PERIODIC ATMOSPHERE FURNACE MAINTENANCE: PART TWO

LESSONS LEARNED

Often, we chose to fix a problem only when it becomes absolutely necessary. This is unacceptable in any industry, but it is especially devastating in heat treating. Part one of this article (July/August 2009 HTP) discussed the need for having proper preventative maintenance planning. Part two shows why it is so necessary.

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Representative pusher furnace line. Courtesy of Aichelin Heat Treatment Systems Inc., Plymouth, Mich.

IQ Furnaces

Integral quench (IQ) furnaces can suffer from myriad problems related to carbon build-up in the heat chamber and quench oil contamination/deterioration. Units that use electric heating elements are particularly vulnerable should carbon (soot) impregnate the refractory and create a current path leading to shorting or melting of the elements. Similarly, gas-fired radiant tube furnaces are susceptible in the area where the tube is embedded in the insulation (Fig. 1).

To try to keep furnaces as soot free as possible, first make sure you are running the right gas flows (i.e., not too rich) and that the enriching gas additions being used are limited over the course of the total cycle to an acceptable percentage (usually 10 to 15%) of the total gas flow. It is noteworthy that most automatic systems add enriching gas in short increments of high flow. These should be timed to determine exactly how much enrichment is actually entering the furnace, and in many cases, the peak flow should be limited to prevent too much enriching gas to enter the chamber in too short a time.

Next, performing a routine furnace burnout dependent on use from as frequently as once a week to no longer than once every other month is strongly recommended for any integral quench furnace operating above a 0.50% carbon and running with an endothermic, nitrogen/methanol or methanol only atmosphere enriched with either natural gas or propane.

There are several ways in which a burnout can be accomplished:

1. Use of pressurized air sent through a lance or wand and manually directed at the furnace interior to remove heavy soot deposits. This is normally followed by the introduction of air through a flowmeter for a fixed amount of time (typically 4 to 12 hours). In this procedure, the atmosphere has been removed from the furnace before starting.
2. Use of a fixed volume of air entering through a flowmeter for a prolonged period of time (typically 12 to 36 hours). In this procedure, the atmosphere has also been removed from the furnace before starting.
3. Raising the furnace dew point with the protective atmosphere still inside the chamber to around +70°F dew point by using air additions for a prolonged period of time (typically 36 to 72 hours).

While all methods are used in the industry, care must be taken to prevent overheating of the furnace. For this reason, the furnace temperature is usually lowered to around 1550 to 1600°F, and the process is stopped if the fur-

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Fig. 1 — Top section of a radiant tube damaged by soot accumulation in the insulation.

nace temperature increases by 100°F or more. Using method (1) requires extreme care to avoid damaging the furnace interior or striking interior components such as fans. Soot (carbon) burns at approximately 4500°F, high enough to melt through any of the materials in the furnace. In terms of effectiveness, method (1) is most effective in the shortest amount of time, while method (3) is the least effective taking the longest time.

Finally, it is a good idea to perform frequent shim tests or use "hockey pucks" (see below) to make sure that the actual carbon potential is within specified tolerances and that the furnace atmosphere control system is properly calibrated. Periodically verify the carbon potential with a three-gas analyzer making note of the readings for CO, CO_2, and CH_4 (monitoring the free methane is especially important in continuous furnaces). An automatic burnout of the oxygen probe during processing is mandatory to make sure it does not soot up and give erroneous results. In addition, the reference air system should be checked to be sure it is operating properly. Most companies change oxygen probes out at least every year.

Soot not only will shorten alloy life, but also it will deposit on the work and in the quench tank where it negatively influences the performance of the oil and contributes to staining and overall life issues.

Continuous Mesh-Belt Furnaces

Mesh-belt furnaces using controlled atmosphere require a careful understanding of the conditions that may result in heavy and uncontrolled sooting (Fig. 2). For example, a roll-supported mesh-belt carbonitriding furnace having four control zones operating at 1690°F (Zone 1), 1675°F (Zone 2), 1650°F (Zone 3), and 1600°F (Zone 4) was forced down for maintenance every 3 to 4 weeks due to binding of the rolls from soot buildup.

