HOT SEAT

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CONVECTION PHASE

Velocity, boundary layer, and turbulence in quenching have implications on heat transfer in batch and continuous furnaces.

ANYONE WHO HAS ATTENDED A technical seminar on quenching has heard of the three stages of oil quenching: the vapor phase, the film boiling phase, and, finally, the convection phase. We've also learned that the first and last are the slowest forms of heat transfer. And we've been told that in high pressure gas quenching (HPGQ), there is no film boiling or vapor phase, only the convection phase. But we probably haven't had it explained with much detail why or how all of this occurs and its implications for part loading in batch and continuous furnaces.

It's mostly about the boundary layer — that phenomenon that accompanies all natural and forced convection heat transfer modes. Conduction plays a role, but radiation, potentially the fastest heat transfer mode, plays a role in all fluids when the parts are initially quenched.

Natural convection occurs when a hot part is removed from a furnace and placed on a support table without a fan blowing air on it. The part cools by simply losing heat to the environment primarily by radiation. However, there is a convection component, but it's a natural one. As the air immediately surrounding the part heats and becomes lighter as it does when used to elevate a balloon, cooler air immediately replaces the heated air removing more heat. In addition, the hot part radiates heat to whatever surface is nearby. What's nearby? Air, specifically the water vapor in air. Air may seem invisible to radiation, but air, although a poor conductor of heat, does have mass. The closer to the radiation source, the more heat is felt. Move away from the source, and the air absorbs the energy and less radiation is felt. Remove the air like in a vacuum, and the radiation from a hot part to the walls is relatively unchanged. Therefore, the surrounding air is heated by radiation and convection.

Now, if a fan was placed in front of the part, cooling would obviously increase at atmospheric pressure because the increased gas velocity is displacing hot gas with colder molecules and the increased velocity pressure is thinning the boundary layer. The reason helium is used for HPGQ is twofold: its thermal conductivity is 5.5 times greater than air or nitrogen, and its density is one-seventh, so it requires one-seventh the horsepower to operate the cooling fan.

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The same physical parameters that apply to gases also apply to quenching liquids. However, liquids have one big advantage — they have higher densities than gases even at 20-bar pressure. But they also have their own form of boundary layer, generally referred to as a vapor barrier. Salt is the only exception. Water, polymer, and oil all produce a vapor barrier when a hot part is immersed into the fluid initially. Without agitation as the part cools to the "black" range, the vapor diminishes to the boiling stage. The violent boiling action at the part surface produces an extremely fast heat transfer effect much faster than the vapor phase and the final convection stage.

There are a few theories regarding how boiling improves the cooling rate. Just like water evaporation removes heat from our skin, it's believed that oil boiling and vaporizing would likewise increase the heat transfer from a quenched part. When the three stages of oil quenching of a cylinder are viewed in slow motion, the vapor phase can be seen slowly diminishing and boiling progressing up the cylinder via gravity. Liquid quenching consists of complex interactions between the part and the vapor forming liquids of oil and water related to gravity and vapor vs. liquid densities. Although the oil vapor that forms and surrounds the part acts as a boundary layer, heat transfer via radiation as previously discussed still occurs and is by itself a significant part of the quenching process.

The one common denominator for all quenching processes is velocity. Velocity, feet/minute or feet/second, is the flow quantity divided by the area. In either situation, gas or liquid, the higher the velocity, the smaller the boundary layer and vapor barrier will be, thus higher heat transfer from the part. Velocity generally increases the turbulence of the fluid. And just as the boiling of a liquid creates turbulence, so does increasing the velocity.

Why is this "inside baseball" discussion of quenching relevant to the heat treater? Because how parts are loaded affects the quench. Most of the time when parts are loaded in baskets, great care is taken to align parts so as many as possible can be processed. Yet, how is it possible that seemingly very dense randomly loaded parts can be successfully quenched? It all goes back to velocity, the boundary layer, and turbulence. Case in point occurred in 20-bar helium quenching of truck universal joint crosses. A very large load of crosses were stacked one on the other and all bearing journals were perfectly aligned in stacks. The load looked beautiful, but the hardness results were not. After some head scratching, the crosses were randomly stacked so that the journals did not align vertically and the hardness improved at all locations. The same principle applies to all quenching applications. Construct the load to create as much turbulence and allow for maximum fluid flow without regard for part symmetry.

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