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Furnace design: A host of challenges that can be addressed

Many processes today involve various types of fired furnaces 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 also becomes an issue. Due to the exotic materials incorporated in some furnaces, a catastrophic failure can typically lead to extended downtime due to material availability.

Because of these extreme conditions, the support structure for the furnace coils is pushed to the limit as well. Often, the flow rates are higher and two-phase flow conditions lead to potential vibration problems with the coils. Often a catch-22 situation develops where heavy supports are needed to prevent vibration but it causes problems with thermal expansion. To compound the problems for the designer, the furnace tubes typically operate in the stress rupture curve in the creep range of the material.

Contained within the process are transient process conditions during feed changeover that are sometimes overlooked. During this transient period, the stress varies with time. This is a strain-controlled event and is subject to relaxation. As the peak stress/strain rates are experienced, creep accelerates until self relaxation occurs and load controlled responses of the system will take place. These transients can greatly reduce life of affected components.

One might summarize a few major furnace design issues as follows:

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

Anytime owners desire to upgrade their furnace, it's a good idea to review the eleven items above along with your furnace expert or consultant.

In many furnace designs, a typical mechanical analysis is limited to an elastic response of the system. This is because of the complexity of conducting a plastic analysis with creep. While an elastic analysis is good for a first pass design, it does not adequately define the load redistribution that will occur with creep.

With today's finite element tools, it is possible to evaluate a furnace accurately, considering the plastic response with creep. Also, much advancement has been done in tube material. Now the mechanical response can be evaluated in an accurate manner to ensure reliable operation of the furnace. These same tools are also used to study the use of possible advanced materials in a furnace. Creep and elastic plastic subroutines are incorporated into finite element models to evaluate the response. It is always a good idea to develop a numerical tensile test to compare against actual test data. This should be done in the creep range as well. It is important to validate the model before proceeding to the actual furnace model. Another aspect is determining the actual weights of all components and hardware. It is typical that furnace fittings are heavy and in some cases are specifically forged for the configuration. It is important to consider shadowing effects in the radiant section of the furnaces. These effects can lead to tube bow and cause the support mechanisms to jam up from start-up to shut down.

The computational fluid dynamics tool is also used to evaluate the temperature and flow distribution in the furnace as well. Designers can model numerically and predict the response of the furnace. These models include the burner placement to account for localized heat transfer conditions. The overall heat transfer performance can be developed to optimize design and increase performance.

With the right approach and tools, an experienced furnace designer can develop a mechanically reliable furnace with a highly efficient fire box. All design work should be done under the direction of an engineer competent in furnace design.

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