The carbon deposits built up in the area where the rolls pass through the furnace insulation. This was due in part to an unstable atmosphere and in part to conditions in which a carbon reversal reaction (Equation 1) was taking place.

$$CO \rightarrow C\,(soot) + CO_2 \qquad \text{(Eq 1)}$$

The solution involved the following steps:

- The true carbon potential inside the furnace was determined by running low carbon "hockey pucks" through the furnace together with the parts. These 1.250 in. diameter by 0.250-in. thick discs were subsequently analyzed by spectroscopy for surface carbon content. The results were compared with values obtained by readings from oxygen probes, infrared (three-gas analysis), and dew point. It was determined that the atmosphere sensing equipment was not providing accurate data to the control system. Subsequent investigation revealed the sampling system was not at the proper insertion depth into the furnace. Further, the oxygen probe control factors (tuning constants) were based on incorrect information.
- The incoming part condition was reviewed. Parts were extremely wet, oily, and in some cases had a phosphate coating on their surface. Although this did not affect the overall metallurgy of the final result, these contaminants made control of the furnace atmosphere extremely erratic.
- The quench chute eductor flow was measured and adjusted to ensure that a positive pressure was maintained in the furnace.
- The atmosphere flow pattern in the furnace was changed by modifying the endothermic gas flow rates, limiting the amount of enriching gas (natural gas and ammonia) allowed to enter individual zones, and making sure that valves were set and functioning properly.
- The fan settings (speed and rotation) were returned to manufacturer's settings.
- Maintenance procedures with re-

Fig. 2 — Soot formation on the front load table of a mesh-belt furnace after one hour with a furnace atmosphere out of control.

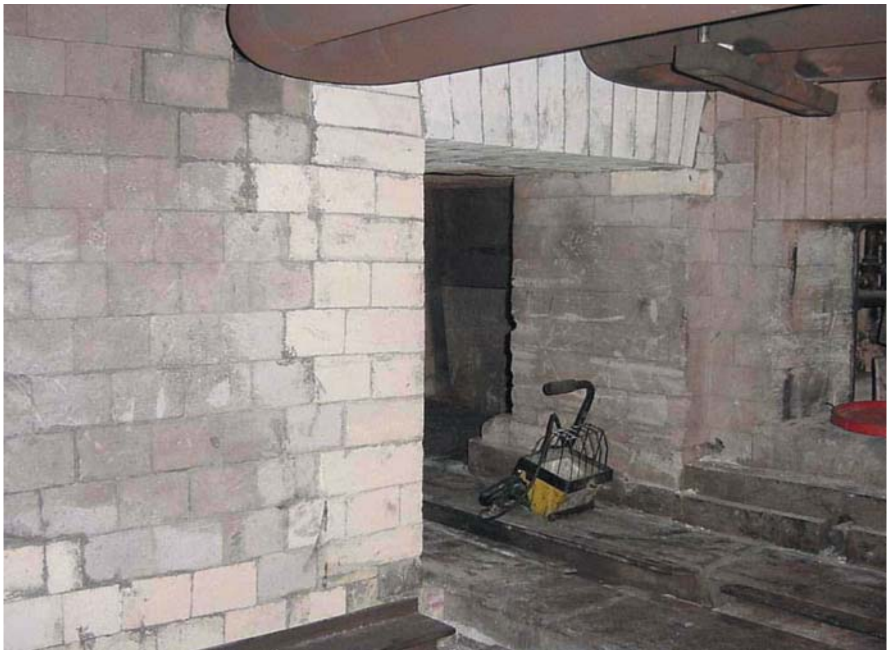

Fig. 3 — Jack-arch repair. Courtesy of Surface Combustion Inc., Maumee, Ohio.

spect to the rollers were thoroughly reviewed to ensure proper techniques were being used and that the manufacturer's required expansion clearances are being observed.

