

LEVERAGING PROCESS KNOWLEDGE TO MAXIMIZE RELIABILITY

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Unplanned downtime of a process unit is a painful experience in the hydrocarbon processing industry. Sometimes an entire facility has to be brought down as the result of a key process unit failing. The cost of such an event is upwards of US\$1 million per day. At other times a process unit is taken off-line and the facility continues to operate but product blending becomes a nightmare, often at the cost of expensive imported components. In both cases, maintenance and inspection costs skyrocket. To add to the drama, each outage increases the risk of damage to the unit and/or the catalyst.

Less dramatic, but economically painful none the less, is the experience of having a process unit lose its ability to operate at 100% of its planned capacity or severity. A 1000 BPD throughput reduction in a process unit with an average incremental throughput value of US\$6/bbl can reduce a facility's profit margin by US\$2 MM/year.

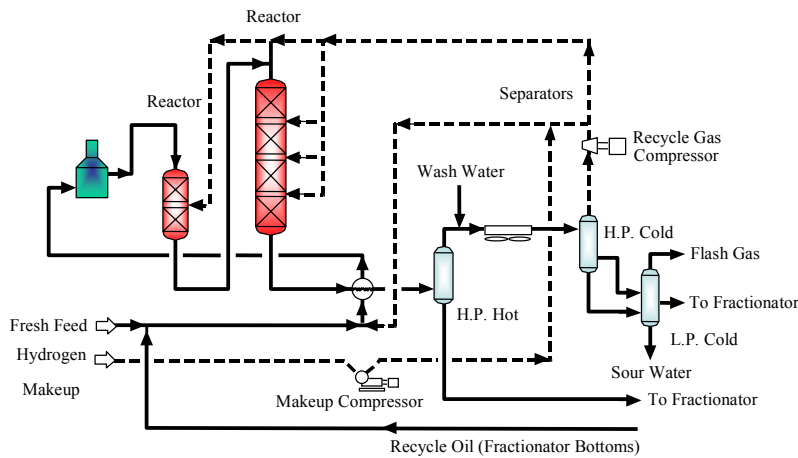
Process reliability is the key to avoiding these painful experiences. Process reliability is the ability of a process unit to perform its required function under stated conditions for a stated period of time. Process reliability is critical if a process unit is to deliver its products on stream, on specification and on demand.

The cornerstone of process reliability is process knowledge. Process-related factors - such as reactor temperature control, feed quality, water wash rates, etc. - have a large impact on an individual unit's ability to operate reliably. When properly applied, process knowledge can be used to maximize the reliability of a process unit.

TAKE A HYDROCRACKING UNIT FOR EXAMPLE

Hydrocracking is the conversion of hydrocarbon feed into lighter products in the presence of hydrogen and catalyst. The feedstock for a hydrocracking unit consists of high molecular weight hydrocarbons with high levels of sulfur, nitrogen, and unsaturates. The feedstock is mixed with recycle gas containing hydrogen and exposed to catalyst at moderate to high pressure of 100 - 200 kg/cm²(g) (1400 - 2800 psig) and moderate temperatures of 300°C - 450°C (570 - 850°F). During the reactions that take place, hydrogen is consumed, heat is released and products are formed. The products are lower molecular weight hydrocarbons with low levels of sulfur, nitrogen, and unsaturates. The key products are typically high quality kerosene and diesel.

Typical Hydrocracking Unit Reactor Section

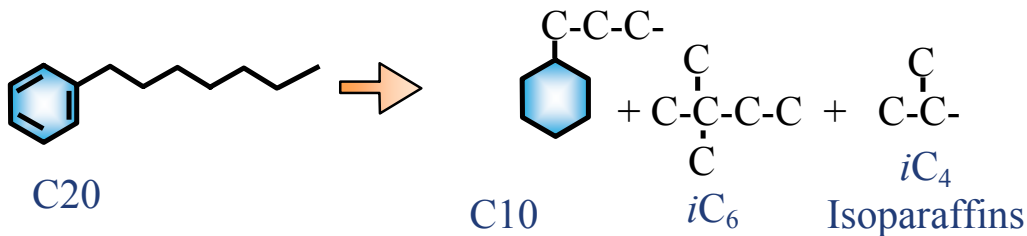


Three major areas where process knowledge can be used to increase the reliability of a hydrocracking unit include:

- Preventing reactor runaways
- Controlling catalyst deactivation
- Maximizing conversion while still controlling HPNA accumulation

PREVENTING REACTOR RUNAWAYS

Many of the reactions in a hydrocracking unit's reactor system are both exothermic and reaction rate limited. For example, in the overall reaction mechanism shown below, energy is released during the formation of the products. The energy is absorbed by the surrounding gas, oil and catalyst in the reactor and contributes to the general increase in temperature that is normally observed as reactants flow across the catalyst bed.



