TECH TALK
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HEAT TREATING USING OIL QUENCHING AND MOLTEN SALT BATHS

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This Tech Talk discusses potential fire and explosion hazards associated with metal heat treating using oil quenching and molten salt baths.

AT-A-GLANCE

- Controlled heating to high temperatures, combined with rapid and controlled cooling, enables metal parts to be hardened and/or tempered to provide desired properties.
- Fire and explosion hazards exist during heating and quenching operations due to combustible gas atmospheres in furnaces, combustible oil baths, reactive properties of salt baths, as well as the presence of ignition sources.
- Risk reduction can be achieved by preventive and protective means, such as control of water content in oil, redundant level, temperature and agitation controls in oil tanks, proper maintenance of furnace units, proper storage of salts, and the installation of automatic fire extinguishing systems.

INTRODUCTION

Hardening is a widely used metallurgical process used to alter the physical properties of a metal workpiece. Heating to high temperatures and subsequent cooling are combined to achieve the desired physical properties, such as improved strength and wear resistance by changing the metal's crystalline structure.

Four different methods are typically used for the heating process:

1. In a gas atmosphere (most common)
2. Under vacuum
3. In a salt bath (less common due to environmental and health concerns)
4. Induction or flame

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Two different methods are used for rapid cooling/ quenching:

1. In fluids (i.e. oil, water, polymer, molten salt, molten metal, etc.)
2. In a gas atmosphere (i.e. air, nitrogen, helium, etc.)

Not every quenching medium can be used with any heating method. For instance, a polymer solution quenching medium should not be combined with a closed heating system since the water vapor generated during the quenching operations would contaminate the furnace atmosphere. Therefore, depending on the type of heating method, a suitable quenching technique should be chosen as indicated in Table 1.

Table 1: Possible Combinations of Heating and Quenching Medium

	Quenching Medium				
Heating Process	Oil	Polymer solution	Salt	Water	Gas
Gas atmosphere open bath	x	x	x	x	
Gas atmosphere closed bath	x				x
Vacuum (closed bath)	x				x
Salt bath	x	x	x	x	
Induction	Very rare	x		x	
Flame	Very rare	x		x	

(Source: Süddeutsche Metall-Berufsgenossenschaft, Dipl.-Ing. Wolfram Schmid, Juli 2001, *Gefahren beim Betrieb von ausgewählten Abschreckbädern in der Härterei*, Technischer Aufsichtsdienst Stuttgart)

FIRE & EXPLOSION HAZARDS

In this Tech Talk, only the fire and explosion hazards related to the heating in industrial furnaces using gas atmospheres and quenching in oil and molten salt baths are discussed.

HEATING IN A GAS ATMOSPHERE

The gas atmosphere used in heat treatment furnaces consists of different gases; mainly hydrogen (H_2) and carbon monoxide (CO), but also small amounts of carbon dioxide (CO_2) and nitrogen (N_2), which can be generated from propane, ammonia, natural gas and various types of alcohols.

Some of these gases used in the gas atmosphere are flammable, such as hydrogen and carbon monoxide. When mixed with a sufficient amount of air/oxygen (depending on the concentration of the gas mixture and the explosion limits), explosive atmospheres can be formed. In furnace operations, the constant presence of an ignition source, such as hot surfaces, sparks caused by friction, etc., should be taken into account. Therefore, the primary precaution should be to prevent the formation of an explosive atmosphere inside the furnace.

Some occasions where the formation of an explosive atmosphere can be observed are:

- During the change of gas atmosphere to air or vice versa (e.g. on the weekends or at the start/end of the heat treatment process).
- During the workpiece charging process by opening/ closing the furnace door.

Negative pressure in the furnace space is also one of the potential reasons for the generation/formation of an explosive atmosphere. Negative pressure, when combined with the unsealed areas in the heat treatment unit (e.g., doors, inspection glasses, loose fittings, etc.), can lead to air/oxygen entry into the unit. This can occur when a workload is quenched in an oil bath and the volume of the gases in the atmosphere above is reduced due to the cooling effect.

