants (such as corrosion products, coke fines and salts) as well as reactions products formed inside the reactor (such as polymers, iron sulphide or crusts on the catalyst).

One of the key products for pressure drop control is the TK-26 TopTrap macroporous particulate trap. Larger-sized inorganic contaminants deposit in the spaces between traps; fines or smaller-sized materials enter the pore system and are trapped within the structure of the particles themselves. TK-26 TopTrap features a 61% particle void fraction as well as a large internal pore volume.

TK-26 TopTrap is often used in combination with other spe-

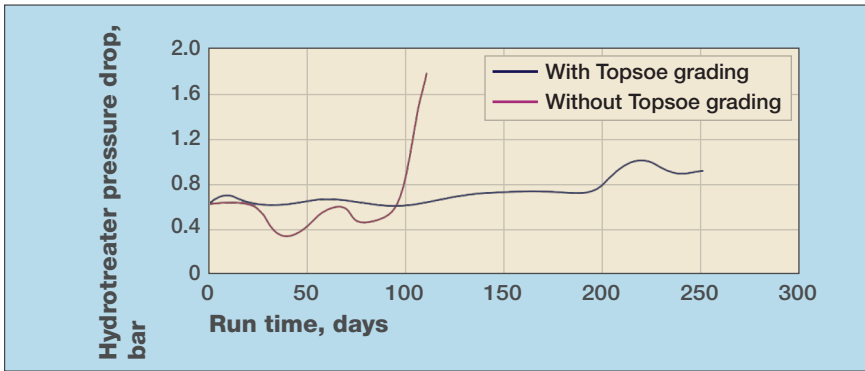


Figure 6 Pressure drop development over time in a naphtha hydrotreater

cial guards, such as the Topsoe SiliconTrap series in coker naphtha services. The conjugated diolefins in these streams can lead to polymerisation and subsequent bed fouling and the olefins and silica can form a crust on the catalyst – all leading to pressure drop build-up. The SiliconTrap series catalysts, TK-441, TK-447 and TK-449, allow optimum design of the graded catalyst system that, depending on feedstock reactivity and operating conditions, can be selected to maximise cycle length (see Figure 6).

This naphtha hydrotreater was experiencing severe fouling of the catalyst bed. This was caused by carbonaceous material spalling from the heater and heat exchangers. The installation of a graded bed solution removed this bottleneck and extended the cycle length. By avoiding three unit turnarounds, including replacement catalyst cost savings, the substantial financial impact at the refinery was significant.

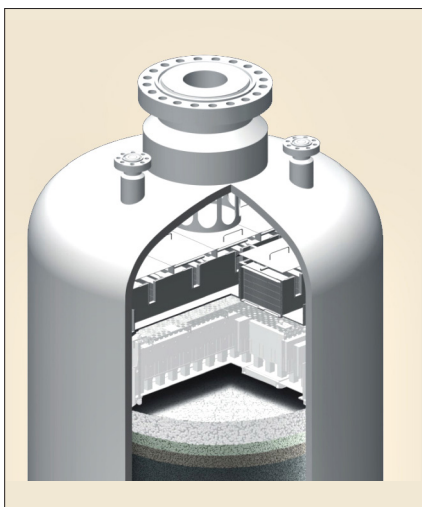


Figure 7 Topsoe's HELPsc scale catcher in the void above the distribution tray

### Scale catchers

Sometimes it is impossible to design the ideal grading solution because the amounts of contaminants are disproportionately high, and the grading required to deal with them and ensure a long cycle length – free of skimmings – would take up the whole volume of the reactor. In such cases, the best solution is usually a scale catcher installation in order to prolong run length, by preventing premature plugging of the catalyst bed below.

Topsoe scale catchers are well documented in hydroprocessing reactors worldwide. These scale catchers put any unused space in the top of the reactor vessel to effective use, providing the feed with sufficient time to settle, while slowly overflowing onto the distribution tray below (see Figure 7).

Scale catchers collect corrosion and erosion products, inorganic material, carbonaceous material and virtually any kind of solid phase particle. Low turbulence and long retention times make sure heavier particles settle in scale catcher compartments before the feed travels to the catalyst bed. This can reduce the amount of top

grading material needed – which therefore increases the volume available in the reactor for active catalysts.

Topsoe provides scale catcher solutions for both liquid and gas phase operation, capable of trapping both large and small particles. The designs are uncomplicated, easy to maintain, and easy to clean.

### High-Efficiency Liquid Phase scale catcher

The High-Efficiency Liquid Phase scale catcher (HELPsc) is a dual-stage set-up that combines mechanical equipment and tailored graded catalysts in filter cassettes. These cassettes can easily be removed during shutdown, keeping costly cleaning procedures inside the reactor to a minimum. The filters in the system are able to catch the smallest particles. This protects the catalyst bed and ensures longer cycle length (see Figure 8).