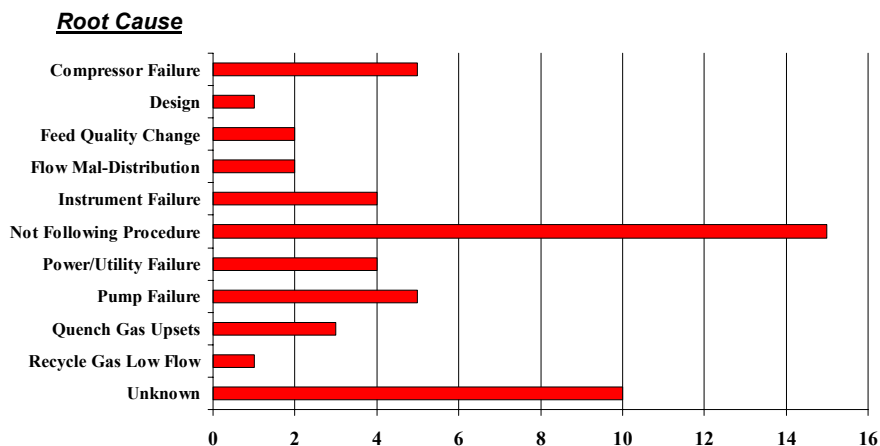
Because the reaction is reaction rate limited, and not equilibrium limited, increasing the temperature increases the rate of reaction. The heat release rate increases as a result which causes the temperature to increase further. Without proper heat dispersion the reaction can get out of control in a matter of a few minutes. Once the reaction “runs away”, the temperature inside the reactor gets hot enough to severely damage the catalyst and possibly damage the reactor itself. The result is a long and expensive unit outage.

Operating procedures can be devised to keep the reactions from getting out of control. Example procedures include:

1. Limit the temperature rise in hydrocracking catalyst beds. This limits the possibility of a localized portion of the reactor reaching an energy imbalance where the energy released by the reaction is not dispersed quickly enough.
2. Establish a minimum firing rate for the reactor furnace. Open bypass valves in the reactor feed / effluent exchanger train if necessary. This provides the ability to quickly reduce the reactor inlet temperature if needed.
3. Limit throughput and operating severity based in part on the need to operate with the quench gas control valves partially closed. Hydrocracking units are typically designed with quench gas addition to the reactor between catalyst beds. The addition of quench gas provides a heat sink for the energy. During an emergency, the quench valves must be able to open fully and deliver a significant sudden increase in quench gas flow in order to quickly disperse energy released by a runaway reaction.
4. Depressure the reactor section rapidly when the reactor temperatures exceed the normal operating level by an excessive amount (typically 25 - 30°C).

The significance of this issue with regards to the reliability of hydrocracking units is shown in the bar chart below - the most common root cause of temperature runaways is not following the appropriate procedure.

Temperature Runaways *Informal Survey of 52 Cases*



CONTROLLING CATALYST DEACTIVATION

Any attempt to define and measure process reliability for a hydrocracking unit has to take into account the fact that catalyst deactivation is expected in a hydrocracking unit. The “required function” portion of the reliability definition is “produce a given product slate with specified characteristics”. The “stated conditions” portion of the reliability definition is “process a given feedstock with specified characteristics”. The

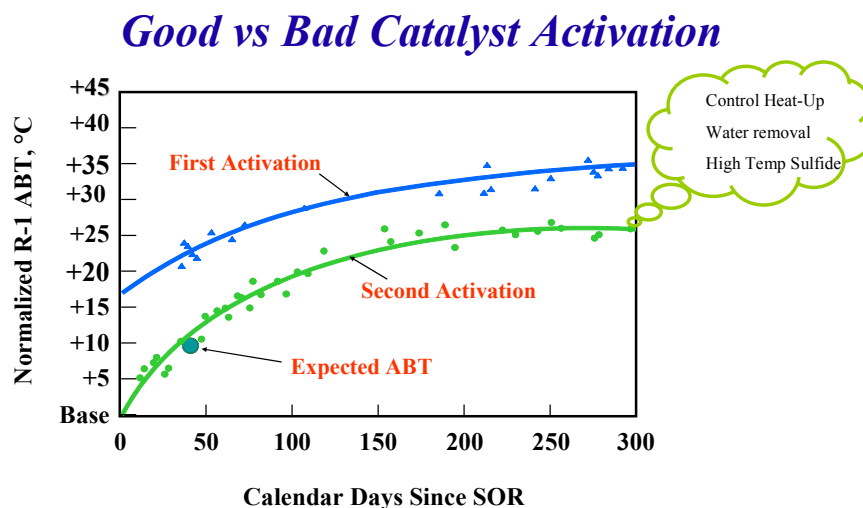
“stated period of time” portion of the reliability definition is the time between unit outages for catalyst and other unit maintenance.