The result of all of these actions was to allow the furnace to operate for a minimum of six months without roll maintenance.

Pusher Furnaces

Pusher furnaces are by no means immune to maintenance. By their very nature, pushers are designed for high volume production in a 24/7 operating mode. As such, anything that can cause damage inside the heating chamber threatens production, and must be designed so that maintenance can be performed on routine shutdowns, typically every six months or so.

Typical pusher problems include:

- Alloy deterioration, especially if high carbon potential atmospheres or high operating temperatures are used. Metal dusting around fan shafts, sample ports, thermocouple wells and wear of chain guides, and alloy hearth components (especially in older units with alloy hearth designs).
- Internal tray transfer mechanisms that normally sit at right angle turns in the furnace and include tray flippers and limit sensing rods.
- Load jam-ups (Fig. 3) due to pusher/puller chain problems, misaligned or misadjusted side transfer or linear pushers or index rods resulting in placement of trays in the wrong positions.
- Operator error (i.e., putting too many trays in the furnace); this is a big problem.
- Hearth (silicon carbide or other re-

fractory materials) wears over time.

- Bad fixturing; if trays/baskets become deformed or crack over time, they have a tendency to get stuck in furnace, often in the worst possible locations causing peripheral damage as these jam-ups are cleared.

All other concerns are the same as for batch furnaces (atmosphere seals around fans, radiant tubes, tube failures, etc.). For example, one of the most serious problems is making sure that radiant tube leaks are detected early and either replaced or repaired. If this is not done, compositional variations in the furnace atmosphere will occur affecting case uniformity. If enough tubes are shut down, temperature uniformity may be compromised.


Fig. 4 - Fractionation of quench oil in the form of a carbonaceous residue.

Rotary Hearth Furnaces

The frequent door openings on rotary hearth furnaces create both thermal stability and atmosphere problems. For example, in a rotary running a nitrogen/methanol atmosphere enriched with natural gas or propane to maintain a 0.80% surface carbon, the furnace is prone to heavy sooting. Atmosphere control is improved by weekly air burnout cycles. A typical burnout procedure is as follows:

- The furnace is purged with nitrogen and the temperature lowered to 1550°F.
- The burnout starts with a low air flow rate (typically 10 to 25 scfh) and then gradually increase in flow first to 50 scfh then to 100 scfh if no temperature spikes or other adverse affects from soot burning off are observed.
- The length of time required depends on the amount of soot buildup and the volume or air used and can vary from four hours to all weekend.

Maintenance of the Oil Quench System

Special attention needs to be given to the care of quenchants. For example, oil should be analyzed to determine the relationship of the physical properties of the quench oil to its performance. Quench oil analyzers are available (which use an induction-heated probe) that creates a cooling rate onsite. By using one of these units, a baseline cooling curve can be determined on new oil, and then periodically monitoring the oil in the quench tank to detect any change in cooling curves due to viscosity or contamination problems. In some instances, a sample is pulled from the quench oil tank and in other cases the probe is inserted into the quench tank itself.

