The CONTACTOR™

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Heat Loss in a Thermal Reactor at Turndown

Heat loss in a thermal reactor can be a real concern. Cold climate conditions and turndown are just a few examples of when this starts to become significant. In this edition of The Contactor, we will investigate the extent to which heat loss can affect critical, temperature-dependent reactions, such as ammonia destruction.

To get a better understanding of why we might be concerned with heat loss, we first need to understand kinetic reactions, such as that of ammonia destruction. Ammonia destruction is a kinetically rate-limited reaction and fundamentally relies on several factors. These include time (or how much residence time is available in the reaction vessel), temperature (the higher the temperature is the faster the reaction proceeds), and turbulence (or how well the process gas stream is being mixed with combustion air in order to get a good mix between the fuel and air). Typically, at turndown, the gas stream is flowing at a much-reduced rate through the same reactor volume, so residence time is usually not a concern as it is much longer at turndown compared to operation at design rates. Mixing is provided by the burner nozzle, so depending on the characteristics of the burner, mixing can start to become a problem, especially at highly turned-down rates. Burners usually have a turndown limit, so understanding what this is for your specific burner and maintaining a flowrate above that limit is crucial to maintaining the mechanical integrity of the burner. SulphurPro® can account for some of the imperfect mixing seen in most commercial burners, but in no way is it a rigorous burner model; thus, in this study, will not be focused on mixing. Temperature is the final piece of the kinetic reaction picture and it is the focus of this study. Specifically, for ammonia destruction, as the temperature drops below a certain threshold (typically less than 2300ºF or 1260°C), the rate at which the reaction proceeds slows appreciably.

Heat loss in a thermal reactor results from several causes. These include cold climate temperatures, heavy rain, and poor thermal insulating (shroud, etc.), problems that can be further exacerbated under turndown conditions from the reduced thermal mass passing through the vessel.

The case study here shows quantitatively how turned-down rates affect the heat loss from a unit. Keep in mind that the actual results may vary from plant to plant. This particular unit is a gulf coast refinery processing both amine acid gas (AAG) and sour water stripper acid gas (SWAG) at a combined rate of approximately 125 TPD in a two stage Claus Sulphur Recovery Unit (SRU). Both the AAG and SWAG were fed into the main burner of the thermal reactor at a ratio of approximately 6:1 (AAG:SWAG).

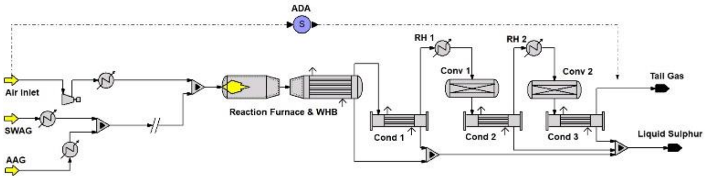

Figure 1. SRU Flowsheet

With any calculation, there are some inherent assumptions that need to be made. The assumptions here include assumed ambient air temperature, wind speed, shroud air gap, thickness of brick, and thickness of the refractory. Since we're talking about a gulf coast refinery, the assumptions outlined below are typical for that region.

Table 1. Assumptions for Heat Loss Calculations

Ambient Air Temperature	75°F (24°C)
Wind Speed	5 mph (8kph)
Shroud Air Gap	4 in (10 cm)
Thickness of Hot-face Firebrick	6 in (15 cm)
Thickness of Cold-face Refractory	4.5 in (11.4 cm)

With these assumed parameters, heat loss can be estimated for the given location and ambient conditions.

At normal rate, the thermal reactor operating temperature was approximately 2350°F (1288°C). This is right on the edge of the 2300°F (1260°C) lower limit for adequate ammonia destruction. The amount of heat loss here is almost negligible only accounting for about a 40°F difference between the case with no heat loss to the case which did account for heat loss. As we turn the unit down, the heat loss starts to become a bit more significant. Table 2 shows the difference between no heat loss and heat loss at each step in the turndown process.

Table 2. Calculated Operating Temperatures with and without Heat Loss

Flow Rate (TPD)	No Heat Loss (°F)	With Heat Loss (°F)
125 (Full Rate)	2388	2350 (ΔT = –38)
75	2399	2336 (ΔT = –63)
40	2408	2293 (ΔT = –115)

As the unit is turned down, the heat loss starts to become more significant the further the flowrate is reduced. What does this mean for kinetic reactions such as ammonia destruction?

Table 3 shows each step in turndown and the corresponding ammonia effluent concentration in ppmw. Generally, industry accepts 150 ppmw as an acceptable amonia level thermal reactor effluent.

Table 3. Effluent Ammonia Concentration vs. Turndown (Accounting for Heat Loss)

Flow Rate (TPD)	Effluent Ammonia (Dry ppmw)
125 (Full Rate)	96.6
75	8.7
40	0.5

It may be surprising that as the temperature drops with the feed rate, ammonia destruction goes to almost 100%. After all, ammonia destruction kinetics increases with *increasing* furnace temperature, whereas, this shows the opposite. The reason is the concomitantly longer residence time. This is a reactor of fixed dimensions, and its residence time is a function of the reactor volume and flowrate. Because the flowrate is being significantly reduced, the residence time is increasing correspondingly and this means there is enough reactor residence time to counter most of the thermal limitations. Table 4 below shows the residence time as a function of feed flowrate.

Table 4. Residence Time in the Thermal Reactor vs. Turndown

Flow Rate (TPD)	Residence Time (seconds)
125 (Full Rate)	1.3
75	2.2
40	4.2

This case study illustrates that although heat loss can be a significant factor (especially under turndown), as far as the kinetic rate-limited reactions are concerned, the greatly increased residence time gained under the turndown conditions is enough to overcome the thermal limitations imposed by the increased heat loss.

The conclusion here might not be the same for a lean acid gas with lower temperature to start with. However, with a tool like SulphurPro®, this analysis becomes straight-forward because the simulator has accurate reaction kinetics and heat transfer rate calculations build right into the model.

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To learn more about this and other aspects of gas treating and sulphur recovery, plan to attend one of our training seminars. Visit www.protreat.com/seminars for details.