Catalyst activity – the ability of the catalyst to perform the “required function” at a given catalyst bed temperature – is reduced in a variety of ways including coke formation, metals agglomeration and metals poisoning. As the catalyst deactivates operators have to increase the catalyst bed temperature. Each degree of temperature increase is considered one degree of activity loss. When the reactor’s temperature limit is reached the operating cycle is ended and the unit is taken off-line for maintenance. Alternatively the catalyst bed can become fouled to the point that run length is limited by pressure drop in the reactor. Therefore the “stated period of time” portion of the process reliability definition is particularly relevant here.

The “stated conditions” portion of the process reliability definition also requires close examination. One should not call a hydrocracking unit 100% reliable when an avoidable catalyst deactivation event is masked by switching the feedstock to a less than economically optimum alternative. For example, a 20% coker gas oil (CGO) / 80% straight run vacuum gas oil (SRVGO) typically has a greater marginal feedstock value than a 15% CGO / 85% SRVGO feedstock. The latter feedstock has a lower coking tendency. If an avoidable catalyst deactivation occurs, throughput and run length can be maintained by switching to the 15% LCO / 85% SRVGO. However, from a planning perspective, this is not the envisioned “stated condition”. After the deactivation event, the unit is inherently less profitable than it would have been had the event not occurred.

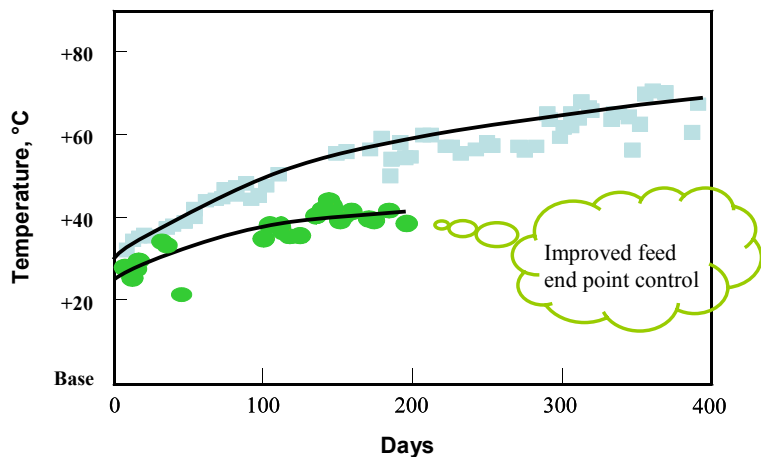
Fortunately, operating procedures can be used to control the rate of expected catalyst deactivation and avoid other modes of catalyst deactivation. Example includes:

1. Take care to properly activate the catalyst after loading it into the reactor. A poorly executed catalyst activation procedure can result in a 10-15°C activity loss.



2. Monitor the feedstock and take corrective action to maintain the specified feedstock characteristics. Process related corrective actions include:
 - a. Adjust the performance of upstream fractionation units to lower the feedstock's end point. Allowing the feedstock end point to exceed the allowable limit can create a 10-20°C activity loss.

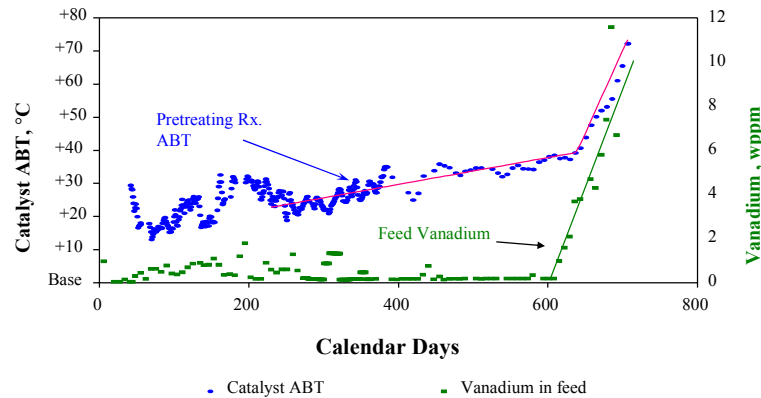
Feed End Point Control (2 Cycles with the Same Catalyst)



- b. Adjust the performance of upstream fractionation units to prevent entrainment of metals into the hydrocracking unit's feed. Also, pay close attention to the quality of the crude slate. The metals content of the crude slate should not exceed the upstream unit's ability to prevent excessive metals from ending up in the hydrocracking unit's feedstock. Catalyst in a hydrocracking unit has the capability to tolerate a defined amount of metals in the feed. Excessive metals in the feed results in a significant loss of activity.

