A Review of WHB Tubesheet Thermal Protection Parameters

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Why?

- Numerous published papers on subject
- Numerous questions
- Attempt at clear answer
What will be discussed

- Background
- Scope
- System Description
- Criteria
- Model description
- Results
- Conclusions
- Recommendations
Background

- Analysis of Tubesheet Stresses in a Sulfur Recovery Unit – 1996
- Computational Fluid Dynamics Investigation of a High Temperature Waste Heat Exchanger Tube Sheet Assembly - 2005
Background – contd.

- A Robust SRU Waste Heat Boiler Design - 2012
- Designing a Robust Waste Heat Boiler - 2015
So…

- Are 12.2 Kg/m²·sec and 0.15 psi Limits? **NO!**
- “What we’ve got here is a failure to communicate!”
Scope

- Tubesheet Thermal Protection System
- Temperature, Mass Flux and Pressure Drop
- Ferrule Design Agnostic
- Two-piece Removable for Illustration
System Description
Cases Considered

- Two primary tube sizes – 2” and 3” Sched 80
- Two paper thicknesses – 1.6 and 3.2 mm
- Three paper conditions
  - Solid – industry standard method
  - Perfect porous – realistic perfect condition
  - Loss of 1/6 of paper layer – realistic damaged condition
- Three mass fluxes, 12.2, 18.6 and 26 kg/m²-s
Overall Models

- 60° periodic models considered of generic 2-piece ferrule assembly
Paper Models

- Paper separated into layers to allow assignment of different porosities
Fixed Conditions

- **Process Side**
  - 1,370 °C

- **Water Side**
  - 254 °C
  - 41.5 bara
Criteria

- 343 °C for metal protection
- HTRI 280,000 W/m² for DNB
Physics

- Ideal gas
- $k-\omega$ SST turbulence
- DO radiation solver
- Porous paper for some cases
Matrix

- Two tube sizes
- Two paper thicknesses
- Three paper conditions
- Three heat fluxes

Result $2 \times 2 \times 3 \times 3 = 36$ combinations
Comparison of Velocities

12.2 kg/m²-s Mass Flux

18.6 kg/m²-s Mass Flux

26 kg/m²-s Mass Flux
Comparison of Recirculation Strength – 2” Thin Paper

Velocity: Magnitude (m/s)

0.00000 12.000 24.000 36.000 48.000 60.000

12.2 kg/m^2-s Mass Flux

18.6 kg/m^2-s Mass Flux

26 kg/m^2-s Mass Flux
Comparison of Recirculation Strength – 2” Thick Paper

0.00000 12.000 24.000 36.000 48.000 60.000

Velocity: Magnitude (m/s)

12.2 kg/m²-s Mass Flux

18.6 kg/m²-s Mass Flux

26 kg/m²-s Mass Flux
Fluxes Downstream from Ferrule for 2” Tube

Comparison of Heat Fluxes as a Function of Mass Flux and Paper Thickness for 2” Tube

- Thin Paper 12.2 kg/m²-s Mass Flux
- Thin Paper 18.6 kg/m²-s Mass Flux
- Thin Paper 26 kg/m²-s Mass Flux
- Thick Paper 12.2 kg/m²-s Mass Flux
- Thick Paper 18.6 kg/m²-s Mass Flux
- Thick Paper 26 kg/m²-s Mass Flux

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Fluxes Downstream from Ferrule for 3” Tube

Comparison of Heat Fluxes as a Function of Mass Flux and Paper Thickness for 3” Tube
Pressure Drop versus Mass Flow Rate, 2” Tube
Pressure Drop versus Mass Flow Rate, 2” Tube

Graph showing the relationship between pressure drop (in Pa) and mass flux (in kg/m^2-s) for 3" tubes with different paper types.
2” Thin Paper Temperature Contours

Solid  Porous  Damaged

12.2 kg/m²-s
18.6 kg/m²-s
26 kg/m²-s

Temperature (°C)
270.00  296.00  322.00  348.00  374.00  400.00
2” Thick Paper Temperature Contours

- 12.2 kg/m^2-s
- 18.6 kg/m^2-s
- 26 kg/m^2-s

Solid  Porous  Damaged

Temperature (°C): 270.00 296.00 322.00 348.00 374.00 400.00
3” Thin Temperature Contours

12.2 kg/m^2-s

18.6 kg/m^2-s

26 kg/m^2-s

Solid  Porous  Damaged

Temperature (C)

270.00  296.00  322.00  348.00  374.00  400.00
3” Thick Temperature Contours

12.2 kg/m$^2$-s

18.6 kg/m$^2$-s

26 kg/m$^2$-s

Solid  Porous  Damaged

Temperature (°C)