In addition to the above, minimum furnace temperature is another critical point in heat treating operations to prevent the potential formation of an explosive atmosphere and to enable a safe combustion of the process gases in the furnace chamber. For instance, in DIN-EN 746-3 the minimum temperature, which is also called safety temperature, is set at 750°C (1382°F).

QUENCHING IN OIL BATHS

Three main types of quench oil baths are typically encountered in industrial processes:

- Open-top
- Semi open-top (attached to continuous-type systems)
- Closed-top (integrated in the furnace unit)

The following scenarios can lead to hazardous conditions when quenching in oil baths, particularly in open-top and semi open-top systems:

- **Water in oil bath**: Water can enter the oil bath by a leaking cooling system (e.g. water heat exchanger) or by leaks in the building's roof, or piping systems, or even condensation on utility lines. When the heated workload is immersed in the oil bath, a boilover or a steam explosion (if the bath operating temperature is well above 100°C or 212°F) can occur depending on the amount of water present in the bath. In closed-top systems, the presence of water in oil baths is stated to be one of the most common causes of oil fires.
- **Partial immersion of a workpiece**: When the workload is not completely immersed in or removed from the oil, oil can overheat on the bath surface. This can lead to the formation of combustible oil vapors on the surface and ignition by the heated workpiece. Partial immersion of the workpiece is another common cause of quench oil fires.
- **Lack of sufficient cooling/agitation**: Sufficient agitation of oil provides a homogenous distribution of heat within the oil bath, reducing the risk of localized overheating. In case of loss of agitation, the risk of insufficient oil cooling and subsequent oil ignition increases.
- **Loss of temperature control**: An improperly

functioning temperature sensor/control unit can result in heating the oil above its flash point, which can cause a fire.

- **Too low or too high oil level**: When the oil level in the quenching bath is too low, the heat released by the workload cannot be sufficiently absorbed by the oil due to the lack of medium in the oil bath. This could result in oil being heated above its flash point and posing a fire hazard. High oil level can result in oil overflowing or splashing out of the bath and ignition of the combustible liquid.

Hazards associated with semi-open top oil baths attached to furnaces include the following:

- Part to be quenched becomes stuck in the drop shaft, causing local overheating of oil above its flash point
- Oil level lower than the bottom of the drop shaft, resulting in air entry into the furnace unit and potential generation of an explosive atmosphere
- If a larger, hot piece of soot deposit in the chute breaks off during burnout and falls into the oil bath, it floats on top and can set the oil bath on fire
- Ignition of oil accumulations caused by the hot furnace surfaces

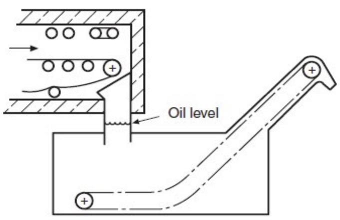

Figure 1: Semi-Open Top Oil Bath (Source: NFPA Fire Protection Handbook, 20th Edition, Section 8, Chapter 9, Oil Quenching and Molten Salt Baths, Figure 8.9.2)

Closed-top oil baths can present a fire hazard when a workpiece leaving the quenching system becomes stuck at the flame curtain.

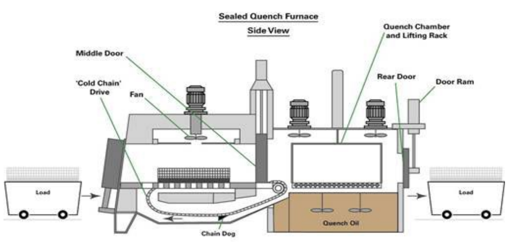

Figure 2. Closed-Top Oil Bath (Source: Innov@te, Brian J. Birch, Brian Ellis & Leanie Mackenzie (September 2003) – Bodycote outsourcing for industry – (Heat Treatments, Hot Isostatic Pressuring, Materials Testing, Metallurgical Coatings) – The Sealed Quench Furnace Module 1)

QUENCHING IN SALT BATHS

Molten salt baths are also used in industrial heat treating of metals, ceramics and polymers. The hazards associated with salt bath quenching operations include fire caused by contact of molten salt with combustible materials, explosion of the salt mixture due to physical or chemical reaction, and the generation of corrosive and toxic fumes.

