

Heat Flux, Tube Wall Temperature, and Sulfidic Corrosion in a Waste Heat Boiler

The Claus Waste Heat Boiler (WHB) is arguably one of the most fragile pieces of equipment in the Sulphur Recovery Unit (SRU) because of the harsh operating conditions and reliability challenges to which it is subjected. The WHB not only provides critical heat recovery from the thermal section, but also affects the unit's hydrogen balance and COS levels through the recombination reactions that occur in its front end. The design of the WHB plays a critical role in determining the extent of these reactions as well as the peak heat flux at the front end of the boiler tubes. This edition of the Contactor discusses how tube length and mass flux decisions in the design phase affect a number of critical reliability aspects, including peak heat flux, tube wall temperature, and corrosion.

Heat flux is a very important factor in the reliability, life cycle cost, and the safe long-term operations of the WHB. The heat flux varies greatly along the tube length with the highest flux at the process inlet and which then decreases as the process gas cools. In terms of reliability, it has been stated in prior publications that failures tend to become more common with heat fluxes that exceed 50,000 Btu/hr-ft². The life cycle cost of a WHB depends greatly on the corrosion rate of the boiler tubes resulting from elevated heat flux and tube wall temperatures. The tube wall temperature in conjunction with the concentrations of H₂S in the process gas inside the tubes correlate directly into the sulfidic corrosion rate.

To demonstrate how these conditions are affected by WHB design, a matrix of cases was evaluated. The SRU, as shown in Figure 1, is a typical two-bed 125 LTPD Claus unit processing both Amine Acid Gas (AAG) and Sour Water Acid Gas (SWAG) with low level oxygen enrichment (28% resulting O₂). The WHB tube sizes were set at 1.5, 2, and 3 inch outside diameter with process-side mass fluxes of 2, 3, 4, and 5 lb/ft²-s at each of the tube sizes. The WHB model was set to sizing, where the outlet temperature is specified and the tube length and tube count are varied to obtain the specified temperature and mass flux. The cases were run and results obtained using the kinetic heat transfer and chemical reaction rate-based simulator, SulphurPro™.

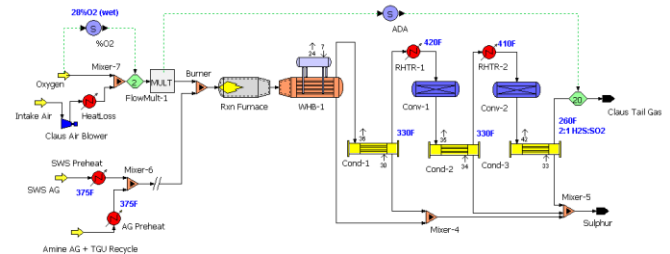


Figure 1. PFD of SRU for Case Study

At each matrix point, the heat flux and tube wall temperature were evaluated along the length of the tubes as shown in Figures 2, 3, and 4.

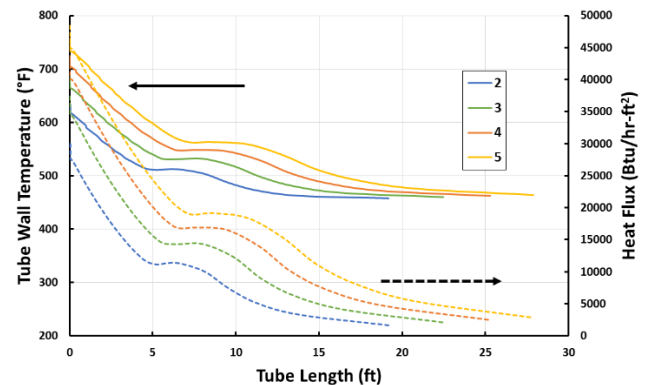


Figure 2. Tube Wall Temperature and Heat Flux for 1.5" OD Tubes at different Mass Velocities

