The CONTACTOR™

Published Monthly by Optimized Gas Treating, Inc.
Volume 13, Issue 11, November, 2019

Sulphur Processing Operations during Startup, Shutdown, and Turndown—Part II

In Part I of this series, we discussed in detail the operations of sulphur plants during startups, shutdowns, and turndown scenarios and presented a case study. The results and findings from that case study are discussed in this issue.

As seen in Table 1, as the unit is turned down from 100% to 60%, and then 30%, the most notable change is in the WHB operating conditions. At 30% turndown, the peak heat flux is reduced to nearly half of the base case of 100% throughput. This results from the severely reduced mass flux through the unit. The overall sulphur conversion, sulphur recovery, and CS_2 in the tail gas seem not to be highly affected. Pressure drop, although not directly calculated, reduces significantly with turndown.

Hydrogen in the Claus tail gas drops quite significantly from the Base Case design as turndown progresses. This can have significant impacts on the performance and reliability of a reduction-quench-amine type Tail Gas Treating Unit (TGTU) downstream. The reducing gas demand is increased per unit volume of feed gas as the unit is turned down, meaning either more external hydrogen or more natural gas must be combusted substoichiometrically in the TGTU Reducing Gas Generator (RGG) at turn down. Insufficient hydrogen increases the risk of SO_2 breakthrough during turndown operations. Additionally, if the TGU Hydrogenation Reactor catalyst is not fully active, then COS and CO conversion tend to fall off first [1].

At turndown, there is significantly higher COS concentration in the Claus tail gas. Even though rates are reduced, meaning more residence time is available in the Hydrogenation Reactor catalyst, if the TGU catalyst is sick, then unconverted COS will slip through the TGU amine system to the Incinerator.

If there is not a TGU downstream of the Claus unit, then stack emission concentrations directly increase in proportion to the unconverted sulphur. Incineration systems that are permitted on a concentration basis of SO_2 in the stack will see an increase in SO_2 at turndown, which should be considered at the design stage.

In addition to these points, there are two further complications with turndown operations. The first is the formation of sulphur fog in the sulphur condensers. The second concerns heat loss. In the case of sulphur fog, conversion to elemental sulphur is not affected directly. It is the recovery of sulphur within the Condensers that suffers. At low mass velocities (< 1 $lb/s\cdot ft^2$), fine droplets of elemental sulphur mist evade capture by conventional mist elimination equipment leading to loss of sulphur recovery efficiency. The risk of reaching the sulphur dew point in a downstream sulphur converter increases, and this is compounded by increased heat loss.

	100% of Design 125 LTPD Base Case	60% of Design 75 LTPD Case 1a	30% of Design $\approx$40 LTPD Case 1b
Sulphur Throughput (LTPD)	125	75	40
Air Flow (lbmol/hr)	928	560	302
Reaction Furnace Temperature (°F) #	2390	2400	2410
WHB Peak Tube Wall Temperature (°F)	545	530	517
WHB Peak Heat Flux (Btu/hr·ft²·°F)	36,000	26,200	18,200
WHB Mass Flux (lb/s·ft²)	3.0	1.8	0.97
Sulphur Conversion (%)	96.95	96.85	96.75
Sulphur Recovery (%)	96.46	96.43	96.33
Hydrogen in Tail Gas (mole %)	1.9	1.5	1.18
COS in Tail Gas (ppmv)	319	374	455
CS_2 in Tail Gas (ppmv)	0.6	0.55	0.5

Simulations ignore heat loss.

Table 1. Parametric Results from Turndown Case Study

Besides the sulphur dew point concerns in the catalyst beds, heat loss reduces the temperature in the Reaction Furnace and is exacerbated at turndown. Blais et al.[2] provided a methodology to estimate heat losses in the Reaction Furnace.

Because both the heat loss and sulphur fogging concerns are highly specific to plant configuration, we chose not to explore these facets in this particular work. However, these relative influences are blunted somewhat also by the choice to limit the turndown in a sulphur plant to 30% of design. In the case of a well-designed sulphur condenser, the risk of fogging losses is minimal at 30% hydraulic load.

Table 2 compares the unit operating at 30% turndown on acid gas only versus operating at 30% hydraulic turndown on a mixture of acid gas and natural gas. This latter case is illustrative of an operating point half way through pulling the acid gas out during a shutdown. The Reaction Furnace temperature is a significant concern (+400°F) for both these cases. Here, we limited the temperature by adding tempering steam in the simulation.

	Base Case	≈30% of Design Acid Gas Only Case 1b	≈30% of Design 50:50 Acid Gas with: Natural Gas Case 2
Sulphur Throughput (TPD)	125	40	20
Air Flow (lbmol/hr)	928	302	341
Reaction Furnace Temperature (°F)[#]	2390	2410	2815
WHB Peak Tube Wall Temperature (°F)	545	517	530
WHB Peak Heat Flux (Btu/hr·ft^2·°F)	36,000	18,200	26,200
WHB Mass Flux (lb/s·ft^2)	3	0.97	0.865
Conversion (%)	96.95	96.75	91.29
Recovery (%)	96.46	96.33	89.65
Hydrogen in Tail Gas (mole %)	1.9	1.18	4.6
COS in Tail Gas (ppmv)	319	455	720
CS_2 in Tail Gas (ppmv)	0.6	0.5	0.4

[#] Simulations ignore heat loss

Table 2. Parametric Results from 50% Startup/Shutdown Case Study

Note also from Table 2 that significant changes occur in the WHB and downstream tail gas. The peak heat flux for acid gas alone shows a considerable reduction compared to the full-rate operation. However, when operating on the acid gas plus natural gas mixtures, the peak heat flux shows much less decrease. This can be explained through the much higher Reaction Furnace temperatures for the mixture cases. Because a considerable amount of the combustibles are now hydrocarbon rather than acid gas, the temperature within the furnace is much higher. Tempering steam is needed while combusting significant amounts of hydrocarbons, not only to keep the temperature moderated, but also to mitigate soot formation.

The overall conversion and recovery is quite considerably reduced under the startup/shutdown operations compared to both the full rate, and even vs. 30% turndown on acid gas only. If the operating company is mandated to meet a certain percent recovery or a given SO_2 concentration in the stack, this could very plausibly prevent the plant from meeting the permitting requirement.

Conclusions

Although startup and shutdown procedures are short term actions in any sulphur processing facility, there are long term implications if not properly considered integrally, both during the design phase, as well as during operations. Careful measures need to be taken to avoid damaging the integrity of the unit, which will cause untimely repairs to be required. Utilizing the kinetic and heat transfer rate-based sulphur simulator, SulphurPro®, will help give much better understanding of the operations during these procedures, allowing steps to be taken to plan for and mitigate potentially costly events revealed by the simulations.

Turndown also needs to be carefully monitored and given ample consideration right from the start. Knowing the limitations of the unit and what may occur during these turndown operations will help prevent unnecessary repairs and downtime. Design targets can additionally be set more intelligently using the rate based kinetics of SulphurPro.

References

1. *Low Temperature Tail Gas Kinetic Functions – What They Are – Really*, Karl Krueger, Fernando Maldonado, Michael Huffmaster, Brimstone Conference Proceedings 2016
2. *How Hot is Your Reaction Furnace — Really?*, Blais, D., Marshall, C., Wissbaum, D., Proceedings of the Laurance Reid Gas Conditioning Conference, February, 2012, Norman, OK.

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