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Furnace design — It can give you the 'creeps'

Many industry processes today involve some type of fired furnace with radiant and convection coils containing the process. As with most mechanical equipment, the furnace is fired hotter and is run 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 failure, which is usually catastrophic, can lead to extended down times due to material availability.

Because of the extreme conditions that many furnaces are operated at, the support architecture for the furnace coils is 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, a "catch 22" situation develops where heavy supports are needed to prevent the vibration, which can then lead to problems with thermal expansion. To compound the problems for the designer, the furnace tubes typically operate in the stress rupture curves in the creep range of the material. Oh yeah, there are also those transient process conditions during feed change over that are sometimes overlooked.

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 an owner desires to upgrade their furnace, it's always a good idea to look over the 11 items listed 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.

Now a question that you might ask is, "What is 'creep?'" Before this question is answered, we must first talk about the behavior of materials at high temperature. Typically for furnace coils that operate under a sustained stress due to weight and pressure, the coil will plastically deform with time both in length and diameter. When the furnace is operated for a period of time and shut down, the coils will look stretched and exhibit permanent deformation. The condition that occurs is called "creep" because deformation creeps along with time. Notice that the creep is dependent on time and sustained loading. We can't do anything about time, but we can address the sustained loading. Sustained loading is caused by pressure and weight. The wall thickness of the furnace coils addresses the creep due to pressure. Weight is addressed by the additional supports.

The response of high temperature furnace coils is complex and must consider the load redistribution due to plastic deformation. There is yet another more complex problem with furnace coil design. It is called transient creep, which involves the peak thermal stresses that occur during startup. If a coil design has large strains due to thermal expansion, there will be remarkable transient creep. This effect can lead to an early life of furnace coils. This is an area that few designers consider.

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. 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.

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 accurately predict the response of the furnace. All work should be reviewed by a professional engineer competent in furnace design.

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