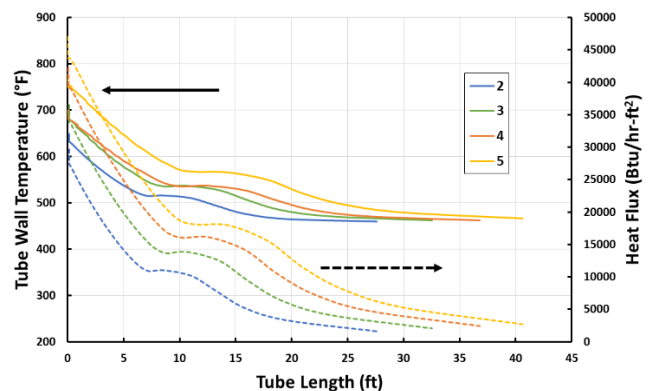


Figure 3. Description Same as Figure 2 but with 2" OD Tubes

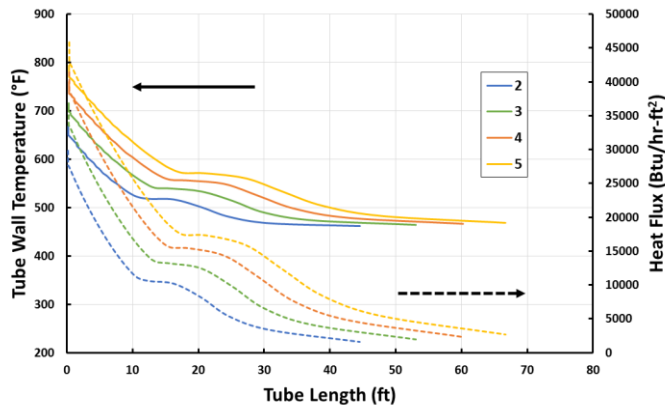


Figure 4. Description Same as Figure 2 but with 3" OD Tubes

Note that the inflections in the curves approximately 1/3rd of the way along the boiler tubes is caused by the sulphur species shifting exothermically from S_2 at the higher temperatures to more S_6 and S_8 as the process gas is cooled. The heat flux shown in Figures 2–4 do not account for the thermal protection provided by ferrules, nor for the eddy effects at the ferrule exits. As the mass flux at a constant boiler tube size is increased, both the peak heat flux and the peak tube wall temperature increase. This critical tube-to-tubesheet joint is where almost all failures from sulfidic corrosion occur.

As was previously mentioned, the tube wall temperature ties directly into the sulfidic corrosion rate. As the mass flux through the boiler tubes increases, the tube wall temperature increases by approximately 150°F with this delta translating directly into a higher sulfidic corrosion rate as shown in Figure 5.

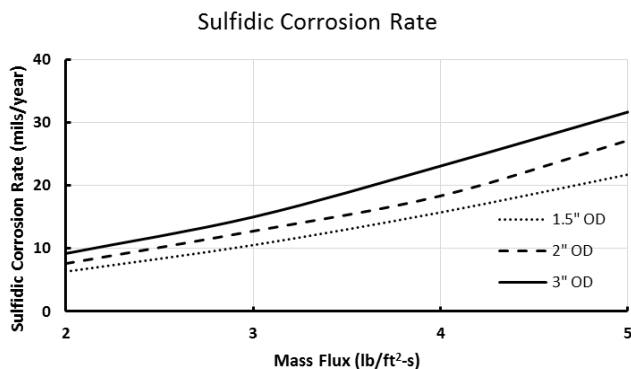


Figure 5. Sulfidic Corrosion Rate (mils/year) at the Front End vs. Mass Flux (lb/ft²-s)

At a constant mass flux, the larger boiler tubes tend to produce a higher tube wall temperature and, consequently, a higher corrosion rate. Corrosion concerns tend to increase at tube wall temperatures greater than 600–650°F. From Figure 4, the tube wall temperature is below this point for mass fluxes between 2 to 3 lb/ft²-s. The service life of the exchanger is directly determined by the corrosion rate, and the life cycle cost is strongly influenced by service life. Looking now at the sulfidic corrosion rate along the length of the exchanger, the higher mass flux case has an elevated corrosion rate through the first 5 feet or so of the tube length. Figure 6 shows how

corrosion rate trends along the length of the tubes for a 2 inch OD tube at mass velocities of 2 and 5 lb/ft²-s.

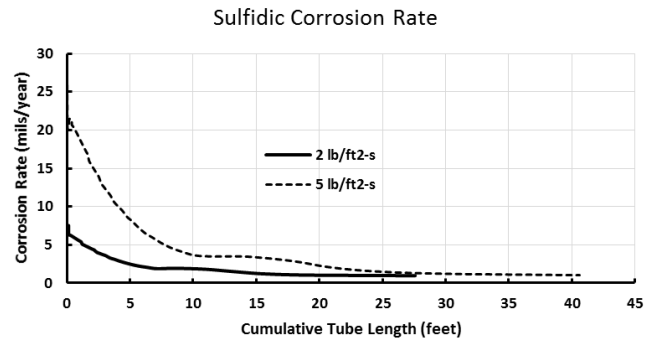
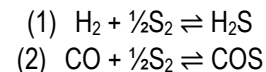


Figure 6. Sulfidic Corrosion for 2" OD Tubes at 2 and 5 lb/ft²-s

Notice that the corrosion rate increases by a factor of nearly 4x at the higher mass flux.

One factor that plays into properly calculating the heat flux and thermal performance of the exchanger is the recombination reactions that occur at the front end of the boiler tubes.



These are kinetically limited, exothermic reactions that can have a significant effect on the peak heat flux at the front end of the exchanger. Because the hydrogen and carbon monoxide are recombining with sulphur that was formed in the furnace, they also have implications on the hydrogen available in the tail gas, the performance of the first converter for hydrogenation of COS and CS_2 , and the overall sulphur recovery. Most simulators only account for the heat transfer, but neglect these important reactions. Models that do not properly account for the recombination reactions and the sulphur redistribution will not only inaccurately calculate the heat flux, but also the sulphur recovery efficiency of the unit and the thermal performance of the exchanger, especially in the tube region nearest to the critical tube-to-tubesheet joint.

Factors that have implications on the reliability of the WHB can only be seen by using a fully rate-based simulator. SulphurPro™ is a rigorous heat transfer and kinetic chemical reaction sulphur plant simulator that accounts for all of these factors on a first principles basis.

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.

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