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Furnace design — It can give you the creeps

Many processes in industry involve some type of fired furnace with radiant and convection coils containing the process. As with most mechanical equipment the process is fired hotter and runs longer. Designers are searching for materials and designs that can meet the expectations of production. With the limits pushed, reliability becomes an issue. Due to the exotic materials incorporated in some furnaces, a catastrophic failure can lead to extended down times due to material availability.

Due to the extreme conditions that many furnaces are operated in, the support architecture for the furnace coils is also pushed to the limit as well. Typically the flow rates are higher and two-phase flow conditions lead to potential vibration problems with the coils. Often where heavy supports are needed to prevent the vibration it causes problems with thermal expansion. To compound the problems, the furnace tubes can operate in the stress rupture curves in the creep range of the material. There are also transient process conditions during feed change over that are sometimes overlooked.

A few major furnace design issues are:

1. Meeting process expectations.
2. Furnace tube material.
3. Potential vibration.
4. Low cycle thermal fatigue.
5. Stress rupture of tubes.
6. Creep limit of tubes.
7. Stress rupture and creep of supports.
8. Process transients.
9. Fluid dynamics of the furnace.
10. Burner design.
11. Furnace controls.

If you want to upgrade your furnace it's a good idea to review over the items above with your furnace expert or consultant. The following is a general overview of furnace modeling and does not include all details that a qualified furnace expert would include.

In a typical furnace system a "first pass" analysis will consist of an elastic analysis. This analysis is not realistic, as it does not account for the plasticity of the tubes or the mechanical creep. It should be used to obtain a rough idea of where and how to support the floating tubes within a furnace system. Once the supports are roughed out a more detailed model must be conducted.

To perform the detailed analysis a computational fluid dynamics (CFD) analysis of the furnace is conducted to aid in the determination of heat transfer coefficients for the elastic plastic furnace model that will include creep. The CFD model will include draft effects and have burner location as source input. And most importantly, radiation effects are in the model.

It is generally best to consider using the finite element (FE) code for modeling furnace tubes. The heat transfer film coefficient on the outside of the tubes will vary about the circumference and along the length depending where the section is in the furnace. Care should be taken to consider the introduction of the complex physics into the model one step at a time. The "second pass" model will typically be an elastic plastic model with average film coefficients on the inside and outside. It will be used to further refine support locations. The next model will consider the complex heat transfer coefficients on the outside that vary around the circumference and along the length.

The detailed FE model would consider the expected run time of the tubes. Other elements to consider are vibration and "thermal walking." Sometimes the flow field will cause the furnace tubes to vibrate and reduce life and cause supports to break. Thermal walking is caused by the cycle response of the system starting up and shutting down.

With today's finite element tools it is possible to evaluate a furnace accurately considering the plastic response with creep. Much of the advancement has been done in tube material.

The computational fluid dynamics tool is used to evaluate the temperature and flow distribution in the furnace as well. Designers can now model numerically and predict the response of the furnace. All work should be reviewed and performed under the direction of a professional engineer that is an expert in this area.

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