270.00  296.00  322.00  348.00  374.00  400.00
Maximum Metal Temperature versus Mass Flux, 2” Tube

Maximum Metal Temperature versus Mass Flux

- 2” Thin Solid Paper
- 2” Thin Porous Paper
- 2” Thin Damaged Paper
- 2” Thick Porous Paper
- 2” Thick Damaged Paper

Mass Flux (kg/m²s) vs. Maximum Metal Temperature (°C)

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Maximum Metal Temperature versus Mass Flux, 3” Tube

![Graph showing maximum metal temperature versus mass flux for different materials (3” Thin Solid Paper, 3” Thin Porous Paper, 3” Thin Damaged Paper, 3” Thick Solid Paper, 3” Thick Porous Paper, 3” Thick Damaged Paper). The graph indicates a linear relationship between mass flux and maximum metal temperature.]
Conclusions

- No “Rule of Thumb”
- Bigger tubes normally run cooler
- For this example:
  - 2” tube clearly fails
  - 3” tube marginal
- Mass flux and paper condition count
Recommendations

- CFD
- There are other factors not covered
Designing Waste Heat Boilers (WHB) for a Claus unit is a challenging and complicated task. In spite of the fact that Engineering companies use different types of designs but all agree on the following. It is not possible to evaluate the robustness and effectiveness of the design of a WHB by only looking at the mass flux and tube diameter alone. The design of the water side in the WHB associated with tube orientation, pressure level, blow down control, riser & downcomer orientations and many other factors must also be taken into account. The effectiveness and robustness of the overall design of the WHB is governed by all these design considerations and parameters. Examination of the process gas side alone only provides insight to the expected heat flux. Such analysis does not provide any insight as to how heat is transferred to and removed by the water/steam side operation which is also critical to the boiler design.

The article presented in MESPON clearly states that it is only looking at the tube size and the mass flux of a WHB design using Computation Fluid Dynamic (CFD) modeling without taking all other critical design considerations into account. Therefore the conclusion that “larger tubes tend to present a more fault-tolerant and reliable Waste Heat Boiler design” as presented in the article is in our opinion not correct. There are many waste heat boilers designed with 1½ and 2 inch tubes, generating steam at 40-45 barg have been operated successfully for the past 20 some years. The tube size itself is never the single criterion that determines if and when the boiler will work or fail. The effectiveness and robustness of a WHB design is a complex task which takes a combination of the intended operating window, design expertise and know how regarding how the heat is being transferred to the water/steam side and how it is being removed as efficiently as possible. The tube size and mass flux alone are not the only deciding factors in this design task.

Based on our field experience it is a well-known fact that most of the WHB failures are caused by operation outside the normal and designed operating window. The start-up and shut-down procedures, purging gas flow rates and purging durations are especially critical for waste heat boiler operation of a Claus unit and should always be adhered to. Cutting short these recommend operation procedures and related time lines is not a recommended practice as such practice has led to many waste heat boiler failures, no matter what tube size and mass flux the boiler is designed with. Another critical operating practice is the exercise of intermittent boiler feedwater blowdowns to ensure the long term operation and life span of a WHB.

The benefit of using smaller tubes (1 1/2and 2 inches) in a WHB design is that the length of the tubes could be relatively short, which is also a key parameter in the waste heat boiler design in terms of cost and plot space. Bigger tubes, especially for large capacity waste heat boilers will lead to much longer tube length requirements as a result of lower heat transfer rates. The resulting long tubes will create design, operation and reliability issues in addition to extra cost investment band undesired plot space requirements.

In short, designing waste heat boilers for a Claus unit is difficult and complicated, but reputable engineering companies in the field of Sulfur recovery licensing agree that when the design has been carefully done based on design expertise/experience and takes into consideration of all the feed cases and operating scenarios, small diameter tube waste heat boilers have proven to be very cost effective, reliable and successful.
This rebuttal is based on the input of the following engineering companies and licensors in the Sulfur recovery business who have successfully designed a combined total of well over 1000 sulfur recovery units in the range of 2 MTPD to 2,600 MTPD of sulfur production. All these waste heat boilers have been operated successfully for many years without failure and were designed based on design expertise and know how without the use of any Computational Fluid Dynamics (CFD) modeling. Please note that CFD modeling could be a useful tool in assisting the design of a waste heat boiler or any other equipment if and only if all design and operating aspects and considerations are taken into account by the model and by an experienced designer who prepares the model as was stated in the referenced paper.

Thomas Chow – Fluor
Steve Pollitt – WorleyParsons
Frank Scheel – Jacobs Comprimo Sulfur Solutions