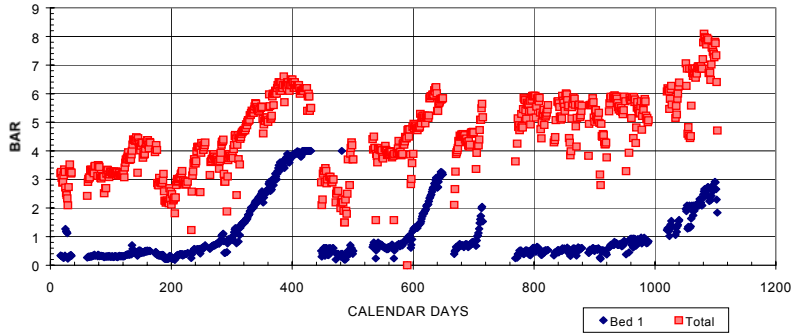
Catalyst Poisoning

Effect of Contaminant Metals in Feed



- c. Pay proper attention to upstream feed handling practices - prevent the formation of large molecular weight polymers during cold storage of the feed; select crude slates that are appropriate for the metallurgy of the upstream units so as to avoid excessive generation of corrosion products that find their way into the feed; take care to strip out H₂S in the fractionation section of hydrocracking units with recycle of fractionator bottoms to the reaction section to avoid generation of corrosion products in the recycle loop. Large molecular weight polymers and solids in the feed contribute to serious flow resistance across the catalyst beds. As the flow resistance increases, so does the pressure drop across the catalyst. The unit has to be taken off-line for maintenance when the pressure drop reaches the design limit.

Catalyst Bed Pressure Drop



MAXIMIZING CONVERSION WHILE STILL CONTROLLING HPNA ACCUMULATION

Heavy polynuclear aromatics (HPNA) are polycyclic, condensed hydrocarbons that contain seven or more fused aromatic rings. The vast majority of HPNA's with 7 to 10 ring (coronenes and ovalenes) are not native to straight run vacuum gas oil feed stocks but are instead formed in the hydrocracking unit's reactor section. HPNA's with 11 or more rings also exist. These larger HPNA's are also formed in the reactor section of the hydrocracking unit.

If permitted to accumulate in the reactor section of hydrocracking units where fractionator bottoms are recycled to the reactor section, HPNA's can cause equipment fouling and accelerated catalyst deactivation. One traditional method for controlling HPNA accumulation has been to limit the conversion of feedstock to products to less than 100%. This method typically requires a 5 to 10% fractionator bottoms drag stream to purge HPNA's from the unit.

Process knowledge can be applied to increase the conversion level from the traditional limit while still controlling HPNA accumulation. Examples include:

1. Do not limit the conversion level to a constant value throughout the catalyst cycle. Take advantage of the fact that HPNA formation is kinetic driven and that the reverse of the HPNA formation reactions are favored when the catalyst's hydrogenation function is strong. Both low reaction temperatures and strong hydrogenation function exist at start-of-run. Therefore, it is possible to elevate the conversion level at start-of-run and then slowly reduce the conversion level as the run progresses. The overall amount of product formed in the hydrocracking unit will be greater than if the conversion level was capped at the traditional constant value.

2. Instead of recycling the fractionator bottoms directly to the hydrocracking unit's reactor section, recycle the fractionator bottoms to the feed of the vacuum unit upstream of the hydrocracking unit. The vacuum column will route a significant portion of the HPNA's to the slop wax stream and will direct diesel left in the fractionator bottoms back to the hydrocracking unit. The conversion level in the hydrocracking unit can then be increased without creating an HPNA accumulation related problem.

CONCLUSION

Process knowledge, the cornerstone of process reliability, can be used to maximize the reliability of a process unit in the hydrocarbon processing industry. Using a hydrocracking unit as an example, three major areas where process knowledge can be used to avoid unplanned downtime or prevent loss of production capability were presented. For hydrocracking units, these three cases were preventing runaways, controlling catalyst deactivation and maximizing conversion while still controlling HPNA accumulation. Similar examples exist for all process units in the hydrocarbon processing industry. The value of using process knowledge to avoid unplanned process unit downtime or prevent the loss of process unit production capability can reach into the millions of US dollars annually.



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