A variety of chemical salts are available, but nitrates and cyanides are the most commonly used, which present the following hazards:

- Nitrates increase ease of ignition and burning intensity of combustible materials by furnishing oxygen, creating a fire that is very difficult to extinguish.
- Cyanides in contact with acids or moisture produce highly toxic and flammable hydrocyanic acid gas.
- Mixing nitrates with cyanides with heat could result in a severe chemical reaction.

ARC RECOMMENDATIONS

The following recommendations can greatly reduce the potential for property damage and resulting business interruption caused by fire or explosion involving heat treating using oil quenching and molten salt baths. Please contact ARC to discuss your specific needs prior to installation.

1. GENERAL

a. Provide adequate process safety and safe operation training to all relevant employees/operators.

b. Perform testing, inspection and maintenance in accordance with the equipment manufacturers' guidelines.

c. Prohibit combustible materials from being stored in the vicinity of oil and salt baths.

d. Provide portable fire extinguishers throughout the area with annual hands-on training for all relevant employees/operators.

e. Avoid operating the heat treatment equipment during non-occupied periods.

2. GAS ATMOSPHERE FURNACES AND QUENCHING IN OIL BATHS

a. Separate heat treating units from other occupancies with at least one-hour, fire-rated construction. Locate these units preferably on the ground floor.

b. Adhere to the maximum allowed size and amount of the workload to be quenched.

c. Provide effective emergency response to safely immerse the workload into the oil bath or extract it out of the bath in case of partial immersion or power outage.

d. Provide redundant oil level (high and low), temperature and agitation controls.
e. Ensure the oil bath operation temperature is at least 60-70°C (108-126°F) below the flash point of the quench oil. Provide interlocks to shut down heating when the oil bath temperature reaches 30°C (54°F) below the flash point of oil.
f. Provide overflow drains for larger quench tanks (capacity exceeding 570 L (150 gal) or surface area of 1 m^2 (10 ft^2) or larger). Drains should direct oil to a safe location outside the building or into specific tanks.
g. Provide automatic sprinkler protection over quench tanks and associated equipment that use combustible liquid. Interlock the heating system to shut down in event of sprinkler system operation.
h. Provide an automatic fire extinguishing system (i.e. water spray, carbon dioxide, foam, etc.) to protect open-top or semi open-top oil baths. Interlock the heating system to shut down in event of fire extinguishing system operation.
i. Prevent formation of an explosive atmosphere, negative pressure and entry of oxygen/air into the furnace by purging the furnace with an inert gas (i.e. nitrogen) when changing the gas atmosphere or equalizing the pressure.
j. Ensure no combustible process gases are fed into the furnace if the safety temperature is lower than the minimum set value. In case the temperature is lower than the safety temperature, it should be possible to purge the furnace with an inert gas (i.e. nitrogen). Purging should also be possible during a potential power outage by providing emergency power.
k. Check water content in oil at least weekly to ensure it does not exceed 0.1% by mass.
l. Start the agitator at least five minutes before the first quenching operation.
m. Ensure that auxiliary equipment located above the oil baths, such as piping systems, utility lines, etc., are free of water that may be caused by leaks or condensation.
n. Monitor the pressure difference between the water and oil side when cooling is provided via heat exchangers. Ensure the oil pressure is higher than the water side so that in case of leakage in the piping, oil would enter the water side and not vice versa.
o. Monitor proper operation of the flame curtain and the gas flaring of gas atmosphere furnaces. If a pilot flame at a furnace door is not functioning, the door should not open.

3. QUENCHING IN SALT BATHS

a. Store salts in tightly closed containers to prevent the absorption of liquids or moisture. Ensure the salts to be melted are dry.
b. Store nitrate salts in a fire-resistive, damp-free room that is separated from heat, liquids and reactive chemicals.
c. Do not mix or store nitrite and nitrate salts with cyanide salts.
d. Avoid splashing salts out of the bath and provide splash protection.
e. Clean the equipment used in the baths thoroughly before using in other baths.
f. All connections, such as pumps and pipes, should be properly designed and tight to avoid leakage.
g. If the molten salt bath is combined with a protective atmosphere furnace heating system, soot accumulations should regularly be controlled and cleaned to prevent falling into the bath.

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QUESTIONS OR COMMENTS?

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