



## Factors Affecting Waste Heat Boiler Design and Operation: Part 1<sup>†</sup>

Perhaps because of oxygen enrichment and pushing throughput, the Claus Waste Heat Boiler (WHB) has become the weak link in the SRU. Consequently, more attention is now being given to its design and operation. New performance standards are being considered to limit the mass flux of future designs; however, this may be an unwarranted simplification.

This issue of The Contactor reviews factors beyond mass flux that can have vital consequences for boiler reliability. Indeed, in some cases, limiting mass flux may lead to other unintended complications. Unless the boiler is treated as a heat transfer device with simultaneous chemical reactions and radiative heat transfer, these complications may go unnoticed.

### Background — Sulphur Plant WHBs

Sulphur recovery units generate two products: sulphur and steam. Often steam is more valuable than sulphur. Steam is generated by recovering the significant amount of energy generated in both the thermal and catalytic stages of the Claus process. High Pressure (HP) steam is typically generated at pressures of 450 – 650 psig. Low Pressure (LP) steam is usually produced at about 50 psig in the condensers downstream of the catalytic converters. HP steam is a valuable utility that is generated in the WHB that can be used for SRU catalytic indirect reheat, feed stream preheat and to drive a turbine on the combustion air blower. In most applications, the SRU is a net exporter of steam and both HP and LP steam generated in the SRU are used outside the SRU, e.g., LP heat source for amine reboiler, sour water stripper reboiler, steam tracing etc. and HP steam to spin a turbine.

Modern designs generate much higher pressure steam, thus presenting mechanical design and operating challenges. It is recommended that the design of SRUs, and in particular the WHB, be done by experienced sulphur technology licensors and EPC contractors with proper design expertise. Modern designs are typically done for the pressure range 450–600 psig and steam temperatures in the 457–496°F range.

Excessive temperature, rapid process temperature changes and thermal cycling associated with start-ups and shut-downs affect the reliability of the WHB by degrading the tube sheet system (refractory, ferrules, tube-sheet, tube-sheet-to-tube joint, and the tubes themselves). Thermal cycling reduces WHB tube-sheet system longevity and reliability. Industry experience suggests that the Reaction Furnace and WHB could have a thermal-cycle life expectancy (a limited number of cycles) of as long as 20 years, in well-designed, operated and maintained

systems, but as short as only two or three years for inadequately-designed, poorly-operated and badly-maintained systems. Damage to the tube sheet protection system from poor operation results in unscheduled outages and affects SRU reliability.

### Heat Exchanger Fundamentals

General heat exchanger design principles are based on the following:

- Heat transfer requirements (surface area),
- Cost,
- Physical size,
- Permissible pressure drop.

In the process industry heat exchangers are often bought off-the shelf, the selection being made on the basis of cost and specifications furnished by the various manufacturers. However, the Sulphur Recovery Unit WHB using water as the cooling medium is much more specialized.

For the WHB, there are several factors particularly on the water side that are of vital importance. It has been well documented<sup>[1],[2],[3]</sup> that the following design and operational considerations need to be addressed during the design and operation of the WHB to provide the most robust design that can handle longer operating runs:

- Tube diameter
- Tube pitch
- Tube wall thickness
- Tube-sheet thickness
- Materials of construction.
- Welding methods for tube-sheet joints
- Kettle versus thermosiphon design
- Ferrule design and installation
- Blowdown design and operating practices
- Operator & maintenance training.

### WHB Failure Mechanisms

There are multiple design options (e.g., tube ID and tube length) that can be used to satisfy the design principles listed above; however, experienced designers understand that two primary factors are critical to reliable design: the maximum metal temperature and the maximum heat flux through the tube wall.

An industry survey of WHB design and operation in existing SRUs was performed in 2017 to explore the determining

factors in good WHB design and operational practices<sup>[4]</sup>. It indicated that neither *mass flux nor tube diameter* is really an indicator of risk of failure. The survey confirmed that the failure mechanisms can be attributed to a *combination* of factors that may be design or operations related.

#### Maximum Metal Temperature

High temperature sulfidic corrosion becomes increasingly significant at temperatures above 650°F. Therefore, a successful WHB design will have predicted conditions well below this temperature. This necessarily accounts for tube sheet thickness and water side factors such as adequate distribution of boiler feed water and removal of generated steam.



**WHB Failure from Overheated Tubes**

Maximum Heat Flux: Heat flux is determined not only by the tube-side (process gas) convective heat transfer coefficient, tube wall conductance and the water side heat transfer coefficient, but also by radiation. The primary variable driving heat flux is the process-to-water temperature difference which can vary by a factor of ten over the length of the tube. The radiation component can add approximately 20% to heat flux. Although of no real significance below about 1,000°F, in areas where failures are more prevalent (front-end), radiative heat transfer cannot be ignored; otherwise the heat flux will be seriously under predicted.

Avoiding conditions of steam blanketing on the boiler tubes is important. The heat flux rates over the entire tube length of the WHB should be evaluated, especially the turbulent entrance area near the end of the ferrules. The heat flux should not exceed 50% of maximum nucleate-boiling flux at design, and 65% for maximum service conditions. These limits will keep the tube wall within 18°F of the water boiling temperature at design, well below the 72°F value where break-over to Leidenfrost film boiling occurs when the critical nucleate flux is exceeded. The in-service, fouled condition will be a substantially lower heat flux than maximum clean condition although tube wall metal temperatures are substantial higher.

A further complication results from a recirculation region that exists downstream from the ferrule. The turbulent eddies introduced into the flow in this region increase heat transfer there. In extreme cases the increase leads to heat fluxes that cannot be successfully transferred to the WHB's water, leading

to the switch from nucleate to film boiling and much higher tube wall temperatures.

#### Feed, Steam & Blowdown Connections

The importance of proper design of the boiler feed water, steam and intermittent blowdown connections deserves emphasis. It is imperative that the correct amount of boiler feed water is directed to the critical inlet tube sheet location, and a boiler feed water distributor may be beneficial in ensuring that the colder water is properly distributed throughout the boiler.

By looking at the entire WHB system and not just the process parameters through a single tube, WHB failure cause-and-effect analysis leads to the discovery of all possible reasons and outcomes associated with the failure. The process is directed at uncovering possible or probable causal factors and their manifestation. It identifies how they are linked but does not necessarily lead to the root cause. Focusing exclusively on mass flux will most likely lead to false conclusions. Data and advanced analytics produce unexpected correlations, and separating the real opportunity from the spurious tease is essential.

#### **Conclusions**

There are many important design parameters besides mass flux that influence the heat transfer performance and reliability of the WHB. This will be examined in Part 2. While mass flux is important, it should be recognized that limiting the mass flux may result in less economical WHB designs than may be warranted in many cases. WHB failure cause and effect analysis helps to avoid the false conclusions that will most likely result from exclusively considering heat flux.

#### **References**

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- [4] *Reliability of Boiler Tube Protection Systems – a Case History: Operation in Air-based and Oxygen Enriched Conditions*, N. Engelhardt, Domenica Misale-Lyttle and Elmo Nasato. Sulphur 2017, Atlanta, USA

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† Taken from a paper coauthored with Elmo Nasato