Carburizing and hardening atmospheres without intergranular oxidation using cold plasma gas activation

Customer benefits:

• Elimination of intergranular and surface oxidation of alloying additions; a vacuum-like quality without a vacuum furnace

• Elimination of external atmosphere generator and methanol tank equipment

• Flexible, just-in-time adjustment of atmosphere production rate and compositions, depending on plant requirements; no more flaring of atmosphere gases

• Minimized consumption of hydrocarbons for atmosphere production and heating of the endothermic reactions; reduced emissions

• Real-time carbon diffusion modeling by carbon flux sensor

Air Products’ patented cold plasma technology has been designed to eliminate the internal oxidation defects that traditionally occur during atmospheric pressure carburizing of alloy steels.

Our novel method injects a cold plasma-activated nitrogen-hydrocarbon blend that eliminates the intergranular oxidation, as no oxygen-containing gases are introduced to the furnace, providing improved part quality and cost benefits compared to conventional processes. Easy to install, Air Products’ cold plasma system offers minimized atmosphere toxicity and environmental impact, accurate control of the carburizing potential, and an instant turn-on/turn-off capability.
Pre-blended nitrogen/hydrocarbon gases are introduced to the conventional 1-atm carburizing furnace through a compact, externally attached plasma gas injector. Plasma discharge catalyzes the reaction between the gases and the heat treated steel; the gas blend and the amount of hydrocarbon introduced are controlled by an in situ carbon-flux sensor and a carbon diffusion modeling software.

Carburizing and neutral carbon potential annealing are achieved by injecting cold plasma-activated blends of nitrogen and hydrocarbon gas such as methane or propane, where the hydrocarbon concentration is varied between 0.1 and 4.5 vol %. Since no oxygen-containing gases, such as carbon monoxide or carbon dioxide, are introduced to the furnace, intergranular and surface oxidation of the steel alloying additions is prevented (see figure 1).

![Figure 1](photo courtesy of Capstan)

No intergranular oxidation defects (IGO) form in tight, air-free atmospheric furnaces. In integral-quench furnaces that can aspirate as much as 5% of ambient air into the atmosphere, formed IGO are reduced to less than a negligible 3-micrometer depth.
High-voltage/low-amperage plasmas, also called non-equilibrium and including corona-, glow-, and gliding arc-discharges, can enhance chemical reactions between gas molecules without excessive heating. The lifetime of non-equilibrium plasma electrodes ionizing gas is orders of magnitude longer than for thermal arcs and plasmas.

Various cold and warm, non-equilibrium plasma discharges are simultaneously generated in the injector due to pressure differentials inside gas vortices formed. The gas crosses the discharges along the path of an external and then reversed, or internal, vortex. Molecules of premixed reactant gases are subject to a dynamically controlled ionization, resulting in chemical reactions and products including radicals, atoms, and vibrationally excited molecules. The product stream is electrically neutral.

Iron wire resistance sensor is used to measure dissolved carbon, which enables direct monitoring of the mass-flux of carbon entering the metal. Integrated over the carburizing treatment time, the mass-flux is balanced against the diffusion into the metal core to predict carbon concentration profile, real-time. The Protherm controller compares the result to the specification and regulates flow valves of the plasma injector.

The desired carburizing profile is achieved using a real-time atmosphere control and simulation system. The key components of this system are the carbon flux sensor and the Protherm controller from Process Electronic.*

*Process Electronic GmbH, a member of United Process Controls
The process control method developed jointly by Air Products and Process Electronic predicts the carbon profile under the steel surface from the mass of the carbon entering the metal and not by the commonly used measurements of the carburizing gas concentration in the furnace atmosphere. The accuracy of this predictive method is high because it is not affected by the unreacted gases, typically present in the carburizing furnaces (see figure 3).