This figure shows how an installed HELPsc has improved the unit performance and profit of an FCC pretreater reactor. Before the installation, the reactor encountered pressure drop build-up after 100 days. In the first cycle after installation, the reactor did not experience pressure drop build-up and was shut down after 300 days due to insufficient catalyst activity. In the second cycle with HELPsc, the unit was able to operate for more than 500 days before pressure drop build-up was observed.

The process gas stream bypasses the scale catcher compartments entirely, keeping pressure drop across them negligible. Once the scale catcher is filled up, the entire process stream (both liquid and gas) simply bypasses the scale catcher,

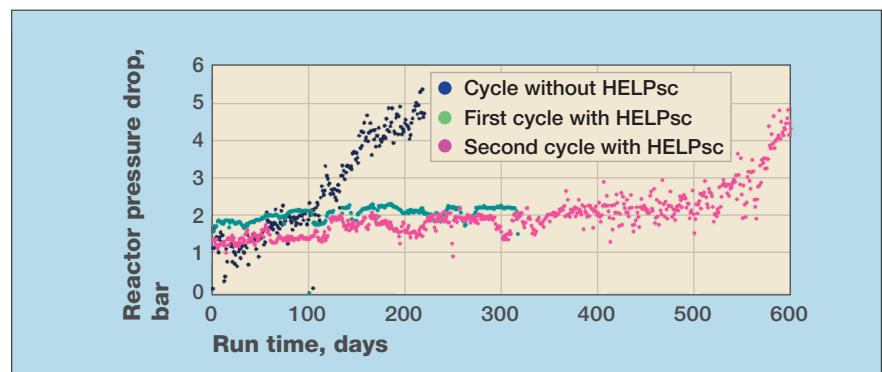


Figure 8 An installed HELPsc has improved the unit performance and profit of an FCC pretreater reactor

preventing any impact on reactor operations.

### UpScale scale catcher

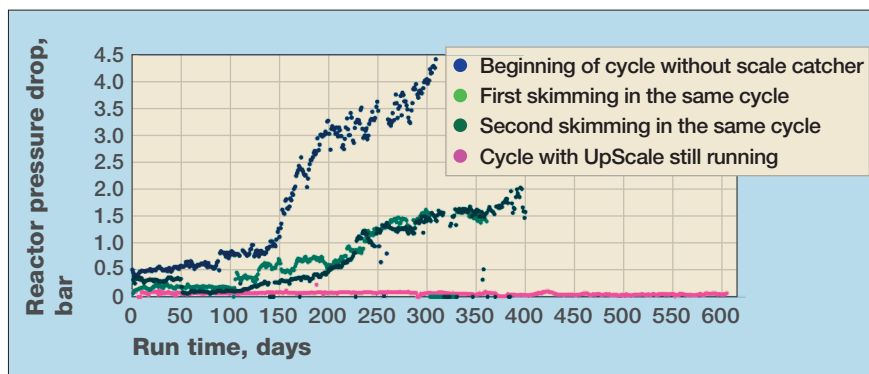
Gas phase reactors generally have a much longer cycle length than their liquid phase counterparts, and contaminants also build up over a longer period.

Nevertheless, many naphtha reactors are plagued by significant scale accumulation and fouling problems of this kind, with the particular difficulty that the characteristics of the scale particles are seldom known in detail. Unless the operator takes appropriate measures, such contaminants end up in the grading bed and/or catalyst, creating occlusions, hot spots and build-up of pressure drop.

As a result, many naphtha hydro-treaters are forced into frequent shutdowns so the affected part of the grading bed and catalyst load can be skimmed and replaced with fresh material. This significantly impacts the refinery's cost of operations as well as revenue flows.

In gas phase reactors, Topsoe therefore recommends installing UpScale scale catchers as a preventative measure that separates foreign material from the feed before it reaches the top of the catalyst bed. This can give a two/three-fold increase in the cycle length (see Figure 9).

UpScale gas phase scale catchers feature two distinct stages of scale capture. Large particles settle by gravity in the first stage, whereas tiny particles are captured by impaction in the second stage. The design also includes special features



**Figure 9** Performance of a 15 000 b/d naphtha hydrotreating unit before and after installation of UpScale. The installation of the gas phase scale catcher was able to save this refinery from one skimming until now and is projected to save the unit from at least five skimmings in total by the end of the cycle

to prevent particle re-entrainment.

Depending on the details of the scale formation the refinery wants to deal with, the two stages can be installed together or separately, or easily retrofitted as and when required.

Both HELPsc and UpScale scale catchers are easy to retrofit into existing reactors – installed above the reactor tangent line or the existing top distribution tray – making it possible to maintain the full catalyst volume inside the reactor.

### Conclusion

With pressure drop under control, a refinery can often increase cycle length by as much as 300%. With experience from over 6000 grading charges in 600 different units in more than 350 refineries all over the world since the company first introduced the idea of active catalyst grading in 1979, Topsoe is able to draw on a wealth of comparative, long-term data in order to optimise a refiner's capabilities.

HELPsc, UpScale, SiliconTrap and TopTrap are trademarks of Haldor Topsoe.

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