- In many operations, it is common to add make-up oil to the quench tank to compensate for oil dragout. A representative oil sample is sent to an outside testing laboratory to check for contamination and to run comparative cooling rates, usually on a quarterly basis. A report about the condition of the oil is then issued. The key questions are: Do the people receiving the report understand what it says and what actions do they take as a result of the analysis? Below is a listing of various test procedures and insights into the meaning of the results obtained[1].
- *Viscosity*: As discussed earlier, quenching performance is dependent on the viscosity of the oil. Oil viscosity changes with time due to degradation (the formation of sludge and varnish). Samples should be taken and analyzed for contaminants, and a historical record of viscosity variation should be kept and plotted against a process control parameter such as part hardness.
- *Water content*: Water from oil contamination or degradation may cause soft spots, uneven hardness, staining, and perhaps worst of all, cause fires! When water-contaminated oil is heated, a crackling sound may be heard. This is the basis of a qualitative field test for the presence of water in quench oil. The most common laboratory tests for water contamination is either *Karl Fisher* analysis (ASTM D 1744) or by distillation.
- *Flash point*: The flash point is the temperature where the oil in equilibrium with its vapor produces a gas that is ignitable, but does not continue to burn when exposed to a spark or flame source. Two types of flash point values that may be determined are closed-cup and open-cup. In the closed-cup measurement, the liquid and vapor are heated in a closed system. Traces of low-boiling contaminants may concentrate in the vapor phase resulting in a relatively low value. When conducting the open-cup flash point, the relatively low boiling byproducts are lost during heating and have less impact on the final value. The most common open-cup flash point procedure is the *Cleveland Open Cup* procedure described in ASTM D 92. The minimum flash point of an oil should be 90°C (1600°F) above the oil temperature being used.
- *Neutralization number*: As an oil degrades, it forms acidic byproducts. The amount of these byproducts may be determined by chemical analysis. The most common method is neutralization number, which is determined by establishing the net acidity against a known standard base such as potassium hydroxide (KOH). This is known as the "acid number," and is reported as milligrams of KOH per gram of sample (mg/g).
- *Oxidation*: This variable may also be monitored, and is especially important in tanks running marquenching oil or oils being run above their recommended operating range. Oxidation is detected by infrared spectroscopy. Nitrogen blanketing of the oil is one way to reduce both oil oxidation and sludge formation.
- *Precipitation number*: Sludge is one of the biggest problems encountered with quench oils. Although other analyses may indicate that a quench oil is performing within specification, the presence of sludge may still cause nonuniform heat transfer, increased thermal gradients, and increased cracking and distortion. Sludge may also plug filters and foul heat-exchanger surfaces (the loss of heat exchanger efficiency may cause overheating, excessive foaming and possible fires). Sludge formation is caused by oxidation of the quench oil and by localized overheating ("frying") of the quench oil. The relative amount of sludge present in a quench oil may

be quantified and reported as a precipitation number. The precipitation number is determined using ASTM D 91. The relative propensity of sludge formation of a new and used oil may be compared, providing an estimate of remaining lifetime.

- *Accelerator performance*: Induction coupled plasma (ICP) spectroscopy is one of the most common methods used to analyze quench oil additives. When additives (such as metal salts) are used as quench rate accelerators, their effectiveness can be lost over time by both drag out and degradation. Their effectiveness can be quantified by performing ICP spectroscopy (a direct analysis for metal ions), and compensating measures can be taken, such as the addition of specific percentage of new accelerator.

Other important items to remember about oil quenching is that the hotter the oil temperature, the better the distortion control, but the faster the oil degradation. Also, the higher the austenitizing temperature from which a part is quenched, the more damage to the oil and the faster the oil will deteriorate.

Other common concerns are oxidation and sludge/contamination buildup. These can be minimized to a degree by the addition of antioxidants and with the use of a protective atmosphere cover (such as a nitrogen blanket) over the oil during heat-up and operation. Oil without antioxidant additives will give the brightest and most consistent part surface appearance, but will oxidize rapidly, then discolor the work. Antioxidant additives will normally produce a consistent surface finish while extending the useful life of the oil. Fresh or make-up oil can be added to further reduce oil degradation. A hidden danger is heating oil too rapidly, which can also degrade the oil (low velocity burners or low-watt release resistance heaters should be used).

It is important to note that oil capacity is not always an assurance of success. For example, parts run in continuous furnaces that discharge parts into quench chutes may see problems with low hardness or staining due to breakdown (fractionation) of the oil in a small localized area, lack of proper heat extraction, or poor oil circulation in the quench chute (Fig. 4). Cooling systems should be sized to handle the heat extraction, and should be free of copper and other materials known to be catalysts for oxidation of oil products.

Final Thoughts

There is no excuse for poor heat treatment or not taking the time to properly maintain equipment. Often we chose to fix a problem only when it becomes absolutely necessary to do so. This is unacceptable in any industry but especially devastating in heat treating. **HTP**

References

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2. John Gottschalk, Surface Combustion Inc., private correspondence.

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