In Part One, we discussed why oil is a preferred quench medium for many fastener materials, considered the various stages of quenching in a liquid and looked at some of the properties that are important to oil quenching. The discussion continues here.

Oil Quenching of Fasteners – Part 2

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The Effects of Increasing Agitation

The stages of cooling described in Part 1, may not all occur at all points of the part configuration at the same time, even with a properly selected oil and correct quench environment design. The quality of the quench oil is a function of a few key factors: part cooling; part geometry; fixturing; as well as loading techniques. As the part's internal heat moves to the surface, and based on the surface configuration, differences in heat rejection will vary. Consequently, the need for a uniform and controllable agitation of clean properly controlled liquid flow over the part surface is imperative. Controlled movement of the quenching liquid is vital as it causes an earlier mechanical disruption of the vapor blanket in the first stage and produces smaller, more–frequently detached vapor bubbles during the "vapor transport" cooling stage. Agitation constantly provides a cooler liquid to the part surface, providing a greater temperature difference that allows for improved heat rejection. Cleanliness of the oil is an important issue, and it must be free of particulate materials such as carbon, sludge, and water. Carbon is formed after evaporation and fractionation under conditions of insufficient oxygen or is introduced by processes such as carburization. If there is insufficient quenchant agitation oil breakdown on the part surface may occur. Important considerations with respect to agitation are as follows: type and design of agitators (mixers) or pumps, and draft tube design. For example, we often give little consideration to an internal component such as a draft tube, but we should. Draft tubes are important in the overall performance of the system and should have the following characteristics [4]:

- A down pumping flow path (to take advantage of the tank bottom)
- An angle of 30° on the entrance flare (to minimize head loss and establish a uniform velocity profile at the inlet)
- Liquid coverage over the top of the draft tube of at least one–half the tube diameter (to avoid flow restriction and disruption of the inlet velocity profile)
- Anti–cavitation or internal flow straightening vanes (used to prevent fluid swirl)
- Proper impellor positioning (both insertion depth into the draft tube—a distance equal to at least one half of the tube diameter as dictated by the required inlet velocity profile—and diameter, fitting tight enough to prevent fluid flow along the sides of the draft tube)
- Anti–deflection capability (to compensate for occasional high deflection)

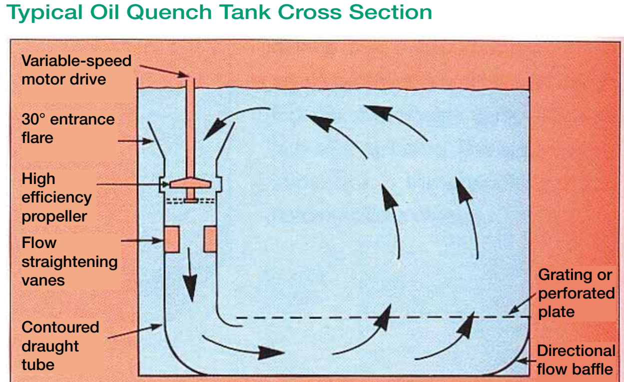
Draft tubes are just one component that highlights an often–overlooked aspect of quenching **(Fig. 1)**. The limitations imposed by the design of the quench tank can have a significant (negative) effect on the ability of the quench oil, or any quench medium, to perform properly. Other key factors that influence quenching are:

- Oil volume,
- Localized instantaneous temperature rise of the bath,
- The ability to circulate the quench medium through the load (measured in ft/sec or m/sec),
- The capacity of the heat exchanger system,
- The overall maintenance of the tank all influence quenching.

The volume of oil contained in a quench tank is important for controlling the overall rate of temperature rise after quenching. The common rule of thumb for oil quench tanks is one gallon of oil per pound of steel. Highly effective agitation systems must be designed for quench tanks that utilize less than this ratio. Of course, having a large volume of oil is no guarantee of success if the quench tank design is inadequate for the job. For example, a mesh belt conveyor furnace utilized a 3000 gallon (11,350 liter) tank but failed to properly circulate oil and dissipate heat from the area of the quench chute—where the actual product was being transformed. The result was

Figure 1

Typical Oil Quench Tank Cross Section



improper hardness and excessive distortion even at production rates of only several hundred pounds per hour.

Common Problems

Distortion and Cracking

Another important advantage of oil quenching is that it minimizes the tendency to cause distortion and cracking. While oil is better than some mediums such as water or brine, other mediums such as salt or high-pressure gas quenching tend to produce less overall distortion. A key consideration, however, is the uniformity/repeatability of the distortion profile, and oil quenching has the ability to produce a very consistent profile. Fast oils that are highly agitated tend to produce the highest rates of distortion while slow or marquench oils tend to minimize distortion. Quenching in still (non–agitated) oil is often used as a means of distortion control on critical parts.

Water in Quench Oil

One of the major concerns regarding oil quenching is the presence of water in the quench oil. This is a particularly dangerous situation since during the quench it will convert to steam, resulting in an enormous volume expansion. As the steam bubble rises out of the quench tank its surface is coated with oil, and as it exits from the furnace—usually under extremely high pressure—it is readily ignited. Water detectors with sensitivity in the range of 0.2 –0.3 percent should be provided on all quench tanks. They should be properly maintained and tested daily. Some manufacturers believe that as little as 0.1 percent may cause dramatic changes in quenching and part surface contamination.

Oil Analysis Methods & Meaning

Oil is often analyzed to determine its performance characteristics, and the testing laboratory issues a report that contains information about the physical property characteristics of the oil. The following describes various test procedures and provides insights into the meaning of the results obtained. [5]

Viscosity

Quenching performance is dependent on the viscosity of the oil. Contaminants such as the formation of sludge and varnish, can cause oil degradation, which changes its viscosity with time. 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 are 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, which is ignitable but does not continue to burn when exposed to a spark or flame source. There are two types of flash point values that may be determined: closed–cup, or 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 (160°F) above the oil temperature being used.

Neutralization Number

As oil degrades it forms acidic byproducts. The amount of these byproducts may be determined by chemical analysis. The most common method is the neutralization number. The neutralization number 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. One way to reduce both sludge formation and oil oxidation is nitrogen blanketing of the oil.

Precipitation Number

Sludge is one of the biggest problems encountered with quench oils **(Fig 2)**. Although other analyses may indicate that a quench oil is performing within specification, the presence of sludge may still be sufficient to cause non–uniform heat transfer, increased thermal gradients, and increased cracking and distortion. Sludge may also plug filters and foul heat–exchanger surfaces, lowering its efficiency. 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

Figure 2

Sludge Buildup in a Quench Chute

localized overheating, or "frying," of the quench oil. The relative amount of sludge present in 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 new and used oil may be compared providing an estimate of remaining life.

Accelerator Performance

Induction coupled plasma (ICP) spectroscopy is one of the most common methods for the analysis of 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 a specific percentage of new accelerator.

Summing Up

Often taken for granted, oil quenching is so routinely used in the fastener industry today that its misapplication and misuse can be a significant concern. As with all quenching, the key is to understand and control the key process variables. Proper selection of the type of oil and use of that oil under ideal conditions in a well-designed and well-maintained quench tank will assure consistent and repeatable results. Oil quenching should be applied in those applications where its advantages outweigh its disadvantages, and as with all technologies should be as completely understood as possible with respect to the performance requirements of the product so as to meet the application's end use.

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